Examining the Challenges to the Adoption of Solar Energy Technologies by Subtropical Fruit Producers in the Tzaneen Region in Limpopo province.

Student:
Chauke Hlulani
(CHKHLU004)

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Supervisor:
Dr. Rolien Terblanche

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DECLARATION

I, **Hlulani Patience Chauke**, declare that this thesis is my original work and has not been submitted for any other degree at this or any other institution.

All sources of information and data utilized in this thesis have been properly acknowledged, and I have adhered to the principles of academic integrity and ethical research practices throughout the process.

I understand that any form of plagiarism or misrepresentation of other works is a serious offense that could lead to disciplinary actions.

This thesis has been prepared according to the guidelines of University of Cape Town and has received ethical approval.

Signed: Signed by candidate

Hlulani Patience Chauke

CHKHLU004

Date: 14 August 2025

ABSTRACT

This study explores the barriers to the adoption of solar energy technologies in the subtropical fruit producers operating in the Tzaneen region Limpopo Province South Africa. The objective of this study is to identify the barriers to solar technology adoption in agriculture. Fruit producers were used as a sample, and interviews were conducted with eight producers to provide qualitative data and validate the experiences and perspectives of the producers themselves.

The findings also identify several significant barriers including substantial initial costs, insufficient technical support, and lack of awareness about available subsidies. Moreover, socio-economic factors and reliance on the national grid inhibit movement to renewable energy sources. Producers acknowledge the potential long-term benefits of solar energy; however acute financial limitations continue to pose a substantial obstacle to its adoption.

With this study, the knowledge of renewable energy usage in agricultural practices has advanced which will offer helpful information for decision-makers and rural extension services. This underscores some of the unique challenges faced by Tzaneen region producers and reflects the need for tailored supporting mechanisms that can promote sustainable energy use and ultimately strengthen agricultural resilience and sustainability.

Keywords: solar energy, subtropical fruit producers, Tzaneen region, Limpopo Province, adoption challenges, renewable energy, financial barriers, agricultural sustainability.

DEDICATION

To my beloved girls, Masana, Ntsakisi and Zazaza

This work is dedicated to you. Your curiosity, and unwavering support have been my greatest motivation throughout this journey. May you always chase your dreams and know that with hard work and determination, anything is possible. I hope this achievement inspires you to pursue your passions and never underestimate the power of education and resilience.

With all my love, Mom

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Finally, I would like to extend my deepest appreciation to my children for their unwavering support, patience, and love. You have been my rock, and this achievement is as much yours as it is mine.

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ABBREVIATIONS

Term	Definition
CSP	Concentrated Solar Power
EROI	Energy Return on Investment
F	Farmer
F1	Farmer 1
F2	Farmer 2
F3	Farmer 3
F4	Farmer 4
F5	Farmer 5
F6	Farmer 6
F7	Farmer 7
F8	Farmer 8
FITs	Feed-In Tariffs
REIPPPP	Independent Power Producer Procurement Programme
IRB	Institutional Review Board
IRP	Integrated Resource Plan
I	Interviewer
LCAs	Life Cycle Assessments
RE	Renewable Energy
RPS	Renewable Portfolio Standards
SELCO	Solar Energy Light Company
PV	Solar Photovoltaic
SIPS	Solar-Powered Irrigation Systems
SDG7	Sustainable Development Goal 7
TPB	Theory of Planned Behaviour
UN	United Nations

CHAPTER 1. INTRODUCTION

This introductory chapter locates the research within the broader context of renewable energy, with a special emphasis on solar technology in agriculture industry in South Africa. It frames the background issues surrounding the industry. The chapter then outlines the objectives, research questions, scope and significance of the study and stresses how lessons from this region can inform efforts to take sustainable practices forward in farming industry policy making development. This chapter provides a solid base for the following chapters in which it defines with clarity what is going to be the outline of research.

1.1 Background and context

Solar energy technologies have been identified as an important area in research and practice, for example, for use in agriculture (in the face of climate change and resource depletion). Solar energy stands out as available and further, a replacement for fossil fuels, which are scarce and coveted globally. South African has a chance to do so, where agriculture is a major sector of the economy and food security. Harvest PV solar energy with their farming activities to maximize yield, thereby encourage environmental and sustainable development (Kruger et al., 2021; Murombo, 2015).
This cannot be overlooked, especially in South Africa's case, as solar energy is key to taking this country into an agricultural revolution. This includes everything from a lack of energy to high electricity prices and required sustainable farming. Solar energy use not only lowers operational costs and makes their businesses more energy secure but can also help to meet national climate change mitigation objectives (Todd & McCauley, 2021). In addition, Baker & Sovacool (2017) contend that smallholder farmers can benefit from solar energy and are provided with the means to generate income in this competitive market.

South Africa has set up different schemes and institutional frameworks to support the utilization of renewable energy, including, among others, the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) as well as FITs. These schemes are tailored to advance the solar technology and to increase investment in the renewable development (Nguyen et al., 2023; Adebayo et al.,2021).

However, those techniques have not really proven effective as we still have very few sectors specific regulations that would allow to solve the complex questions that producers (smallholders especially) have (Wright et al, 2019).

Although the body of scholarly works related to the policy and institutional framework for solar energy adoption in agriculture improved, major gaps and challenges persist. Policy and institutional framework is defined as rules, laws, and organizational setups that either help or hinder the spread of renewable energy sources (Baker & Sovacool, 2017). There is a "lack of investment capital to fund solar development, inadequate technical assistance, and low farmer understanding of the technologies benefits" (Schmidt et al.,2017; Essex & de Groot, 2019). Sometimes, the process of mobilization is based on making money or getting political favours, which leads to unequal adoption rates and missed chances for long-term growth (Baker & Sovacool, 2017; Murombo, 2021).

South Africa's transition towards sustainable energy sources has resulted in heightened enthusiasm for solar energy technologies as a feasible substitute in all industries. This transition was directly affected by the current power outages (loadshedding) (Anekwe, et al., 2024). Nevertheless, the implementation of these technologies is accompanied by challenges, especially in certain geographical areas and sectors (Anekwe, et al., 2024).

The current body of research emphasizes the potential advantages of solar energy in agriculture, including enhanced energy efficiency, reduced expenses, and improved environmental sustainability (Anekwe, et al., 2024). Nevertheless, obstacles to the acceptance of this technology encompass substantial initial expenses, intricate technological intricacies, and uncertainties regarding policies (Anekwe, et al., 2024). Subtropical fruits such as mangoes, avocados, citrus, and litchis are critically important to the agricultural landscape of South Africa, particularly in Tzaneen, Limpopo Province. Limpopo (Tzaneen area) has the right environment for these fruits: warm temperatures all year round combined with adequate rainfall at regular intervals. Tzaneen, owing to its favourable climate with warm weather throughout the year and regular rainfall, provides ideal conditions for growing subtropical fruits.

(Mokoena,2014) Limpopo accounts for about 74 percent of the country's mango production, 56 percent of national total for avocados, and some 22 percent of litchi plantings in South Africa, emphasizing its importance to both national and regional fruit production (SAMGA, 2024; SALGA, 2025).

Nevertheless, despite being crucial to agriculture, the sector faces significant challenges associated with unreliable power supply through load shedding. Power interruptions in this sector compromise activities such as irrigation, cold storage, and processing, which are essential in maintaining fruit quality and maximizing yield in fruit production. This leads to low productivity, crop destruction, and increased operating costs as farmers need supplementary power sources. Electricity disruptions stand to impact on the international competitiveness of South Africa’s subtropical industry (South African Reserve Bank, 2020; Western Cape Dept. of Agriculture, 2023). Hence the importance of this study.

The potential advantages of adopting solar energy, such as financial savings and decreased ecological footprint, have been emphasized in certain research studies (de Jongh, Ghoorah , & Makina, 2014). However, it remains uncertain whether these benefits are applicable to subtropical fruit producers in the Tzaneen Region. Despite the region’s high solar energy potential due to the sunny climate, the renewable energy source is often identified as a potential solution to the problems associated with the current fossil-fuels-based system.

From this perspective, solar energy could be a viable solution supporting sustainable agricultural practices around the world. (FAO, 2018). Yet even though the compatibility of its conditions and needs is reasonable, there is still little research done specifically about the subtropical fruit production sector of Limpopo, especially in Tzaneen. Contemporary research recognizes the capacity of solar energy to alleviate climate change (Akinbami, Oke, & Bodunrin, 2021), yet it lacks comprehensive comprehension of the obstacles encountered by these producers.

1.2 Problem statement

The producers of subtropical fruit face significant barriers to adopting solar energy technologies in Tzaneen. High costs, a lack of infrastructure and limited facilities are among the problems. These problems are compounded by the larger issues of environmental stress caused by climate change and an insecure energy supply prevalent in rural South Africa. The Tzaneen Region, renowned for its subtropical climate, possesses considerable potential for harnessing solar energy.

1.3 Aims and Objectives of the Study

The research aims: -

To investigate the factors influencing the adoption of solar energy technology among subtropical fruit producers in Tzaneen Region, Limpopo province. It's not necessarily trying to prove or disprove a hypothesis in the usual sense. Instead, it wants to find, study, and present the factors that affect the use of solar technologies in this farming situation.

The project aims to get a more profound comprehension of the obstacles encountered by subtropical fruit producers while implementing solar energy technology.

Research Objectives of the study: -

1. Identify the specific issues subtropical fruit growers face in Tzaneen when it comes to solar energy technology adoption.
2. Find the main social, economic, technological, and institutional obstacles that affect how these farmers use solar energy.
3. Understand what farmers think about solar power, why they're interested in it, and how much they know about its benefits.
4. To investigate how current policy setups and support systems influence the way farmers make decisions.
5. Offer at least two practical suggestions for policymakers and stakeholders to tackle major challenges based on research findings.

1.4 Research questions

To guide this research and analysis, this study will focus on the following main research question:

What are the challenges that subtropical fruit producers in the Tzaneen Region of Limpopo Province encounter when considering the adoption of solar energy technology?

Additionally, these sub-questions will be addressed:

1. Why did they consider adopting solar energy technology?
2. What are the challenges hindering farmers from adopting solar energy technologies?
3. Is there any existing support mechanism that farmers are receiving to encourage solar energy adoption?
4. Does sustainability influence the adoption of solar energy?

1.5 Scope of the study

The research will concentrate solely on subtropical fruit producers in the Tzaneen Limpopo Region of Limpopo Province. This research uses qualitative methodology to collect insights from a specific group of eight farmers and the identification of nuanced understandings of their experiences and perspectives. The collected data will enable identification of recurring themes, improving understanding of the relationship between agriculture and the adoption of renewable energies.

1.6 Significance of the study

This research has the potential to provide useful insights in both the academic and practical domains. This project will contribute to the current body of academic work on the use of renewable energy in agricultural contexts. It will focus on the subtropical fruit farms in the Tzaneen region, where a detailed case study will be covered. The findings can provide practical guide to politicians, agricultural extension agencies and farmers in addressing the identified issues thus facilitating the sustainable use of solar energy.

The contribution is notably innovative as it concentrates on the distinct geographic area Tzaneen and the specific agricultural industry of subtropical fruits, offering contextually relevant observations which may not be covered broadly in more general research This particularity amplifies the uniqueness and significance of the research in the field. The implication is that this specificity was established to strengthen the

Pursuing the research is justified due to the potential for lower carbon emissions, greater energy efficiency in subtropical fruit cultivation and long-term financial benefits for farmers through the effective implementation Furthermore, it is in line with international efforts to promote sustainable agriculture and reduce adverse effects of climate change (Anekwe, 2024).

Theoretical significance exists in enhancing the understanding of aspects that impact the use of solar energy technology in agriculture, especially subtropical fruit production. This has the potential to shape the implementation of legislation, training initiatives, and incentives that promote the use of solar energy by fruit farmers, encouraging sustainable farming practices.

The current body of research may discuss broad obstacles in the implementation of renewable energy, but it could not adequately cover the unique difficulties encountered by subtropical fruit growers in the Tzaneen region. These challenges may encompass budgetary limitations, insufficient expertise, or certain climate-related considerations. The project will tackle the research issues in relevant literature concerns by undertaking an extensive investigation that primarily concentrates on subtropical fruit producers in the Tzaneen region.

The research paradigm adopted in this study is pragmatic, which aims to help farmers better understand the practical issues surrounding the use of solar energy (Creswell, 2014). A qualitative case study design was chosen to really dig deep into the perceptions and experiences of farmers (Yin, 2014). Data collection involved 8 semi-structured interviews with purposefully selected farmers. Thematic analysis was employed to identify key themes, drawing upon Braun and Clarke's (2006) framework for these analyses. Throughout the research process, due care was taken to observe ethics: For instance, this always involved informed consent and confidentiality of sensitive information.

By conducting surveys, interviews, and data analysis this study aims to identify and analyse the distinct difficulties encountered by these producers. It will provide specific insights that can enhance the current body of literature to a high level. his expected result includes a full understanding of the problems that come up when trying to develop mobile solar energy and suggested ways to cut down on waste. This is important for promoting sustainability, reducing reliance on traditional energy sources, and making it easier for subtropical fruit farmers to deal with the effects of climate change.

Farmers, consumers, environmentalist’s legislators, and the local community will all experience advantages. Farmers acquire knowledge about sustainable energy methods; policymakers obtain advice for focused initiatives Environmentalists observe decreased carbon footprints, and the local community experiences advantages with a more sustainable and resilient agriculture industry.

This expansion enhances the understanding of renewable energy adoption by providing a more nuanced perspective on the adoption of renewable energy technologies. The rationale stems from the necessity to use local expertise The goal is to facilitate the implementation of efficient policies and strategies for the sustainable integration of energy in agriculture.

Moreover, addressing these difficulties is in line with worldwide sustainability goals, making the research socially and environmentally consequential.

1.7 Structure of the thesis

To answer these research questions and bridge the gap of the aim of this research is as follows: - in Chapter 2 Literature Review: This chapter critically examines the existing literature on the adoption of solar energy technologies, highlighting key themes, barriers, and gaps in current knowledge. Chapter 3 outlines the research design and details participant selection and data collection methods. Chapter 4 Methods: This chapter covers the study design. Chapter 4 presents the findings from the semantic analysis of data collected through interviews and observations. This chapter analyses the implications of the findings, provides recommendations for policy and practice, and identifies areas for future research. Chapter 5: Discussions and Chapter 6: conclusion. Lastly, the list of all sources used in the study. In an upcoming chapter literature review related to solar energy adoption in agricultural industry will be discussed.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter provides a critique of the literature pertinent to the adoption of renewable energy technologies in subtropical fruit production areas. The purpose of this literature is to review the challenges and opportunities about solar energy technologies adoption amongst subtropical fruit producers — A case study of the Tzaneen region in Limpopo province, South Africa.

This review looks at numbers of aspects such as theoretical models and acceptance of renewable energy technologies, market dynamics, economic barriers and enabling factors, infrastructure constraints and drivers, socioeconomical features of the place, and environmental issues that are discussed with reference to their interaction not being limited to technical points but also regulatory frameworks and policy implementations that can pave or hamper the way out for solar energy (Wüstenhagen et al., 2007). Through this review literature and limitations gaps of the existing studies to be identified to reveal the broad extent of research; this will provide an in-depth theoretical setting for this study, as well as controlling on the analytical methodology that follows.

2.2 Theoretical Models and Acceptance of Renewable energy technologies in tropical fruit production areas

For the development of renewable energy technologies, solar photovoltaic (PV) system is significant for region with tropical climate sub. It is important for effective interventions to understand the behavioural and psychological factors contributing to adoption of solar energy technologies. In the TAM framework (Technology Acceptance Model) given by Davis (1989) and general models for adoption of renewable energy, there has been extensive research by such authors as Davis (1989), Venkatesh and Davis (2000).

Theoretical Models for accepting Renewable Energy

Numerous models on how renewable energy is adopted emphasize the weighted aspect of economic, social, and institutional influences. Diffusion of Innovations Theory (Rogers, 2003) points out early adopters, social influence, and support of policy which are all crucial in rural agriculture: (Vargas & Rodriguez, 2020; Lee et al., 2017) show that financial incentives, awareness by farmers to environmental values policies supporting them are all important factors in determining whether energy sources can be adopted.

Technological Acceptance Theories for Agricultural industry

The Technology Acceptance Model (TAM) developed by Davis (1989) shows that perceived usefulness and perceived ease of use are basic driving forces leading to a user's attitudes toward technology adoption (Davis, 1989). Technological acceptance refers to how willing people or organizations are to try out new technology. How others view the technology and communication methods also matter a lot (Rogers, 2003). Many surveys The Enhancement of Instrumental Symbolic Utility done by (Davis and Venkatesh, 2000) indicate that when farmers see solar energy options as benefiting them by for instance by reducing operational costs, increasing productivity, or promoting environmental sustainability, then they are inclined decides to use this kind of technology (Lin & Wang, 2019; Zhang et al., 2018). Likewise, in areas where there are challenges related to installation issues or difficulty in maintenance, those who have problems with such, technology acceptance would naturally be less because farmers generally prefer things that easier to install and use (Imran et al., 2017).

Extensions of TAM, integrating social effect and behavioural control aspects aligned with the Theory of Planned Behaviour (TPB) have further clarified adoption behaviours in rural and agricultural sectors. For example, Venkatesh and Davis (2000) expanded TAM to incorporate social norms and perceptive instrumental processes, which are predominantly relevant in socialist and community oriented rural settings (Venkatesh & Davis, 2000). Diffusion of Innovations theory emphasizes how social networks and communication channels simplify technology dissemination among farmers (Rogers, 2003). For instance, in the case of Kenya according to Njoroge et al. (2019) farmers' decision-making was influenced by perceived economic benefits, such as reduced energy costs, and social influences, including peer testimonials and community leader endorsements.

Environmental and Climate Factors

In sub-tropical zones, climate conditions such as high solar intensity humidity temperature influence both solar energy utilization efficiencies and the perceived reliability of solar solutions. For example, work by Zhang and Li (2016) one high point is that although solar energy has potential value for agricultural businesses in the form of electricity, logistical constraints involve grid connections and maintenance (Zhang & Li, 2016). Zhao and Wang (2017) go on to say that environmental factors together with the necessary infrastructure challenges will to an extent decide whether producers perceive the products developed at home as being worth using or not. Environmental factors cover ecological concerns like land use effects, biodiversity issues, climate conditions, and regional environmental differences affecting solar power rollout (Nguyen, 2023).

To better understand technology adoption behaviours in general, the used theoretical frameworks like Technology Acceptance Model (TAM), Diffusion of Innovations (Rogers, 2003) and Theory of Planned Behaviour (Ajzen, 1991) special local social dynamics are fundamentally neglected in applying these models, but they have produced critical defects at the stage of community engagement. For example, in Ghana, Ansah et al., (2020) explored behavioural factors influencing farmers' willingness to adopt solar irrigation systems. They found that perceptions of ease of use and environmental benefits prompted initial interest, consistent with TAM and TPB frameworks. Social norms, especially encouragement from community leaders, played a pivotal role.

However, financial barriers persisted due to limited access to affordable financing, which hampered widespread adoption Though these models offer valued insights, their application often lacks contextual specificity, especially regarding local social dynamics, cultural influences, and community engagement processes that are critical in rural agricultural settings (Wüstenhagen, Wolske, & Wuestenhagen, 2007; Wang et al., 2023). Unexamined in the context of actual research are considerations such as social capital, community participation, and how much people believe in technology an omission that's rather hard to overlook. (Fraser, 2021; Nguyen et al., 2023)

2.3 Market Dynamics

The adoption of solar power in the agricultural industry has seen significant growth in recent years, driven by the increasing global demand for reliable and environmentally friendly energy sources (Timilsina et al., 2012). In South Africa, the primary motivation behind the uptake of solar energy technologies in both urban and agricultural contexts is the pressing need for affordable and dependable energy (Aroonsrimorakot & Laiphrakpam, 2019). Of all the different types of solar technology, solar photovoltaic (PV) systems have shown to be the best for using as alternative energy sources, especially for heating, irrigation, and powering farm equipment (Aroonsrimorakot & Laiphrakpam, 2019).

The rising cost of electricity, coupled with frequent power outages from the national grid, has further encouraged agricultural producers to explore alternative energy sources (Rahman et al., 2022). Many farmers, especially in the fruit sector, are motivated by the potential to enhance their competitiveness in local markets by adopting solar power, as it offers a means to reduce production costs and increase efficiency (Rahman et al., 2022). By lowering operational costs and enabling more stable business operations, solar energy helps farmers maintain competitive prices for their produce, making it easier to secure market access (Mokhantso, 2018). Furthermore, the growing market demand for sustainably produced goods provides an additional incentive for farmers to adopt renewable energy technologies such as solar power.

There are technological solutions on each energy level. The integration of solar energy into the subtropical fruit business is now more and more important due to reliable sources of energy required in irrigation, cooling, and processing activities. Ibrik (2020), for example, says that using solar photovoltaic (PV) systems is a tried-and-true way to save energy and depend less on the national grid.

There are many benefits to the use of solar energy in agriculture. The biggest one is the energy security Hatamifard et al. (2023) for farmers, which in turn will reduce their dependency on grid electricity and fossil fuels. This is especially important for rural areas that have little reliable access to energy (de Amorim et al., 2018). These energy-efficiency-enhancing technologies not only reduce the greenhouse gas emissions from fossil fuel use but also improve resilience and save the cost of a building.

2.4. Economic Barriers

2.4.1 Initial cost

There are a lot of different ideas in the literature about solar energy. Some say that the economic benefits are a big reason to use it, while others say that the high initial costs are one of the biggest problems (Sullivan et al., 2014). The careful balance in the literature is essential for decreasing bias and increasing confidence among research findings. Solar power is seen as an ideal opportunity for farmers because it can reduce reliance on fossil fuels and the grid, making them more resilient and lowering costs, though in practice many obstacles have limited widespread adoption (Eberhard et al.,2014).

The main barrier inhibiting the widespread rollout of solar technology, regardless of its type is the large upfront costs involved, limited access to finance and lack of understanding about solar technologies on the part of farmers (Eberhard et al., 2014). Despite the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) attracting investment in renewable energy (especially solar) potential benefits of such initiatives with respect to the agricultural sector are not fully exploited yet (Calitz et al., 2017). The difference in the adoption rate in agriculture, compared to other sectors, is primarily associated with the large initial capital cost of each unit and because there are very few options where farmers could get low-interest loans. Although solar energy could save money in the long term, some of its relatively high up-front costs and payback time make discouraging ownership and operation attractive (Eberhard et al., 2014).

Transformation in the move to renewable energy is not just energy and will have just as big an impact on quality of life, equitable socio-economic transformation, and economic growth. Its global importance is also highlighted in Sustainable Development Goal 7 (SDG7) of the United Nations to "ensure access to affordable, reliable, sustainable, and modern energy for all" by 2030 (Hassan et al., 2024). Adopting solar energy can result in considerable savings, as the farmers would be able to generate their own electricity and thereby not have to rely on grid-based power supply, which will lead to economic resilience and sustainability.

2.4.2 Financing options

The potential market availability for solar energy adoption is currently drawing the attention of investors and financial institutions seeking to capitalize on this business opportunity. In South Africa, all banks provide financing for solar investments at a reduced interest rate. Government incentive measures, including tax rebates and private sector pledges, render renewable energy projects highly financially advantageous for farmers (Department of Energy, 2015).

To improve the investment in solar PV for agriculture, it is required that policymakers must look at this barrier and develop a conducive environment. There is a possible option — creation of financial mechanisms aimed exclusively at supporting the agricultural sector. These might include low-interest loans, grants, and subsidies intended to help offset the high initial costs of installing solar for farmers.

2.5. Infrastructure Limitations

Rural and difficult terrains are common in developing countries that have resources but no operational energy infrastructure or physical connectivity. In these areas, insufficient road networks cause most of the problems to investors and engineers as they cannot access the serving communities especially during rainy seasons (Sansaniwal et al., 2018) In many regions, the lack of proper infrastructure necessitates significant investment from solar companies and developers for the development process, which can lead to high-cost side streams, particularly in the early stages (Shahsavari & Akbari, 2018). As a result, investors perceive renewable energy (RE) projects as riskier than the latter fossil fuel-based power plants with lower sunk installation costs and mature infrastructure (Anekwe et al., 2024).

Infrastructure for the new energy development: One of the most significant problems for renewable energy to overcome is that of the inadequate support infrastructure it faces under old, centralized grid designs. Most of the electric grids were developed to accommodate nuclear and gas power, so it can be difficult for renewable energy like solar to fit in the system (Anekwe et al., 2024). Therefore, renewable energy sources need a modern transmission system to effectively operate Anekwe et al., (2024) also say that the energy market is already full of systems that don't use renewable energy. It's also harder to start RE projects in countries where there aren't yet rules based on monopoly providers.

Beyond that, outmoded infrastructure makes it difficult to operate on solar energy more cost-effectively and efficiently (Gorjian et al., 2021). Moreover, the integration of solar power is difficult and costly because old infrastructure does not support large-scale growth that in turn leads to expensive (most resilient, low potential) or ineffective (rapidly installable but a higher cost, low reward). Researchers have found that solar photovoltaic (PV) and concentrated solar power (CSP) are key parts of the path to carbon neutrality (Herzog et al., 2011). However, these sources make electricity in a decentralized way, which could be a big problem for current grids that weren't designed to handle the changing loads that come with more intermittent energy sources like wind power.

One of the major obstacles preventing a larger uptake of renewable technology is that traditional infrastructure does not fit seamlessly with solar systems. Research indicates that regions with established infrastructure have higher rates of using solar technologies, partially because current systems are better equipped to handle power generated from local sources (Wüstenhagen et al., 2007). In addition, a sound energy policy is essential to encourage investments in infrastructure that facilitates the integration of solar power A lot of research needs to be done on how well current infrastructure works with solar energy systems, because old infrastructure can make the switch less successful and cause waste and higher costs (Gorjian et al., 2021).

The difficulty of implementing solar energy solutions is also compounded by physical factors like roof orientation and quality, which further highlights the role of modern infrastructure in allowing the transition to renewable energy Gorjian et al., 2021). So, we need to fix infrastructure problems that impact renewables and their intermittency, but the world is moving toward more renewable energy sources.

2.5.1 Importance of the compatibility of infrastructure to solar energy

While advanced in solar technology has progressed substantially, there is little research into social and economic impact on systems of solar energy in combination with public acceptance (Zell, 2015). Their technical orientation has led to an inadequacy of complete multi-criteria evaluation models that include land use, (Energy Return on Investment) EROI, and socio-economic scaling (Averyt et al., 2011).

However, existing literature does not provide sufficient long-term data that shows how drastically infrastructure changes can change the timeline for widespread solar adoption. By omitting considerations of how infrastructure development affects solar energy adoption, we effectively ignore a vast body of work that seeks to understand the social and economic drivers behind investments in energy and transport infrastructures (Kaldellis & Zafirakis, 2011); (Baker & Sovacool, 2017). The absence of these contributes to a constrained comprehension of the difficulties experienced during solar energy integration.

Furthermore, much of the work has so far looked at the technology and engineering side, rather than how societal aspects and economics affect the adoption of solar energy. However, studies often disregard society's readiness to accept alternative possibilities and their economic value (Hosseini et al., 2018). The lasting impact of installing solar energy in developing regions that lack sufficient infrastructure has also yet to be properly investigated. Even with the promise that these areas could benefit greatly from solar power, inflexible infrastructure continue to be an unaddressed challenge (He & Ma, 2010).

Lack of infrastructure due to the deployment of solar technologies impairs not only national security and sustainability goals (van den Bergh, 2015; Arent et al., 2014) but also social practices. This is particularly relevant in the face of climate change and as we look for sustainable solutions to our long-term energy needs Solar energy infrastructure that isn't well-developed or is very old will always be expensive and less efficient. For example, places with older generation technologies may face problems with scale, technical variation, and location because they don't have modern grid infrastructure (Margolis & Zuboy 2006; Eberhard et al., 2014).

Kamalapur (2001) in the article Technologies and Policies for Competitive Photovoltaics, underlines that institutions are a barrier to the development of solar energy policies. They highlight the pervasive demand for solar-compatible infrastructure, recognizing that the inappropriate design of infrastructure not only prevents solar solutions from being practiced but also strips them of their economic feasibility and social appeal (Ferreira et al., 2018).

2.6 Environmental considerations

Solar power systems do not have any direct emissions, making them a very clean alternative to fossil fuels. Replacing of traditional energy source with solar power can greatly reduce farmer's carbon footprints which are realized the potential for mitigation global climate change strategies (Aroonsrimorakot & Laiphrakpam, 2019).

Recent events highlight the potential of solar energy to displace fossil fuels. The application of solar photovoltaic (PV) systems in combination with solar thermal technologies helps to reduce the reliance on traditional sources of energy, thus reducing carbon emissions. Timilsina et al., (2012) have shown that many parts of the world, particularly in regions with high levels of solar irradiance such as South Africa, can capture sufficient sunlight to make advantageous applications within irrigation for crop production and extend into heating and powering devices normally associated with farms.

Additionally, solar energy also has some benefits for agricultural processes. Majeed et al., (2023) solar power is not limited to irrigation; it can be used in heating or powering any type of equipment used in agriculture. Solar PV system installation allows farmers to produce their own power, which saves the costs of electricity and subsequently reduces carbon footprints.

The usage of solar energy in agriculture could also make farming systems more robust to potential changes in the environment (Eberhard et al., 2014). Renewable energy sources such as solar power have proliferated in recent years following the ever-growing concerns about climate change and environmental damage. This raised consciousness inspires both people and institutions to look for cheaper, extra eco-friendly energy resources (Nelson, 2009) Typically, the desire to protect the environment drives change towards sustainability (Turney & Fthenakis, 2011).

The contribution of solar energy to climate change and improving farmer energy security has been broadly studied in the past (Pachauri et al., 2013), but impacts from different stages of panels life cycles have been lightly tracked (Hirmer & Cruickshank, 2014). Unfortunately, despite a growing consensus on the environmental sustainability of solar power, we are just beginning to understand how this technology might be designed to have minimal environmental impacts while providing benefits as it replaces other sources of energy.

Unfortunately, despite a growing consensus on the environmental sustainability of solar power, we are just beginning to understand how this technology might be designed to have minimal environmental impacts while providing benefits as it replaces other sources of energy (Hirmer & Cruickshank, 2014). Finally, the environmental benefits of solar energy are becoming increasingly relevant as awareness of climate change grows. Pandey et al., (2020) indicate that farmers who are environmentally conscious view solar energy as a sustainable alternative to traditional power sources.

2.6.1 Site suitability

Again, South Africa known to be one of the most perfect countries in the world for a solar energy technology to fast applicated as it has much "more than average" big potential distribution of Solar resources (IRENA, 2015). Part of this includes the country's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) and how they have been used to "help" fund a long list of solar photovoltaic (PV) projects. They also augment farming activities through the installation of energy resources (IRENA, 2015).

But there are several impediments that restrain the knowledge application of solar technologies in agriculture. A major difficulty arises from the time during which sunlight is most needed (during peak irrigation periods) and where not all regions of the world experience direct sunlight in a similar way. Also, the perception of solar technologies is generally underdeveloped, and little awareness about them exists in this target group. These are the people who easily assume that solar energy is expensive and can only be implemented on a small scale, mainly because they have no appropriate information and/or requisite training. These and other perceptions and information deficits are factors contributing to the underuse of solar technologies in agriculture.

2.7 Knowledge and Awareness

2.7.1 Lack of awareness

Solar energy technologies have gained wide attention over the years, increasingly considered indispensable for rural and agricultural sectors when it comes to sustainable development. A larger body of literature in this area has emerged, illustrating the importance of awareness in influencing people and communities to utilize solar technologies. Sometimes citizens of a country must be aware of the potential alternatives, such as solar technology, its benefits, and costs, along with prevailing policies and incentives, which encourage so.

The interrelation between awareness and the adoption of solar energy is crucial in understanding the factors influencing its uptake. Awareness plays a pivotal role in the adoption process, serving as a key element in decision-making regarding solar energy Wang et al., (2023) stress that awareness is more than just knowing about technology. It also includes knowing about the economic and environmental benefits, as well as government policies that encourage adoption. Wang et al., (2023) integrate awareness into the Theory of Planned Behaviour, demonstrating that increased awareness enhances self-efficacy, or the confidence in one's ability to implement solar energy technologies.

Lin and Kaewkhunok (2024) further support this perspective by showing that higher electricity usage among farm households increases the likelihood of diversifying into off-farm activities to manage economic shocks. However, they also identify a disconnect between awareness of solar technology and its actual adoption. Both studies collectively illustrate a strong link between informed decision-making and solar energy adoption, suggesting that public awareness campaigns could significantly impact solar energy penetration.

Despite the importance of awareness, several barriers obstruct clearer pathways to adoption. Lin and Kaewkhunok (2024) highlight that detailed information about solar energy is often lacking in rural areas, where adoption is most needed. The absence of proven case studies and real-time demonstrations of solar technology can lead to misconceptions and skepticism among adopters. These issues are exacerbated by socioeconomic disparities, with lower-income families having fewer educational resources related to solar energy. Pandey et al., (2020) emphasize that low financial literacy among farmers can also hinder their understanding of the economic advantages of solar technologies.

Education and community outreach are essential for increasing public awareness about solar energy. Lin and Kaewkhunok (2024) stress the importance of structured programs that provide comprehensive information about the advantages, costs, and operations of solar systems. Such educational initiatives can fundamentally shift farmers' mindsets, leading to greater acceptance and adoption of solar technologies. Wang et al., (2023) also discuss the role of community awareness efforts, noting that social dynamics, such as peer pressure and success stories from community members, can drive collective action and elevate awareness.

National business-supporting measures, particularly state-led programs, are critical in fostering solar energy adoption. Ge et al., (2017) highlight that measures such as tax credits, subsidies, and feed-in tariffs provide financial assistance and disseminate information about solar technologies. Combining these financial incentives with educational programs can enhance the feasibility and appeal of solar technologies to a broader audience.

2.8 Cultural and Social Factors

In analysing the policy and institutional framework for solar energy adoption in South African agriculture, several significant insights emerge, particularly when incorporating perspectives from behavioural economics and community participation. For instance, using ideas from behavioural economics or getting more people in the community involved in the spread of solar energy technologies might help us understand the challenges and opportunities that affect adoption in a more complex way (Hosseini et al., 2018). This approach acknowledges that the interaction of cultural and social behaviours significantly influences the adoption process, which is often overlooked in conventional policy frameworks.

Wang et al., (2023) show that in collectivist societies, where reputation and social approval are very important, community norms and expectations have a big impact on the use of solar energy technologies like rooftop photovoltaic (PV) systems. This observation fits with the Theory of Planned Behaviour (TPB), which says that subjective norms and how important an activity is seen by important people in your life have a big impact on your choices. Farmers are more inclined to adopt solar technologies if they align with community standards, especially in regions where environmental stewardship is culturally ingrained.

The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) serves as a prime example. According to IRENA (2021), traditional energy sources, such as diesel, remain prevalent in many developing regions, primarily due to their familiarity and perceived reliability. Farmers' reluctance to transition to solar energy may stem from a comfort with established technologies and apprehension about the risks associated with newer, unproven alternatives. To solve these problems, we need educational programs that are sensitive to different cultures and aim to clear up misunderstandings while respecting local customs (IRENA, 2021).

Gender dynamics also play a crucial role in solar energy adoption. IRENA (2021) reports that women, who are often primarily responsible for food production in many regions, face significant barriers to investing in solar-powered systems. These barriers include limited access to credit, land, and technology training. Integrating gender considerations into renewable energy policies is essential to ensure that solar technologies reach all farming constituents, thereby promoting equity in agricultural development.

Durga et al., (2024) further explores how cultural norms related to gender can exacerbate social vulnerability, particularly for marginalized groups such as minority and women farmers. These groups often encounter systemic barriers to accessing information, resources, and decision-making power regarding solar energy adoption.

Addressing these cultural inequities is vital for expanding the use of solar-powered irrigation systems (SIPs) and other renewable technologies.

The influence of social networks and community leaders is also critical in the adoption process. Both Wang et al., (2023) and Durga et al., (2024) underscore that peer influence and social proof (evidenced by positive experiences of other farmers) can significantly impact adoption rates. Community leaders and conduit managers play a pivotal role in facilitating the adoption of solar technologies by endorsing and supporting renewable energy solutions (IRENA, 2021). This highlights the importance of involving local stakeholders and integrating community perspectives in the planning and implementation of renewable energy projects.

Moreover, the role of authoritative figures, such as government and institutional endorsements, is significant in shaping farmers' decisions regarding solar energy adoption. People are more likely to trust renewable technologies and use them when they are backed by the government and institutions (Wang et al., 2023) This shows how important it is for the government and local communities to work together.

The literature confirms that promoting solar energy innovation requires robust awareness and education initiatives. IRENA (2021) indicates that many farmers lack sufficient awareness about the benefits and operational principles of solar technologies. Educational programs must be designed to respect and incorporate local knowledge, thereby bridging the gap between traditional practices and modern technological solutions. This approach can enhance understanding and acceptance of solar energy (Durga et al., 2024).

In conclusion, addressing the complex interplay of cultural, social, and economic factors is essential for fostering the adoption of solar energy technologies in South African agriculture. Including information about how people behave, gender issues, and community involvement in policy and education programs can help get around problems and encourage more fair and effective use of renewable energy solutions.

2.9 Regulatory and Policy Issues

The literature on the adoption of solar energy highlights how important regulatory and policy frameworks are in terms of whether farmers decide to invest in solar technologies. Feed-in tariffs (FITs), financial incentives, tax credits, and renewable portfolio standards (RPS) are often cited as important policy mechanisms to promote solar energy generation (Lipp, 2007). These policies provide large financial and economic incentive which offsets the capital costs of solar installations, enabling more and farmer to rapidly adopt (Timilsina et al., 2012).

But a lot depends on the region-specific regulatory environment for how effective these can be. For example, solar has demonstrated a significant uptake thanks to FITs in Germany and Spain through guaranteed grid-tied solar electricity buybacks at fixed prices (Timilsina et al., 2012). On the other hand, those with inconsistent or unclear regulations must deal with issues related to uncertain costs and viability of solar projects (Timilsina et al., 2012).

Ferreira et al. (2018) also mentioned FITs and net metering along with other policy regulations, which help provide consistent pricing and generate reliable electricity from renewable energy resources. Add to that simplified bureaucratic procedures and a focus on financial sustenance for the small farmer as one of the ways to induce them towards adopting solar in agriculture.

Carlisle et al. (2015) agrees that tax reliefs and grants in the form of a good regulation framework, which is transparent, are necessary to mitigate financial barriers for solar energy investments. They warn, though, that "regulations that are too cumbersome and zoning restrictions that require overly large tracts can quickly make solar out of reach for farmers." Nonetheless, differences in regulatory regimes by region introduce risks that could prevent farmer adoption of solar technologies (Coffman et al., 2016).

Solangi et al., (2011), argue that the differences in policy instruments like FITS and RPS can lead to different levels of diffusion of solar as well among farmers. They say that a broad policy will not effectively address the economic and regulatory challenges, but rather targeted policies are required, such as subsidies and incentives for agriculture.

The literature also shows that regulatory and policy frameworks have a big effect on the use of solar roofs by farmers Solar technology investments can be boosted by policies that offer financial incentives and technological standards. Frameworks that aren't clear or standard are the main things that stop people from investing in solar technologies (Timilsina et al., 2012; Ferreira et al., 2018; Carlisle et al., 2015; and Coffman et al., 2016). The use of well-structured policy instruments that tackle the financial, institutional, and technological problems is very crucial to increasing the solar energy uptake in agriculture.

Fikru (2022) reinforces that the operation of solar as a backup inverter system is not economically appealing to farmers, and tariff mechanisms like net metering are necessary for solar investments to be financially feasible. These mechanisms make it more profitable for solar energy and help gain the wider acceptance. But, as with the carbon price option, unnecessarily complicated or insufficient policies can create uncertainty and risks for farmers.

Add to that, the relationship between local utility policies and state-level regulations incentivizes a fragmented policy landscape that work in divergent ways for farmers depending on where they are located (Fikru, 2022). Solving this challenge through a balanced and standardized policy landscape might provide the necessary support for solar energy adoption that could encourage both deployments to meet energy access goals as well as contribute towards sustainability objectives (Fikru, 2022).

Both Lu (2021) and Nguyên et al., (2023) agree that feed-in tariffs (FITs) and tax breaks, among other supportive regulatory regimes, are necessary to get farmers to invest in solar power. They argue that the walking-on-eggshells regulations can create a patchwork of laws from municipality to municipality, especially in a state rife with small-scale farmers who don't have access to the same wealth of resources and knowledge as big growers. The lack of specialized support instruments for farmers may serve as an obstacle to solar installation (Lu,2021)

Bohac (2020) It is in this context that Kandpal (2020) stresses the importance of combining renewable energy with agricultural policies. This will help resolve the issues of land use conflicts and finance sources facing solar development, with cooperation among government departments and agricultural stakeholders (Bohac,2020).

Wrasse, (2016) states that local partnerships and community engagement as a strategy to tackle barriers of regulation. With partners like (Solar energy light company) SELCO Foundation, successful outcomes have shown that efforts addressing these technical and cultural bottlenecks can increase farmer solar uptake. Bureaucracy and inefficiencies about lifecycle planning, however, seem to be still blocking the way of solar park implementation (Wrasse, 2016).

Finally, the combination of legible regulation and policies also plays an essential role in promoting the use of solar energy by agriculture. Therefore, enforcing clear & consistent regulation and financial aid packages targeting the specific types of increased investment required for penetrating into sustainable solar uptake in farming, coupled with stakeholder engagement, are desirable steps towards driving sustainable solar energy utilization in farming (Dorn, 2016; Lu, 2021).

2.10 Policy and Institutional frameworks in South Africa

The policy and institutional framework of solar energy adoption in agricultural sectors is vital to informing the transition into renewable energy sources for South Africa. Koval et al., (2021) and research such as that conducted by Rodriguez (2021) emphasize the role of state regulation and financial incentives in encouraging renewable energy adoption, specifically solar power, within agriculture.

The study published in Renewable and Sustainable Energy Reviews says "green tariffs" can go a long way toward helping farmers who run high-energy operations that might also determine what they are able to produce (Rodriguez, 2021). This, combined with the selective targeting of tariffs in different regions of our country, will go a long way to overcoming the challenges faced by farmers in any region of South Africa. Also, Koval et al., (2021) say that institutional factors, like easier system licensing and grant-based research programs, are big parts of driving technological change and making it possible for agricultural solar energy systems to be profitable (Zilles, 2021).

In contrast, Anekwe et al., (2024) highlighted the profiled, fragmented policy landscape resulting from a legacy of coal dependence in South Africa. They say that this fragmentation has not generated coherent visions or strategies on how best to incorporate renewable energy into agricultural practices (Anekwe et al., 2024).

For example, Nene and Nagy (2021) look at how the legal system and regulatory patterns affect the spread of solar energy solutions in agriculture. They say that the lack of coordination between different systems and decentralized governance have stopped solar energy from being used for harvesting. The authors add that, although South Africa is home to some of the world's best solar resources, international mandates, such as with the Copenhagen Accord and (United Nations) U.N.

Sustainable Development Goals are not inherently in line with existing agriculture policies, preventing opportunities to fully transition. More integrated policy is essential to overcoming these barriers, as argued by Nene and Nagy (2021) when advocating for solar energy adoption in agriculture.

This ties with a holistic policy approach called for by, which also sheds light on the support structures needed to practice solar powered agriculture (Murombo, 2021). Despite existing key policies such as the Integrated Resource Plan (IRP) and the National Energy Act, Murombo (2021) notes that their non-specificity and unpredictability discourage investment in solar energy programs.

The authors highlight the need for better transposition and enforcement of agricultural policies in line with renewable energy goals, as well as greater clarity on regulations that impede solar implementation. On top of regulatory changes needed to allow for solar power solutions, more public education on the benefits of solar may drive investment among farmers who would benefit from these options (Murombo, 2021).

The paper by Fraser (2021) focuses on the establishment of solar energy pathways, facilitated in part through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) introduced in 2011. This has gone some way to redress socio-economic imbalances, with the completion of REIPPPP rounds working on a competitive auction basis, complete with local employment requirements.

Fraser (2021) comments, though, that social capital and community engagement are too often needed if you want renewable energy projects to be around for a while Strong social networks support solar systems in convergent agricultural settings, but low social capital leads to opposition. This demonstrates why developing active community engagement within renewable energy initiatives is essential.

Essex and de Groot (2019) delve deeper into the impact of past disparities in agricultural practices on already disadvantaged farmers. Essex and de Groot (2019) contend that while programs such as REIPPPP are making progress towards their goal of promoting renewable energy, the advantages tend to fall in favour of the bigger enterprises, leaving the smallholder farmers in a disadvantaged position. The authors call for integrated, locally appropriate, and participatory policy approaches that draw on local knowledge to capture the special requirements of disadvantaged farmers. This would deliver solar energy solutions in a fair and appropriate way while creating long-term sustainability for the agricultural industry.

Kruger et al., (2021) study centres on the effect of competitive bidding programs, more specifically clean energy auctions, in reducing solar costs to make it accessible for agriculture. These auctions have lured massive investment and a price push for solar technologies, making them available also to the farming community. Yet like Essex and de Groot (2019) and Kruger et al., (2021) raise concerns over market concentration in such projects where big players control the market and smaller agricultural players do not have any opportunities left for solar energy projects.

And they make a case for taking a broader perspective to ensure that the conversion to solar power doesn't benefit only a few: that's why they argue that smallholder farmers must be included in any change According to Kruger et al., (2021), local share requirements and community trust arrangements at the auction design level can boost local economies and make rural areas stronger.

Regulatory fragmentation is a common theme in the literature. Murombo (2015) identified the fragmented regulatory environment as a major problem for the uptake of solar energy in agriculture since no linkages between existing energy and environmental laws exist. The focus on larger-scale projects in the REIPPPP has driven up renewable energy adoption, but the centralized and highly structured regulatory framework constrains the IPP's ability to reach down to support solar energy projects in agriculture.

Regulatory framework (Murombo, 2015) suggested that a decentralized regulatory system is necessary to devolved authority to farmers while unlocking investment in solar energy, as well as keeping specific laws on addressing the unique limitations of solar energy adoption. The absence of this will discourage investment in solar energy technologies because of regulatory uncertainty.

This is also echoed by Makina (2014) who further laments the absence of a policy framework that fit together the adoption of renewable energy with the requirements of this key sector. Conflicting policies hinder the adoption of solar energy technology, as noted by Murombo (2015). Makina (2014) posits that the confusion among stakeholders means investors are not likely to invest much since the project appears uncertain. Makina (2014) stressed that for farmers to be able to adopt solar energy, regulatory guidance, financial support, and technical assistance are a must.

Todd and McCauley (2021) also argue that the control of ESKOM, the state utility which favours fossil fuels rather than renewable energy, became another hindrance. The dominance of coal in this sector makes it harder to transition towards solar energy use in agriculture, as farmers would be unwilling to invest in solar technology if the policies are not supporting that. Todd and McCauley (2021) stated that unless there are financial incentives, assistance with the installation of solar energy technology, or a more supportive regulatory framework is put into place, further investment to mitigate the risks farmers face will not happen.

This literature review demonstrates that although South Africa has emerged in the last decade as a global leader in terms of its policy and institutional wrappers for stimulating the uptake of solar energy farming, much remains to be done. These range from broken policy and regulatory frameworks to very significantly broken access to resources, especially by smallholder farmers. To improve and keep up the right use of renewable energy by South Africa's agriculture, these problems need to be logically dealt with in a more integrated, inclusive, and regionally appropriate way (Kruger et al., 2021; Murombo, 2015; Makina, 2014; Todd & McCauley, 2021; Essex & de Groot, 2019).

2.11. Literature review limitations and gaps

2.11.1 Limitation and gaps

Research on solar energy use is already revealing several critical knowledge gaps that require attention. An area of concern identified by Baker & Sovacool (2017) is the lack of solid empirical data linking social and political dynamics with investments in solar energy infrastructure. Furthermore, solar technology already exists within current infrastructure, not relying on new technologies, and remains largely unexplored in resource-deficient areas. Future work on public opinion and social mobilization could further explore this, influencing infrastructure updates for solar adoption (Wüstenhagen et al., 2007).

However, Gorjian et al., (2021) highlight the significance of performing life cycle assessments (LCAs) on solar energy systems integrated with existing infrastructure. Further, Gorjian et al., (2021) Moreover, they suggest further examination of the mixed system with solar power and alternative renewable sources, or energy storage strategies Further investigation is necessary to understand how regulatory regimes and community engagement could facilitate the mainstreaming of solar technology innovations within existing infrastructure.

Lin and Kaewkhunok (2024) also reflect the need to study how these campaigns helped or hurt solar energy uptake in the long term. Several studies have assessed the knowledge and awareness in relation to IHD pathology. However, none have addressed how digital platforms can improve the awareness in rural sectors.

Several barriers to solar energy adoption are present as well, as indicated in the literature. Poor communication or education around potential benefits and lack of knowledge regarding processes involved with solar technology might be a barrier impacting adoption. Ge et al., (2017) state that the current study design is too small-scale and tends to only be fixed on the well-established renewable energies like wind and photovoltaic systems, but not as often including tidal energy or geothermal, for example. Furthermore, existing research by Ge et al., (2017) and Wang et al., (2023), would thus limit generalizability to other socio-economic and cultural contexts.

Most studies currently rely on cross-sectional data, which provide only a single snapshot of awareness or acceptance at one point in time. Well-designed longitudinal studies, as proposed by Ge et al., (2017), Pandey et al., (2020), and Wang et al., (2023) to explore how awareness and adoption rates change over time. Besides, the domination of quantitative approaches in extant research can also neglect qualitative aspects, for example, farmers perceptions and decision-making processes, which may be more clearly explained by various qualitative methods such as interviews and focus groups.

Ge et al., (2017), Pandey et al., (2020), and Wang et al., (2023) have discussed social networks and community dynamics in detail These studies highlight important factors that contribute to the adoption of solar energy and warrant further investigation. It also says that the area where socioeconomic and cultural factors meet needs more research, since factors like education or income may only affect adoption (Wang et al., 2023). While a limited number of existing studies showed the importance, underestimated aspects include behavioural and psychological ones, such as attitudes towards solar energy (Ge et al., 2017) and risk perceptions (Wang et al., 2023).

Financial constraints due to economic feasibility were also (partially) addressed by Ge et al., (2017) and Pandey et al., (2020). Further review is necessary. However, these studies tend to ignore financial literacy and risk perceptions, two important factors shaping whether a household adopts solar. What more research is needed to find out how policies like subsidies and education programs work and what effects they have on the use of solar derivatives in different places and among different groups of people (Wang et al., 2023)?

The literature provides less coverage of environmental and ecological aspects, such as land use or impacts on biodiversity (Ge et al., 2017). Nguyen et al., (2023) also made notes regarding regional variability and comparative studies. Wang et al., (2023), and Durga et al., (2024) investigated how cultural and social aspects affect solar energy adoption for diverse locations.

Furthermore, the designs of policy frameworks and institutional support and their relevance for implementation are pointed out by several papers (Nguyen al., 2023); Durga et al., 2024). Other themes that need replications include trust in technology, community engagement (Nguyen et al., 2023) and the role of social networks in adoption decisions (Wang et al., 2023).

Lastly, research like Wrasse (2016) and Fikru (2022) showed that more research needs to be done on how policies change over time, what causes the economy to grow, and how financial incentives affect the rules that govern businesses An analysis of these areas is crucial as it can provide a comprehensive understanding of the factors that may contribute to the adoption of solar energy or other factors that influence it.

A review of the solar energy policy and institutional framework for agricultural use in South Africa also presents several significant gaps to effective implementation; for example, the lack of a sector-specific supportive regulatory environment that addresses farmer-centric challenges such as access to credit and technical support is a major gap (Wright et al., 2019). Policies such as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) do not adequately capture the needs in dairy, showcasing that more localized interventions are required (Wright et al., 2019). This is one example of the more general challenge for amelioration to work between energy and agricultural policies, which lacks adequate coordination or results in lost cross-sectoral synergy (Wright et al., 2019).

Yet another hurdle is the absence of education and awareness initiatives, which would educate farmers about the advantages as well as practical implications of integrating solar power According to Wright et al., 2019. Furthermore, without proper training and resources, farmers may view solar technologies with suspicion, thereby hindering any potential enhancement of energy efficiency and sustainability in agriculture. This is, in part, due to this low level of stakeholder engagement in policy development. Farmers and other agricultural groups could help make energy policies more relevant and useful if they were involved in the creation of more policies. However, co-production methods have not been used very often.

Baker and Sovacool (2017) also talk about important policy holes that might make it hard for a solar value chain to form in agriculture. These include problems that arise when commercial needs clash with local content requirements. It identifies an additional gap in the literature regarding the intricate relationships within institutional scale (local, regional, and international) that have not been systematically examined to agricultural stakeholders. The absence of literature that specifically looks at these dynamics makes it difficult to understand the implications for farmers and farmer participation in solar energy schemes (Baker & Sovacool, 2017).

Second, the evidence on the economic and environmental consequences of solar technology adoption in agriculture is very limited, which makes it difficult to assess current policy support (Schmidt et al., 2017). Because of this knowledge gap, very few best practices exist in connecting these solar applications with farming. Moreover, there is still limited coverage of public interest and educational resources on the potential of solar power in agriculture (Schmidt et al., 2017).

To close these gaps, we need a more thorough approach to policymaking, better coordination between sectors, and active participation of all stakeholders to create an environment that makes solarization of agriculture possible. Among other strategies, we can achieve this by enhancing financial support mechanisms, stepping up capacity-building initiatives, and involving stakeholders in policymaking (Adebayo et al., 2021). Moreover, an empirical study into the socio-economic and environmental benefits of solar energy in agriculture would also be beneficial for policy development (Todd & McCauley, 2021).

Overall, the research shows that there are several important gaps in the policy and application framework for solarization in the South African agricultural sector. These gaps include the absence of sector-specific policies, inadequate capacity-building programs, insufficient stakeholder involvement, and a lack of empirical evidence on the impacts of solar energy adoption (Fraser, 2021; Murombo, 2021; Nene & Nagy, 2021; Anekwe et al., 2024). ; Fill in gaps that are indispensable to assure a broad and fair distribution of these new technologies within the agricultural production chain (Essex & de Groot, 2019).

There are many papers showing that the adoption of renewable energy can lead to environmental benefits (for example Ge et al., 2017), and some argue with evidence for there being significant financial barriers to its uptake by small-scale farmers (Pandey et al., 2020). Nonetheless, to date, there is limited published empirical evidence from the subtropical fruit sector in South Africa and this study attempts to address this shortfall. This contrast strengthens the literature review. Moving forward the chapter will detail the research methodology of the study.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Introduction

This chapter details the research design and approach used to explore the determinants of solar energy adoption among subtropical fruit producers. This study adopts a pragmatic research philosophy to achieve its objectives. It aligns the methods and approaches with the nature of the research questions. An abductive approach is used in the methodological framework. This lets both existing theories and real-world data be combined to find new insights. The chapter will also describe the overall research strategy, which includes using qualitative studies to obtain in-depth perspectives from participants.

The next sections will go into the sample methodologies used, data-gathering methods (such as questionnaires) and their handling procedures. Over the course of the study, ethical issues regarding reliability and validity are discussed while keeping the integrity of the research process in mind. Finally, the chapter acknowledges the limitations inherent in the study and sets the groundwork for additional chapters that will present the results and discuss their implications. This methodology section leads the reader on the process of how data was generated and analysed to answer the research questions and objectives, serving as a basis for presenting and interpreting the findings.

3.2 Research Philosophy: Pragmatism

This is a brief overview of the study by a qualitative case study approach, with support from thematic analysis to investigate farmer's views about the use of solar energy in subtropical fruit farms. The basis, or philosophical underpinning, for this research is pragmatism. It allows us to bring together several different data collection methods and thus cover our research questions in some depth (Creswell, 2014; Yin, 2014; Braun & Clarke, 2006). This study is based on pragmatism, focusing on practical ways to solve problems, and using adaptable methods (Creswell & Poth, 2018). A constructivist view was applied to understand what participants went through, seeing knowledge as something built through social interactions (Mertens, 2015). This systematic review is intended to find insights that enable producers to make wise decisions and support sustainable practices in their agricultural environment by focusing on pragmatic results.

3.2.1 Constructivist Foundations

This pragmatic framework embeds a constructivist perspective, which asserts that human interactions and experiences generate sociologically produced knowledge (Creswel, 2014). This runs counter to the studies of people like Piaget and Vygotsky, who contend that knowledge arises from the interactions between individuals and their environment (Schunk, 2012). This empirical study is qualitative in its character but allows one to understand the subjective meanings invented by solar energy technology more deeply.

By means of structured open-ended questionnaire the report emphasizes generating rich narratives from participants thereby allowing their voices to shape results and conclusions. It recognizes that knowledge is activated by the complex mix of social context, personal perspective, and group interactions by putting the lived experiences of producers on the site at the top of the list (Charmaz, 2006).

3.2.2 Methodological pluralism:

Encouragement of a methodological pluralism combining both qualitative and quantitative approaches, the pragmatic philosophical stance, supports both (Feilzer, 2010). It also uses qualitative studies in this work. They have been well equipped to investigate the complex reality of current technological adoption. By way of structured open-ended questionnaire, participants can express their ideas and emotions in their own words while guaranteeing that important subjects affecting solar technology adoption are covered with flexibility and depth.

The methodological decision aligns with the assertion of qualitative researchers, who emphasize that quantitative measures alone are insufficient to fully understand complex issues such as those partially related to the acceptance of renewable energy sources. Denzin and Lincoln (2011) argue that qualitative research offers a fuller, contextualized knowledge of these events by analysing the meanings and experiences directly involved in social events.

3.2.3 Reflexivity and researcher orientations

The recognition of reflexivity and self-teaching is a fundamental feature in theoretical philosophy. In qualitative research, it is important to understand that the positionality of the researcher may affect the procedures for data collection and interpretation. According to Finlay (2002), reflexivity means that researchers should always think about how their views and interactions with participants might change the insights they get from the research. To preserve its reflexivity in this study, an open and safe atmosphere was open for communication during questioning for honest participant sharing of their experiences. The study aimed to lower the bias and increase the authenticity of findings by considering the survey procedure and relationships with interview subjects.

3.3 Approach: Abductive

3.3.1 Introduction to the Abductive Research Approach

As a rule, abductive research is seen to get to the best explanation. This study uses this research strategy to look at problems that subtropical fruit farmers in Tzaneen, Limpopo Region face when they try to use solar energy technology. This method focuses on making hypotheses from events that have been seen so that researchers can investigate the complexities of real-world problems (Peirce,1958). The abductive method lets us look at the social, economic, and technical problems that producers (Creswell, 2014) face in a more flexible way as this study tries to figure out how to get people to use solar technology. They also facilitate the relationship between actual observations and theoretical frameworks.

3.3.2 Rationale for Choosing an Abductive Approach

The abductive approach was chosen because it allows for flexible interpretation of data by iteratively moving between data collection and analysis, which is suitable for exploring nuanced perceptions among participants (Saunders et al., 2019). The pragmatic philosophy aligns with the study's focus on practical implications of solar energy adoption, emphasizing real-world relevance. The embedded constructivist perspective was adopted to acknowledge that participants' social interactions influence their experiences, which is critical in understanding their motivations (Creswell & Poth, 2018)

Simply relying on inductive methods that produce generalizations from specific instances or deductive reasoning testing predefined theories would fail to capture the richness of producer experiences in the region. As noted by Morgan (2007) the abductive methodology facilitates the elaboration of theories while simultaneously engaging with the lived realities of research participants, ultimately leading to deeper insights into their challenges and decision-making processes.

3.3.3 Research Design Framework

The abductive approach outlines a flexible yet structured research design framework that consists of several key components: the project design system, the proposal methodology, and its evaluation.

3.4 Qualitative Data Collection

The study will focus on a purposive sample of subtropical fruit producers in the Tzaneen Region. Participants will be selected based on their experiences with solar energy technology to provide a wide representation of opinions about aspects such as farm size, energy requirements, and prior involvement. The incorporation of both small and large industries gives insights into diverse attitudes and barriers associated with solar energy adoption.

The principal method of data acquisition would utilize case study approach that facilitate open-ended dialogues while directing talks to relevant topics related to solar energy technologies (Stake, 1995). The case study approach enables one to delve deeply into participants' motivations and challenges. It allows for both flexibility and understanding of context (Yin, 2014). Each session is anticipated to last between 30 minutes and 60 minutes, which provides ample time for exploring complex topics systematically.

3.4.1 Questioning Protocol Development

An interview protocol was developed to guide data collection that incorporates predetermined key questions while allowing participants the freedom to elaborate on issues they consider important. Questions were designed to elicit insights into financial, technological, and socio-economic factors influencing their decisions regarding solar energy technologies and was guided by themes identified in prior literature (Wüstenhagen et al., 2007).

3.4.2 Data Recording and Analysis

1. Interviews were recorded with participant consent and the richness of the recorded responses will not be lost. Written notes were also taken to capture non-verbal cues and context that was appropriate for additional insights.

2. Following questioning, recordings of transcription were stored verbatim to achieve accuracy of participant narratives and facilitate subsequent analysis according to the elaboration of the plan.

3. Thematic analysis in NVivo 15 was employed to systematically identify the recurring themes and patterns that emerge from the interviews (Braun and Clarke, 2006). This method facilitates the classification of qualitative data into key topics, including awareness and economic viability of solar technology benefits, technical barriers, and institutional support.

3.4.3 Contextual Integration

A vital element of the research methodology involved contextual integration, positioning findings in the socio-economic framework of Tzaneen area. This study seeks to generate context-sensitive insights by integrating local variables, including economic conditions, cultural attitudes, and environmental elements (Kruger et al., 2021).

The contextual analysis will use existing literature to facilitate cross-comparison with data from other research on renewable energy uptake, emphasizing obstacles unique to producers in Tzaneen regions. This element enhances the overarching theoretical discussion on renewable energy transition in agricultural practices as demonstrated by research trends noted in literature (Nguyen et al., 2023).

3.5 Population and sampling: Who and how many

3.5.1 Population Definition

The target population of this study covers all subtropical fruit cultivators in the Tzaneen Region. This group includes a diverse range of producers involved in multiple dimensions of fruit agriculture, such as mangos, avocados, and litchis. The subtropical climate of the region facilitates the cultivation of these fruits and thus creates a larger agricultural population dependent on efficient energy solutions for production activities.

Criteria for Inclusion: Individual criteria were created to assure consistency of the collected data. Participants were required to participate actively in the cultivation of subtropical fruits in the region and possess significant experience or insights in the utilization of solar energy technologies. This criterion guarantees that the ideas obtained from the interviews are grounded in direct experiences related to solar energy adoption.

3.5.2 Sampling Technique

To enable the selection of participants according to how their pertinence to the research topic is selected, a purposive or non-probability sampling strategy was used (Baiju, 2002). This method is especially advantageous in qualitative research, where the objective is to collect comprehensive information from individuals with specialized knowledge or experience (Tongco, 2007).

Purposive sampling was selected to ensure that the study encompasses a variety of perspectives and experiences from diverse categories of producers, thus enhancing data (Mauyra et al., 2015). By intentionally selecting participants, the research may explore the complex problems and experiences that certain farmers have while considering solar energy alternatives (Tongco, 2007).

The eight participants were selected to assure diversity of opinions within the subtropical fruit producer group. This diversity is important to obtain a broad spectrum of inputs, as producers may differ in operations expertise levels and attitudes towards technology adoption. Participant selection evaluated factors such as farm size, fruit varieties grown and prior experiences with renewable energy systems to enhance the richness of the obtained data.

Participants were recruited through local agricultural networks, associations, and extension agencies in the Tzaneen region. This enabled the identification of persons who met inclusion criteria and were willing to share their experiences with solar energy adoption.

Interview Procedure:

Open ended questions were asked to enable participants to express their thoughts and experiences openly (Miller & Lambert, 2014). Each interview lasted 30 to 60 minutes, allowing ample time for thorough conversations and remaining manageable for the participants. The interviews were recorded with consent and later transcribed for comprehensive examination.

3.5.3 Representativeness and Constraints

The sample's representativeness is limited by the purposive sampling strategy which, although it facilitates targeted insights but restricting generalisability of the findings to the wider community subtropical fruit farmers in the region limits. Each qualitative data recorded provides significant insights into the characteristics and challenges of this group of producers.

Potential Limitations: A possible disadvantage of this sample technique is the risk of selection bias, as the experiences and challenges articulated by the selected participants may not represent the perspectives of all producers in the Tzaneen region. Thematic analysis of the comments seeks to identify salient topics that may resonate with a wider audience, providing valuable insights for large-scale agriculture and energy policy discussions.

Finally, the population and sample dimensions of this study have been precisely defined. They ensure that the results accurately represent the experiences and obstacles encountered by subtropical fruit farmers in the Tzaneen region regarding solar energy adoption. This research uses purposive sampling and meticulous participant selection to educate the current environment, thereby leading to plans about the integration of renewable energy technology in agriculture.

3.5.4 Systematic sampling of the target population

In this research, the purposive sampling approach to sample the target population will be used. The idea behind this technique is that the specialists, or individuals directly affected, will have known something about solar adoption in the subtropical fruit sector. For instance, in this abductive study, the people who will be interviewed will have to meet at least this criterion: -

1. Agricultural industry
2. Worked on subtropical fruits industry.
3. Using solar energy regardless of the farm size.

As from Mitchell (2011), purposive sampling is often used in case study research since it allows for the intentional selection of participants with specific characteristics or knowledge that are relevant to the research question. This approach allows researchers to focus on cases likely to yield insight-rich information, increasing the significance and understanding of the study (Patton, 2002). In turn, in the frame of this study, only those individuals will be chosen who meet the set criterion.

3.5.5 Reasoning behind sampling strategy chosen.

The second reason for choosing purposive sampling for this study buttresses the first: the prime benefit of this sampling technique is to ensure that we can locate persons who are in an advantageous position to furnish detailed, on-point, and in-depth information about solar energy adoption in the agricultural industry (subtropical fruit industry). In this way, the data of interest, which are collected, will be exactly aligned with the research goals.

This will assist in avoiding generalizing across a wider population (Lieberson, 2011). The method enables researchers to engage with participants that have the potential to disrupt existing epistemologies, enriching data collection (Hammersley et al., 2011). Purposive sampling generates cases representing different characteristics or general phenomena and provides a depth of understanding about the research topic (Creswell, 2014); (Etikan et al., 2016). Further, purposive sampling is effective in time and resources because it gets the researcher to focus directly on the individuals most likely to give invaluable information (Creswell, 2014).

3.6 Data collection technique: Case study - Interview schedule and observation schedule

This study's research instrument is designed to collect qualitative data from subtropical fruit farmers on their experiences and obstacles in using solar energy technology in the Tzaneen region of Limpopo Province. This instrument consists of two primary elements: a structured open-ended questionnaire and an observation schedule. Both components collaboratively investigate the determinants affecting the solar energy uptake among farmers.

3.6.1 Interview Questions

The interview questions aim to extract detailed comments from participants about their experiences, motivations, and future aspirations related to solar energy technologies. The inquiries are organized into subject categories to enable targeted exploration.

3.6.2 Observation Timetable

When field visits are made to participating farms, the observation program is designed to systematically record contextual and behavioural data. The observations concentrate on pragmatic elements of agricultural practices and the implementation of solar energy technologies.

The subsequent dimensions will be examined:

Overall Agricultural Setting

- Assessment of the farm's entire structure encompassing the variety of crops cultivated and the arrangement for agricultural operations.
- Evaluate the agricultural infrastructure, including irrigation systems, equipment, and observational solar energy installations.

Utilisation of Solar Energy Technologies

- Documentation of the diverse solar technologies employed (e.g., solar panels water pumps and solar heating systems) and their respective positions on the farm.

3.7 Research instrument.

Using various activity-specific qualitative instruments, a multi-faceted research instrument was developed to gather insights on farmers' experiences and challenges related to their use of solar energy technologies in the subtropical fruit farming context. The instrument has two main instruments: the interview script, and form for observation. Below is the list of questions to be used to collect data.

STRUCTURED OPEN-ENDED RESEARCH QUESTIONNAIRE

Introduction

Thank you for participating in this research study. Your insights are valuable in understanding the challenges faced by subtropical fruit producers in adopting solar energy technologies. Please provide concise responses to the following structured open-ended questions.

Section 1: Adoption of Solar Energy Technologies

1. Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

2. What factors influenced your decision to consider or adopt solar energy technologies in your operations?

3. What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?

Section 2: Challenges and Obstacles

1. What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?

2. How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

3. Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes please elaborate.

7. Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?

3.8 Data collection procedure

3.8.1 Data Collection Methods

Data-collecting tools are vital elements of qualitative research. In the specific situation of examining the challenges to the adoption of solar energy technologies by subtropical fruit producers in the Tzaneen region in Limpopo province, although various methods can be used for data collection, a questionnaire will be specifically chosen for this study.

An appropriate data collection instrument for this study would be asking individuals questions. Meetings can be done either in person or remotely, depending on the preferences and availability of the participants. Conducting individual discussions allows for obtaining comprehensive insights into the participants' experiences, viewpoints, and opinions regarding the solar energy adoption in agricultural industry as indicated by Fox (2009).

The data collection will be done using structured open-ended questionnaires, thus giving flexibility to enable a better understanding of the experiences of participants and the insights gained (Creswell, 2014). Site observations will also help to understand more about the way sun-based technology is utilized on-farm, giving some context to how this may vary between locations.

Questionnaires and observations are chosen as our main methods for collecting primary data because of their ability to sensitively measure the experiences and perspectives of participant farmers. Questionnaires are used to provide a more detailed conversation, and both complement one another, as questionnaires allow for in-depth discussion while observations allow for additional context that would facilitate the data findings. This approach is especially useful for insights into complex social phenomena since they afford the researcher the opportunity to probe further into responses and elucidate what may be ambiguities during the discussion (Creswell, 2014).

3.8.2 Justification for Data Collection Methodology

Structured open-ended questionnaires allow for participants to speak in their own voices as they are designed to frame data more naturally and put the participant at ease by giving them a chance to say what is on your mind before bringing the answers into alignment with broader themes of inquiry. This method is particularly well suited to qualitative research, as it facilitates the expression of the complex thoughts that would not emerge when more closed data collection strategies are used, e.g., structured questionnaires (Swanborn, 2018).

Another advantage of the case study nature of the approach is that it enables changes to be made during data collection in response to answers from respondents and thus can follow up on unanticipated strands that may arise (Swanborn, 2018); (Kvale & Brinkmann, 2015); (Turner, 2011). This is especially the case where there are rich and contextualised understandings of participant experiences (Yin, 2018) qualities that are particularly valuable within qualitative research. This type of adaptability is particularly important in research practices that aim to steer clear of closed-response formats because qualitative methods uncover themes and patterns not immediately apparent (Eckstein, 2011).

3.9 Data analysis

3.9.1 Data analysis process

After collecting the data, a consistent method for translating and structuring the narration into information was used. Data management and preparation were the focus of the first phase, followed by analysis (Eckstein, 2011).

Thematic content analysis was used to find main themes in the data set, following the steps outlined by Braun & Clarke (2019). Here are the steps of how it was done:

1. Getting Familiar with Data: The transcripts were read multiple times to be deeply engaged with the information, noting early thoughts and recurring ideas.
2. Create Initial Codes: With NVivo 15, important parts of the data were coded without pre-set categories, focusing on aspects related to adopting solar technology, including its challenges and benefits as well as outside influences. This coding meant marking pieces of text that showed certain ideas or events.
3. Searching for Themes: The codes were looked at and put together into larger themes showing patterns seen in participants' responses. NVivo’s tools helped arrange and compare these coded bits.
4. Checking and Polishing Themes: Themes were checked against what had been coded to make sure they fit well together, stood apart from each other clearly, and

stayed relevant. Any mismatches or overlaps got sorted out by going back through coding steps and discussing them further.

5. Defining and Naming Themes: Each theme received a clear definition and name that captured its essence, making it easier to present findings later.

6. Presenting Results: The identified themes were backed up with quotes from participants along with context to keep their voices heard while giving depth to the analysis.

3.9.2 Analysis of Findings

This research project took a thematic content analysis method. The thematic analysis was chosen for its use in identifying key themes that represented the experiences and perspectives of participants (Braun & Clarke, 2006); (Braun & Clarke, 2019). This process included combing through data from a few questionnaires and observations to identify patterns and relationships that match the research objectives. To ensure the effectiveness of the qualitative research method in promoting beneficiary participation, it was crucial to engage them in all stages of the research process, including designing the research questions, selecting data collection methods, and interpreting the findings (Denzin & Lincoln, 2011).

According to (Abulela & Harwell, 2020), data analysis aids in the creation and confirmation of interpretations, as well as the drawing of inferences and conclusions. To begin, the information acquired was be organized systematically. This includes transcribed interviews, summarizing the output of the interviews. The goal of this was to transcribe recordings for a thematic content analysis of data about emerging themes and trends among Tzaneen's subtropical farmers. After transcribing the questionnaire, the data be carefully classified and coded according to questionnaire sections to aid the organization and identification of significant subjects (Nowell et al., 2017). The next stage was uncovering patterns and linkages across categories, which may entail comparing data from different situations or determining similarities or differences between candidates.

It is deemed thematic analysis to be conducive for the present study since it is a flexible method that can be used across different theoretical frameworks (Braun & Clarke, 2012). The narrative was organized not only to address the research questions but also to provide meaningful insights into participants' experiences and the contextual environment, based on emergent themes. Secondly, it extends the study with a deeper analysis by integrating other outcomes of organizational reports that contribute to achieving a better understanding of the phenomenon under investigation (Flick, 2018).

3.10 Ethical considerations

3.10.1 Ethical Review and Approval

Before commencing the research, the study was submitted for review and approval by an Institutional Review Board (IRB) or an equivalent ethics committee. This process ensured that the research adheres to ethical standards and guidelines, safeguarding the rights and welfare of participants (Hammersley et al., 2011); (Swanborn, 2018). Initiating this research project required strict respect for ethical guidelines, which involved submitting a formal application to the Research Ethics Commission at the University of Cape Town for ethical approval. Prior consent was obtained from the Subprop farmer organization before starting the research. This initial approval also assisted in obtaining ethical clearance from the University of Cape Town.

3.10.2 Informed Consent and Confidentiality

Mouton (2001) highlights that those ethical considerations grow intricate when dealing with individuals, animals, and the environment, especially in the presence of conflicting interests. The researcher is dedicated to gaining informed consent (Creswell & Poth, 2018) from participants before conducting interviews, establishing a thorough knowledge of the research aims before obtaining their signatures on consent forms to address ethical concerns (Creswell, 2014). The data obtained from participants will only be used for the specific research purpose, with careful measures in place to protect its confidentiality. The data will be safely stored on a laptop protected by a password.

To enhance confidentiality (Flick, 2018), fake names and alternate identities will be used until specific approval is obtained from the individuals concerned, thus maintaining the anonymity of participants. The researcher commits to maintaining impartiality during data collection and interviews by refraining from expressing personal opinions to avoid potential biases. This dedication to ethical principles is intended to maintain the research's integrity and safeguard the identity and well-being of the study participants (Turner, 2011).

3.11 Reliability and validity

Reliability and validity are crucial components of all research methodologies, including qualitative research. To ensure the trustworthiness and credibility of this research, the research study on the challenges faced by subtropical fruit producers in the Tzaneen Region, Limpopo Province, prioritizes the dependability and validity of findings.
Reliability in qualitative research pertains to the steadfastness and durability of the study findings. Bashir et al., (2008) assert that to guarantee reliability in qualitative research, researchers must ensure that the techniques and tools used for data collection are consistent and standardized across all locations and participants (Creswell & Poth, 2018). To do this, one must employ a comprehensive data-collecting protocol, employ identical interview questions, and provide training to research assistants on the procedures for data gathering. In the case of this study, the same questionnaire will be used to collect data.

Birt et al. (2016) propose that the use of member checking can augment the reliability and trustworthiness of study outcomes. Ensuring the credibility and trustworthiness of the research findings in a qualitative study on the challenges to the adoption of solar energy technologies among subtropical fruit producers in the Tzaneen Region, Limpopo Province, is crucial by addressing reliability and validity. To guarantee the reliability and validity of data analysis on this qualitative research, some methods have been adopted. First was member checking, in which preliminary themes and interpretations were shared with a sample of interviewees to check the precision of findings (Lincoln & Guba, 1985). This process allowed participants the opportunity to validate their responses and clarify any ambiguities in them, thus strengthening confidence in themes emerged.

Second was methodological triangulation involving different data collection methods: for example, semi- structured interviews and participant observation. By combining results of this kind from various sources, the emerging themes can also be corroborated (Denzin, 1978), adding to our understanding of speakers' viewpoints as documented in our report.

The final strategy was the use of peer debriefing sessions with colleagues during analysis. These consultations facilitated a rigorous discussion regarding themes coding and interpretation, thereby reducing researcher bias in that process and ensuring validation of the theme (Shenton, 2004). Such methods contributed to producing powerful themes in our examination and increased confidence about the findings themselves.

Validity in qualitative research refers to the degree to which the research findings accurately represent the experiences and viewpoints of the participants. Member checking, a method of providing participants with the opportunity to review and approve findings, as well as other strategies, will be employed to address these considerations in this study. In addition, the research will use a similar data collection protocol to achieve more valid findings.

3.12 Limitations

Several limitations and challenges of this research likely influence its findings.
These results are not generalizable to a wider population, so the scope of this study is limited and qualitative. As qualitative research is based on the interpretation of narratives and not number-driven data. Yet, the biases and lens that the researcher brings in analysing qualitative data can have an impact on findings as well (Creswell & Poth, 2018). In doing so, he/she will practice reflexivity which means continuously critically engaging with his/her own positionality and how this could affect the process of research.

Additionally, organizational rules, anonymity issues, and time (especially in complex contexts of sensitive nature where it would be hard to transcribe personal experiences) may limit the access available for questionnaires or to distribute the questionnaires (Creswell, 2014). Differences in participants' inclination to fill out questionnaires may lead to a selection bias creating difficulty in generalizing findings (Yin, 2018). Not only are qualitative questionnaires subject to interpretation, but there is also the risk of bias as this takes place in both the responses given by participants and the way those responses are internally mused (Kvale & Brinkmann, 2015). In the next chapter, results are presented.

CHAPTER 4. RESULTS

4.1 Introduction

In this chapter, detailed results from the qualitative information are provided and explained based on the interviews and observations collected during data collection. The results systematically reveal major themes and patterns concerning the perceptions, experiences, and barriers of subtropical fruit producers towards solar-technology adoption. The main aim of the study is not to validate a hypothesis but to methodically identify, examine, and present the different elements that affect the adoption of solar technology in this specific agricultural context.

This chapter firstly describes the dataset, followed by the presentation of the results, then presents the qualitative results, and ends with the summary of the results.

4.2 Description of data set

The qualitative dataset, which includes responses from 08 participants, offers valuable insights into the experiences and challenges faced by subtropical fruit producers in the adoption of solar energy technologies. The detailed collection and analysis techniques utilized enhanced the reliability and richness of the results, improved the reliability and richness of the results, and facilitated a detailed understanding of the relationship between agricultural methods and the adoption.

4.2.1 Data Collected

One could classify the gathered data for this study as qualitative in character. investigating participants' experiences and viewpoints about the acceptance of solar energy technology in subtropical fruit farming was the focus of the study. Is there any reasonable and complete method to examine the results?

4.2.2 Characteristics of the Data

- Size: The dataset consists of responses from eight (eight) individuals, thus allowing a varied range of viewpoints and analysis about the application Although the sample size is somewhat small qualitative research gives depth over breadth as top priority so that every participant's experience can be thoroughly screened.
- Source: Participants were from Tzaneen and its surrounding areas, South Africa, a place well known for subtropical fruit production. This regional concentration

offers a contextual background needed to grasp local agricultural methods, energy difficulties, and the relevance of solar technology.

Data were gathered by means of semi-structured interviews. This approach was used to support open-ended conversations while yet providing a structure for important topics regarding the acceptance of solar energy. Interviews were either conducted on the phone or in person between thirty and sixty minutes. This adaptive ability lets individuals have much longer time on their experiences.

The emistrated approach combined pre-selected questions with the opportunity for participants to talk about subjects they considered relevant for their background. This methodology provides deep investigation of important problems in the frameworks of solar energy and agriculture as well as space for surprising discoveries.

- Data recording and transcription: Participants' permission allowed interviews to be recorded. The documents were verbatim transcribed following the interviews to preserve accuracy in reflecting the participant's ideas. The transcription procedure produced a thorough record of the conversations, thus facilitating thematic analysis.
- Thematic Analysis: Using thematic analysis, the quantitative data was examined to let one find recurrent themes and patterns among the interviews. Data were examined using our NVivo 15 program. This approach offered a disciplined approach to condense ideas on important subjects, including economic feasibility, technological difficulties, environmental impact awareness and knowledge, and institutional support.

4.2.3 Summary of Data Characteristics

- Type: Qualitative
- Size: 08 participants
- Source: Subtropical fruit producers in Tzaneen and surrounding South Africa
- Method of collection: case study approach (30-60 minutes each)
- Recording: Audio recordings with transcription

- Analytical method: Thematic analysis to identify key themes from interview data using NVivo 15 software based on NVivo 15

4.3 Presentation of results

4.3.1 A thematic Analysis of Solar Energy Adoption in Fruit Production Thematic Anthology

The topic study offers a methodical technique to grasp the various experiences of farmers using solar energy technologies for fruit production. I will go over the themes found below, clarify their relevance, and offer extra background and supporting information for every facet covered.

Key topics that surfaced from fruit growers' adoption of solar energy technologies are investigated using interviews in this thematic study. Direct comments from participants and direct summaries and contextual insights abound in the study, offering a whole picture of the elements that influence solar energy use in agriculture.

Chat1: Word Frequency

Farmers need technical and financial help to install solar energy and battery storage systems. Then they can use less gas and coal, which are expensive and bad for the environment.

Growing green energy requires understanding how to deal with problems like insufficient infrastructure, high start-up costs, and government rules.

4.3.2 Analysis according to research questions

Section 1: Adoption of Solar Energy Technologies

Table 1: Farmers responses on energy adoption experience		
Themes	**File**	**Reference**
(RQ1) Experience with Adopting Solar Energy Technologies	7	16
High initial cost	1	1
Infrastructure Incompatibility	1	1
Infrastructure Requirements	2	4
No Reported Issues	1	1
Positive Experience with Technology	4	4
Security Concerns	1	1
Technology Reliability	2	2
Trust Issues with Solar Energy	1	2
(RQ2). Factors Influencing Adoption	7	15
Financial Arrangements	1	1
High Diesel Costs	3	3
High Electricity Costs	1	1
Load Shedding	6	6
Transition to Renewable Energy	2	2
Uncertainty of Energy Supply	2	2
(RQ3) Benefits Observed	7	9
Cost Comparison	1	1
Cost Savings on Irrigation	6	6
Long-Term Savings	2	2

1. Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

How much solar energy is used in food production depends on the size of the business and how easy access to resources is. Initial costs make installation expensive for small-scale farmers, but it finally finds a reliable power source for important tasks like irrigation. Larger farmers say that moves have gone smoothly, management was good, and they got a lot of benefits after the changes were made. Small farmers may find the start-up costs high, and bigger farms say they do not have any problems.

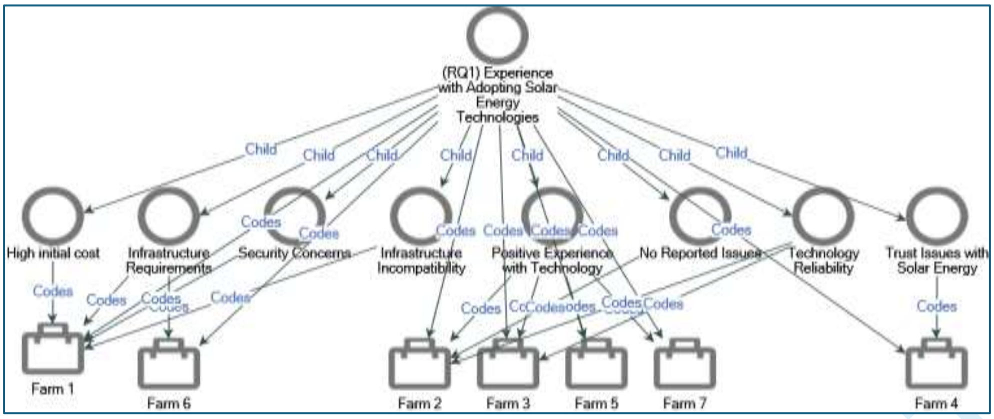

Figure 1: Farmers experience with solar energy technologies

2. What factors influenced your decision to consider or adopt solar energy technologies in your operations?

   Solar power has become a popular option for farmers due to various factors, including economic pressures, environmental concerns, and regulatory incentives. Load shedding and high electricity costs have been the primary drivers for many farmers who are frustrated with inconsistent electricity supply. Environmental considerations, such as reducing carbon footprint and aligning with sustainability goals have also encouraged larger farms to adopt solar solutions. Solar energy is a cheap, affordable, and sustainable renewable alternative. These factors prompted farmers to consider solar energy as a reliable and sustainable energy source.

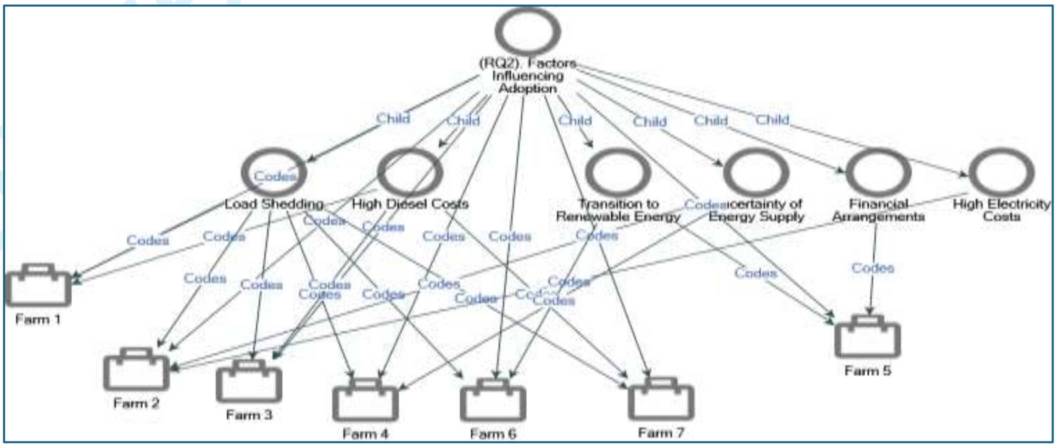

Figure 2: Factors that influence solar energy adoption.

3. What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?

For fruit growers, solar has proven to be a major cost-saving so that they can concentrate on other vital aspects of their business. Farmers claimed rising energy prices dramatically had driven up the energy prices while others claimed solar energy would have replaced irrigation's irrigated water costs. By lowering downtime brought about by power outages associated with the decreased dependability of energy sources, increased operational efficiency and productivity. Since solar energy technologies enable continuous farming activities and reduce loadshedding impacts, their acceptance has also resulted in higher productivity compared with current harvesters. Furthermore, solar energy improves the environment and helps reduce the carbon footprint and dependence on fossil fuels, thus supporting the objectives of many producers towards sustainable farming methods.

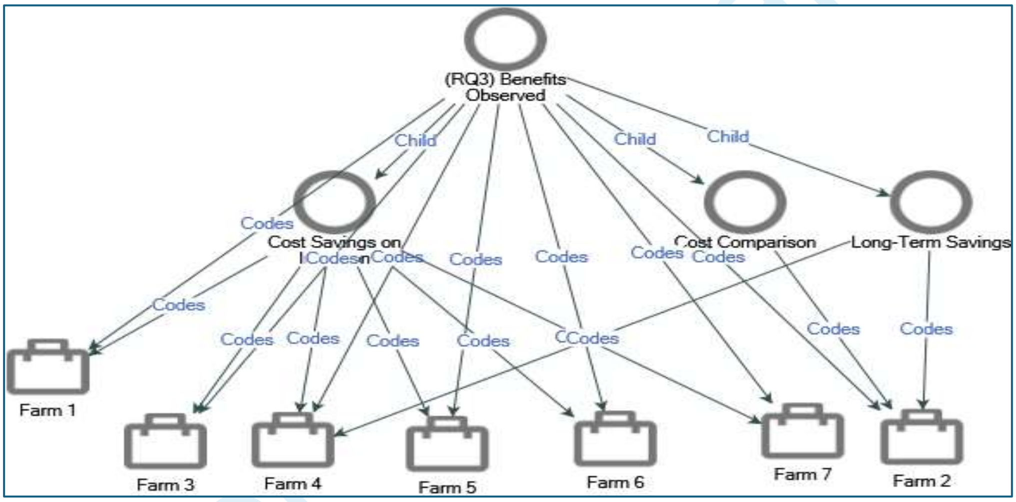

Figure 3: Benefits of solar energy adoption

Section 2: Challenges and Obstacles

For fruit growers, solar products offer several difficulties, such as high upfront costs and hiccups in maintaining quality produce and processing equipment. As commercial technicians in rural areas encounter logistical obstacles, small-scale farmers are burdened financially. Installing and using solar systems is made more complicated by regulatory obstacles such as extensive laws and licensing requirements. It is essential to understand these difficulties to create efficient systems of assistance for farmers.

Table 2: Farmers responses on challenges and obstacles of solar energy adoption		
Themes	**Files**	**References**
(RQ4) Specific Challenges Faced	7	17
Budget Constraints	2	2
Challenges with Battery Dependency	1	1
High Cost of Solar Technology	4	7
Impact of Weather on Operations	1	1
Implementation Delays	2	2
Initial Installation Costs	2	2
Lack of Technical Experience	2	2
(RQ5) Financial Considerations	6	9
Absence of Subsidies	2	2
Economic Viability Concerns	1	1
Initial Capital Expenditure	3	3
Lack of Funding	1	1
Lack of Power Storage	1	1
Minimal Running Costs	1	1
(RQ6) Technical Difficulties	7	12
Concentration of Expertise in Urban Areas	3	4
Delayed Response Times	2	2
Limited Availability of Technicians	2	2
No Current Technical Obstacles	4	4
(RQ7) Awareness of Regulations	8	9
Lack of Awareness of Regulations	8	9

4. What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?

Farmers are becoming more interested in solar technology, but adoption is difficult. Due to limited financial resources, the initial installation costs are exorbitant. Timely deployments are hampered by practical problems, including site suitability and complexity, and farmers find it difficult to justify the expense. Notwithstanding its benefits, adopting and implementing solar technologies presents some obstacles for farmers, such as the need for financing and subsidies and the dearth of local technical assistance.

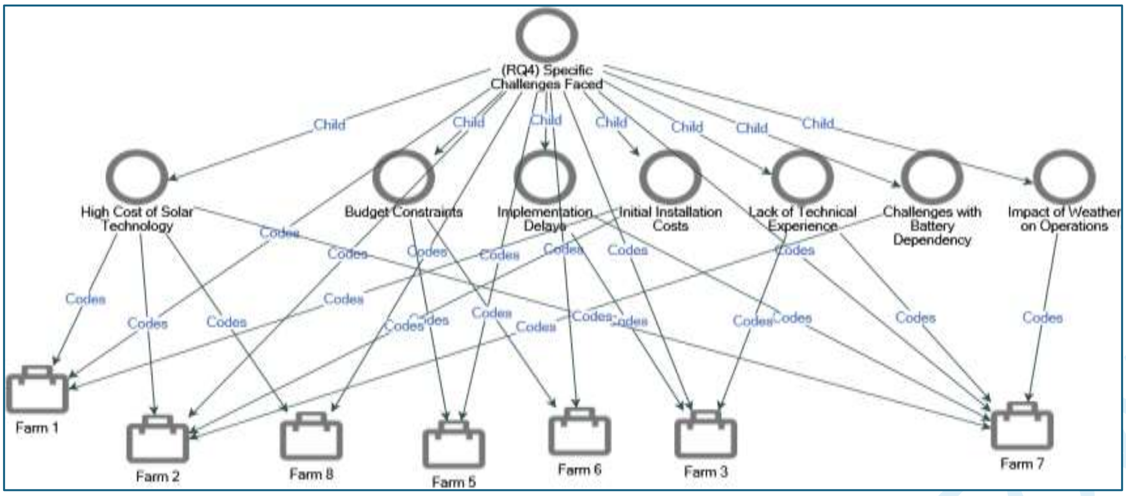

Figure 4: challenges faced by farmers.

5. How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

When adopting solar energy solutions, farmers face significant financial challenges when implementing them. Small-scale farmers often struggle with access to financing and financing options in terms of funding or access to financing options, which limits their capacity to invest in solar systems. Larger businesses, on the other hand, often have the resources to secure finance through partnerships or investment firms. These disparities in funding will raise the need for better financial support methods to level the playing field for smallholder farmers and promote technology adoption. Solar installations generally require a large initial investment, but the long-term benefits are significant. The initial financial burden discourages several people from acting despite the potential savings, emphasizing the importance of financial incentives to encourage initial investments. Access to funding remains a barrier for small-scale farmers.

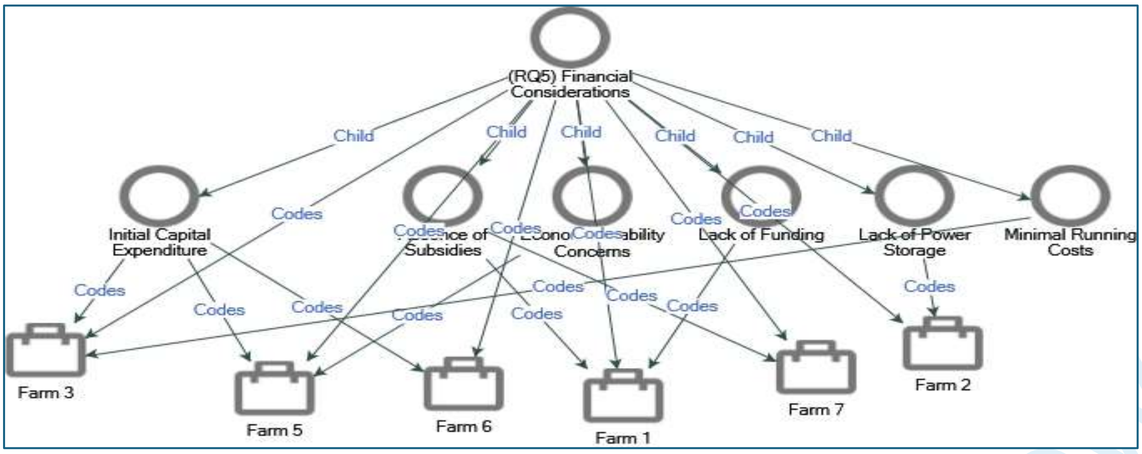

Figure 5: Financial considerations

6. Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.

Technical challenges in solar energy integration have hampered producers' capability to implement solar technologies. Small-scale farmers have difficulty locating local experts trained in solar installation and maintenance, which results in long wait times for assistance. Larger farms report fewer technical challenges because they have established relationships with technical professionals. Nevertheless, some farmers are pleased with their installations and consider this the need for more attention and skill in solar technology.

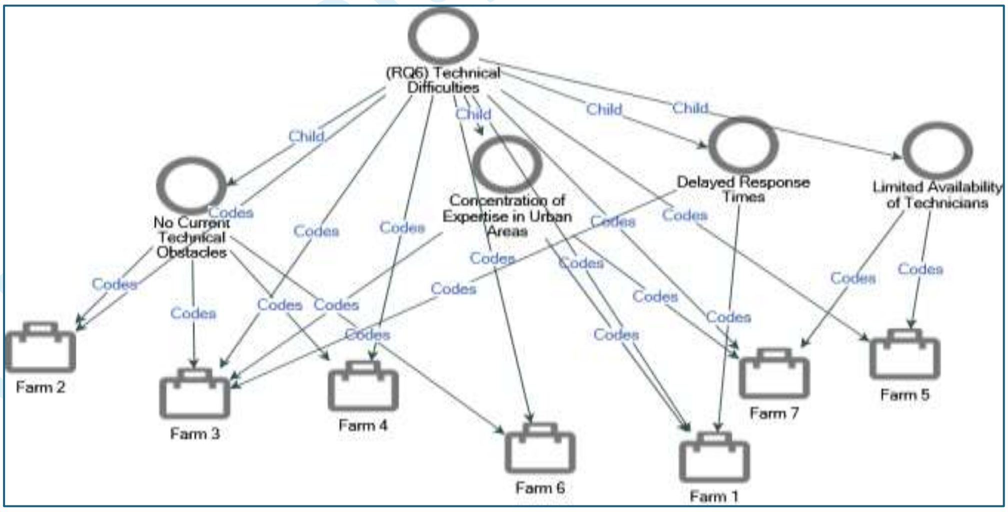

Figure 6: Technical difficulties

7. Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?

Disparities in municipal laws and infrastructure spending make it difficult for farmers to adopt solar power. The uneven environment for energy production, i.e., from farmers facing different incentives and possible regulatory delays, results in an uneven environment for energy production. Small-scale farmers may be deterred from investigating solar solutions by this ignorance, which could influence adoption decision-making.

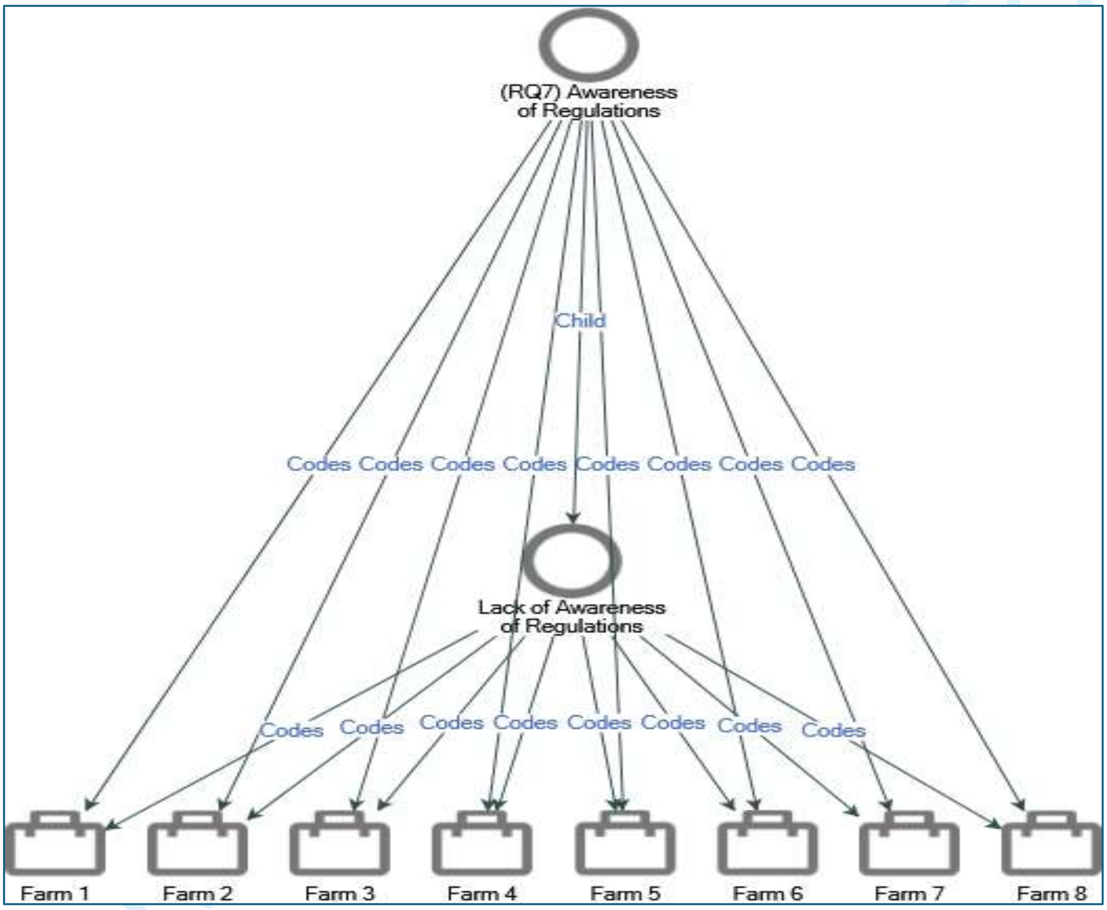

Figure 7: Awareness of Regulation

Section 3: Impact and Sustainability

Table 3: Farmers responses on sustainability of solar energy adoption		
Themes	**File**	**Reference**
(RQ8) Influence on Sustainability	4	8
Decreased Use of Fossil Fuels	1	1
Environmental Benefits	4	5
Reduced Electricity Consumption	1	1
Sustainability Impact	1	1
(RQ9) Improvements in Efficiency or Cost Savings	6	8
Impact on Profit Margins	1	1
Reduction in Production Costs	6	7
(RQ10) Long-term Sustainability	6	7
Free Resource	2	3
Future Trends in Agriculture	2	2
Growing Adoption of Solar Energy	2	2

- In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?

The grower is gradually using solar energy solutions to improve their fruit production operations and reduce its need on fossil fuels and diesel generators. This modification reduces pollutant emissions and meets consumer demand for environmentally friendly agricultural practices. Farmers who claim to reduce wasteful emissions and a greater commitment to sustainability attest to the benefits of solar energy for the environment and the sustainability of their operations.

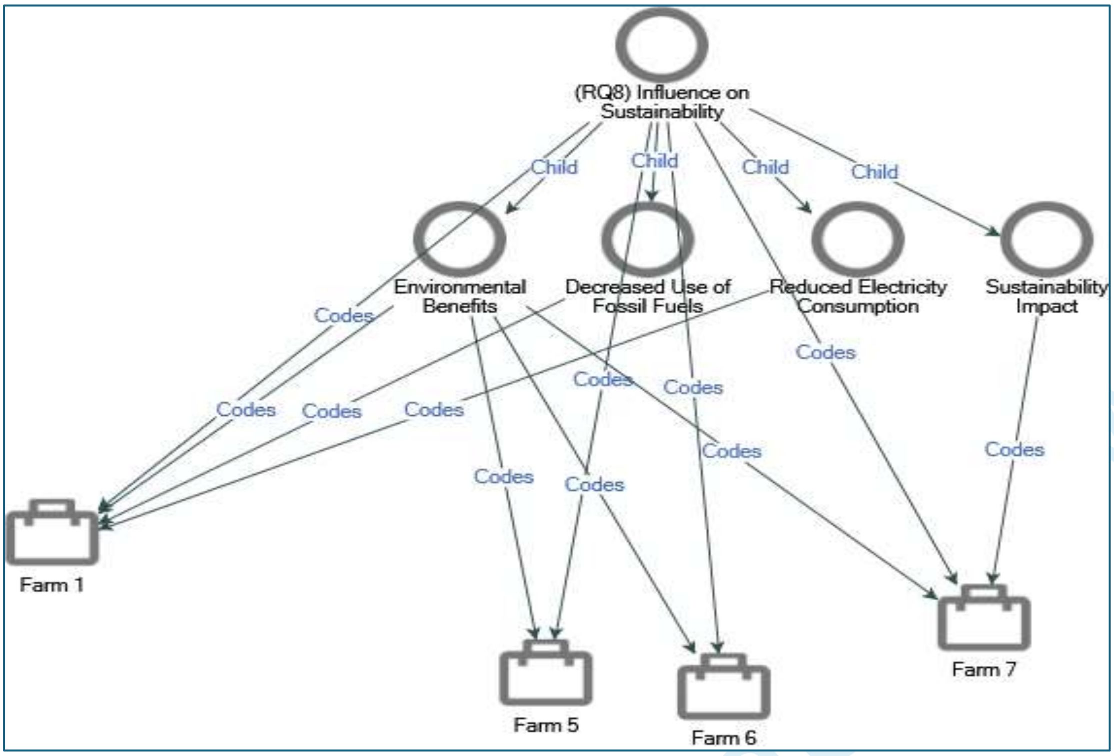

Figure 8: Influence on sustainability

- Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?

The plight of farmers in India is improving with the use of solar energy solutions to improve fruit production operations and reduce need on fossil fuels and diesel generators. This modification reduces pollutants and meets consumer demand for environmentally friendly agricultural practices. Farmers who claim reduction in emissions and a stronger commitment to sustainability attest to the advantages of solar energy for the environment and the sustainability of their operations.

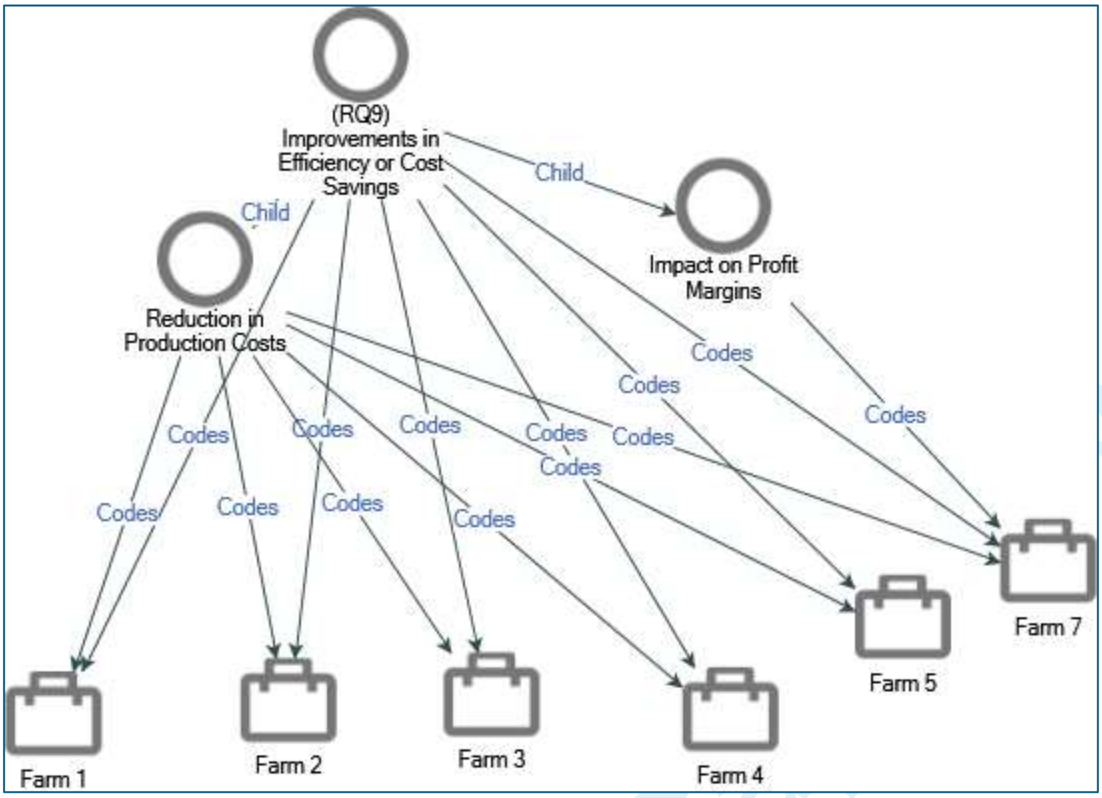

Figure 9: Improvement in efficiency of cost saving

- How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?

Solar technology is increasingly used by farmers to increase the long-term sustainability of their fruit output. It is anticipated that these technologies will increase resilience to erratic power prices and climate variability, opening the door for innovation and expansion in agriculture. As more farmers adopt solar farms, it should increase operational sustainability.

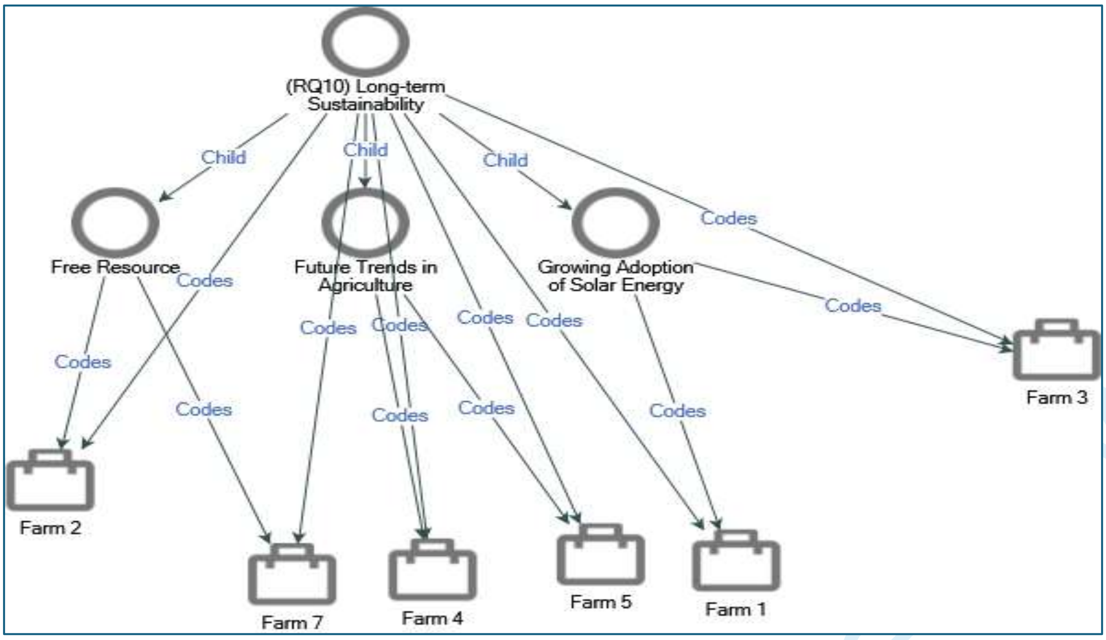

Figure 10: Long-term sustainability

Section 4: Recommendations and Future Plans

Table 4: Farmers responses on recommendations and future plans		
Themes	**Files**	**Reference**
(RQ11) Suggestions for Addressing Challenges	5	6
Government Intervention	4	5
Incentives for Renewable Energy Adoption	1	1
(RQ12) Future Plans for intergration	6	6
Energy Storage Solutions	5	5
Mitigating Power Outages	1	1
(RQ13) Government and Industry Support	4	4
Awareness and Education	1	1
Installation Discounts	3	3

11. What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?

To encourage the adoption of solar energy technologies, farmers are asking for specific government incentives or subsidies. Adoption rates would rise, and the initial investment burden would be lessened. Additionally, setting up regional technician training programs could improve support services and raise general awareness about solar systems. This would increase farmers' access to solar technology and assist them in overcoming obstacles.

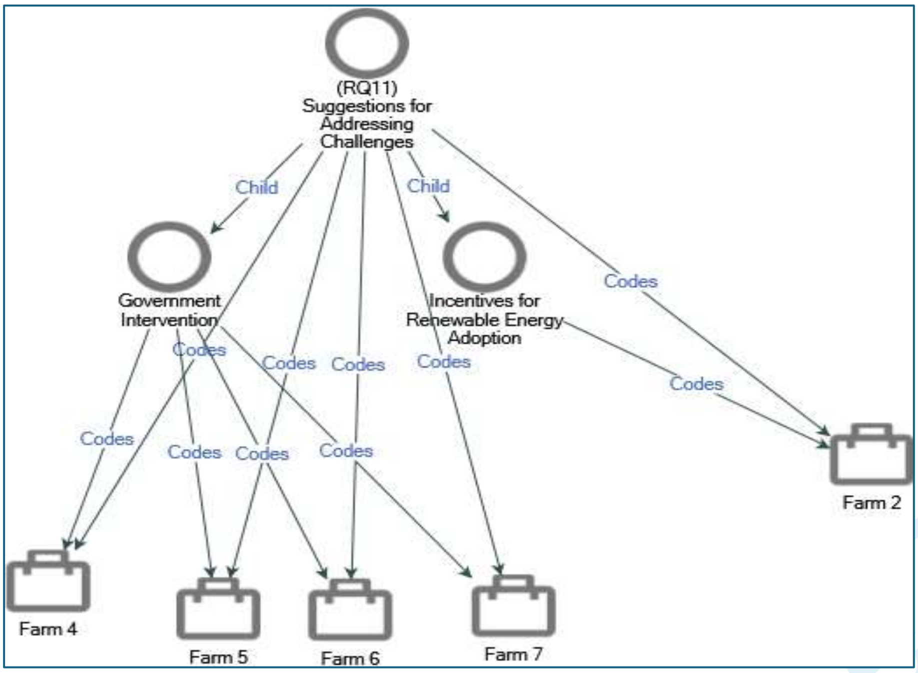

Figure 11: Suggestions for Addressing challenges.

11. Do you have any plans or strategies to further enhance the integration of solar energy technologies into your fruit production operations?

With an emphasis on energy storage systems to counteract weather conditions, farmers are progressively incorporating solar technologies into their businesses. This calculation technique is thought to be a natural next step in securing energy independence, as it guarantees farmers access to electricity even in the face of unseasonably warm weather.

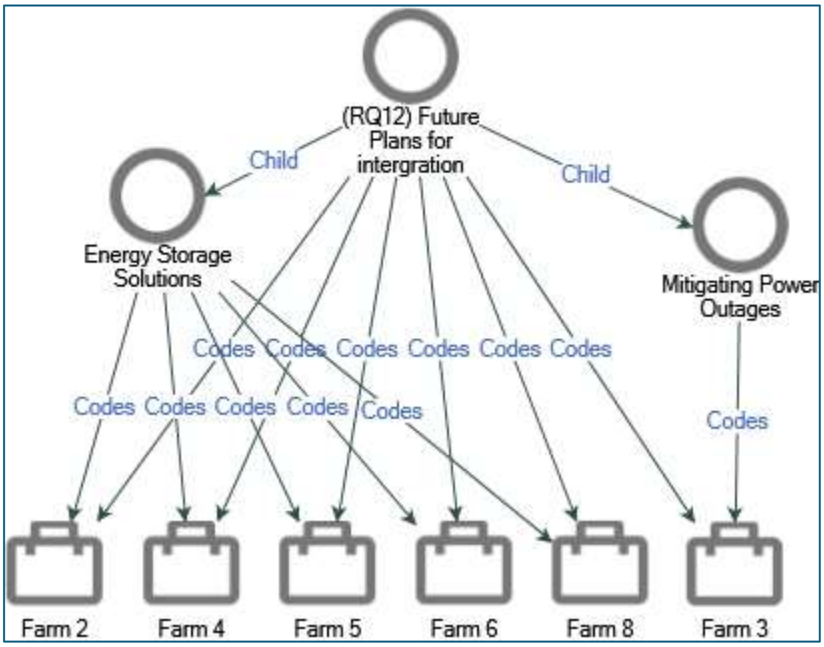

Figure 12: Future for integration

12. How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?

Farmers are pushing for stronger industry initiatives and governmental regulation to encourage the use of solar energy. They also recommend community solar projects, financial literacy initiatives, and more information regarding incentives for renewable energy infrastructure and extra permit procedures. From ensuring that farmers have easy access to readily available information for wise decision-making these tactics seek to promote the wide adoption and use of solar technologies across the country.

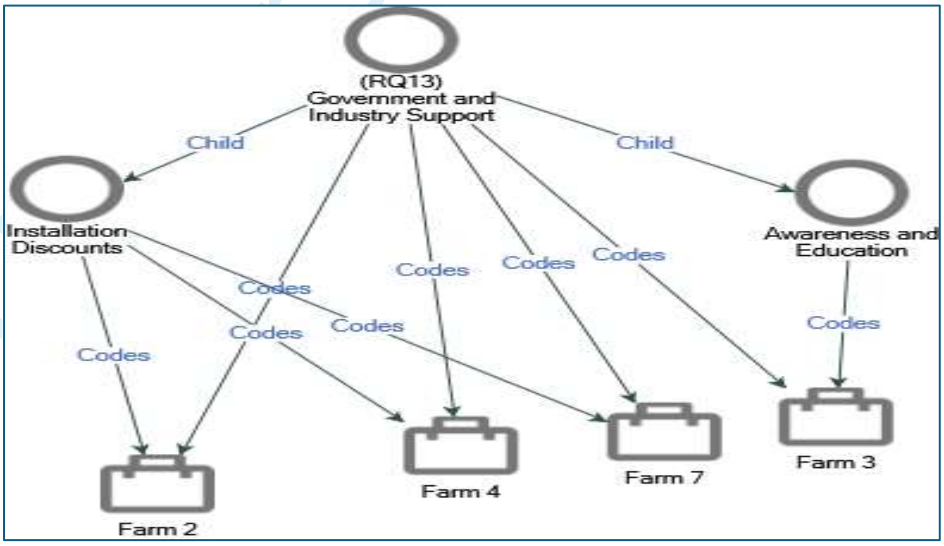

Figure 13: Government and Industry support

Reflexivity

As a researcher, I understand that my interactions with subjects might affect their inclination to report events, therefore impacting the data collection process. Establishing a comfortable environment for communication allowed participants to express themselves honestly, thus adding complexity to the qualitative observations obtained.

4.4 Qualitative results

4.4.1 Key Themes and Patterns Identified in Qualitative Data

Theme 1: Economic Pressures Driving Adoption

Pattern Description: Many fruit growers said that their main drivers for using solar energy solutions were financial constraints, especially load shedding and expensive electricity bills. In many interviews, the need for a more reliable and reasonably priced energy supply was strongly expressed.

Illustrative quotations:

"Solar energy adoption was influenced by high cost of electricity and the loadshedding. We were not sure on when loadshedding will end." (F2).

" Loadshedding and power cuts prompted the introduction of solar, " (F4).

Theme 2: Financial Barriers and Initial Costs

Pattern Description Although solar energy has long-term advantages, manufacturers usually highlighted the high initial installation costs as a major obstacle. For small-scale farmers, particularly, this difficulty is truly evident.

Illustrative quotations:

"Cost of solar and initial cost of installation. As a small-scale farmer its extreme expensive to install solar system " (F1).

" Reasons we don't have batteries yet, is that they are very expensive. They need a big budget. For example, we needed R6 million to install batteries. " (F2).

Theme 3: Reliability and Consistency of Solar Energy

Pattern Description: Unlike the regular disruptions from load shedding, some people generally claimed solar energy offered a reliable and continuous energy source. On this dependability we maintain operational reliability as well as operational efficiency.

Illustrative Quotations:

"The adoption of the solar energy, facilitated for an uninterrupted farm activity, improved productivity amid the continued availability of electricity during the working hours. This also helped in accumulation savings for the farm due to reduction in cost of electricity" (F3).

"The availability of electricity has been continuous, allowing us to focus on other areas of the business" (F4).

Theme 4: Environmental Considerations

Pattern Description: Adopting solar energy turned out to be most beneficial for environmental sustainability. Producers valued the diminishing dependence on fossil fuels and identified solar as a better alternative.

Illustrative quotations:

" The experience has been positive in the sense that it has contributed to the input cost savings, as well as promoting the goal of lessening the company and carbon footprint " (F5).

"In terms of sustainability, solar energy assists us to continue with irrigation even if loadshedding kick in. No environmental pollution compared to generator and fossil fuel usage when you use electricity" (F7).

Theme 5: Limitations in Technical Support

Pattern Description: The lack of technical backing for solar technology worried many farmers. Accessing experienced experts affected their capacity to quickly fix problems.

Illustrative quotations:

" Technicians are limited, and the experienced ones are in big cities. So, if u face a challenge it gets to be expensive as well and sometimes you must wait for more than a day for someone to come." (F1).

"The delay in getting technical assistance can be frustrating, sometimes taking days for someone to come out" (F3).

Theme 6: Regulatory Challenges

Pattern Description: Some manufacturers claimed to have encountered legal obstacles, making the acceptance of solar energy difficult. Experiences differed, though; some claimed their installation was free of regulatory problems.

Illustrative quotations:

"Cumbersome legislation surrounding distribution licenses has affected our ability to implement solar smoothly" (F5).

"I haven't faced any regulatory challenges; it seems straightforward for us" (F4).

4.4.2 Comparison and contrast

Comparison and Contrast of Solar Energy Adoption among Fruit Producers in China and India between 2005 and 2013

Studying the acceptance of solar energy among fruit growers has important new perspectives on the experiences of different kinds of farmers—more especially the differences between smaller-scale and larger enterprises. These analogies produce insightful results about technical support, financial constraints opinions of advantages and legal implications. Unexpected results about farmer attitudes and regulatory experiences also point to opportunities for focused interventions and more research.

Comparisons Between Small-Scale and Larger Farms

1. Financial Barriers to Adoption:

One recurring topic among small-scale farmers is the financial burden associated with the first outlay needed for solar energy. There are those that have also said that implementing solar systems presents a significant financial difficulty given limited resources and restricted access to subsidies or funding. One farmer observed that "as a small-scale farmer it feels out of reach" (F 1). This attitude shows a sense of exclusion from developments in renewable energy; hence, adopting technology seems frightening.

More Larger Farms Larger agricultural operations, on the other hand, claimed that their financial situation helps them to negotiate the early expenses more successfully. These farmers have set up alliances or financial routes that let them take large upfront financing outlays. "We have the capital needed for installation and can see the savings down the road," said a producer bigger than F5. He stressed how operational expenses increase with economic benefits. Financial disparity underscores the need for specific financial support policies, including subsidies or low-interest loans, particularly for small-scale farmers trying to implement sustainable technologies.

2. Technical support is available from a technical expert in the field of computer hardware and software:

Small-scale farmers: Further affecting small-scale farmers' access to technical support are their limitations.

Many others highlighted the difficulty in finding qualified experts, as specialized services are typically found in metropolitan regions, and timely support is demanding work. One farmer commented that of this view, finding a technician is tough... it gets expensive as well(F1). This limitation not only reduces operational effectiveness but also feeds uncertainty on the dependability of solar technology.

On the other hand, larger farms often demanded more consistent technical support systems and financial means to hire professional help when required. Their articulation of security in maintenance indicated that "we can afford to hire experts so technical problems are solved quickly" (F5) thus implying a sense of security and trust in maintenance. This benefit let bigger solar manufacturers guarantee better running and maintenance of their solar system.

These differences draw attention to a significant gap in the provision of services for small-scale farmers, which calls for the development and implementation of localized technical support programs and training projects to increase capacity and confidence in solar technology.

Contrast in Perceptions of Solar Energy Benefits

Economic versus environmental considerations

Many farmers mostly examined the advantages of solar energy from an economic perspective, generally giving great weight to cost savings from lower electricity demand. One of the surviving commentators said that electricity is very costly. So solar energy you pay once and no monthly fees" (F2) highlighting the instant financial relief solar adoption brings in a context of high energy bills.

Other producers, particularly those first accused of eschewing it, grew to see environmental sustainability as a major advantage along with financial gain. One proponent for example said: "Solar energy has not only saved us money but also helped reduce our carbon footprint" (F5) thus signifying a paradigm change whereby the acceptance of solar technology aligns not only with financial aims but also with enhanced environmental responsibility.

The difference in viewpoints on solar advantages points to the necessity of policies addressing both economic and environmental issues, thereby improving the attractiveness of solar technology in different farming environments.

Unexpected Findings and Their Implications

One interesting result was the degree of uncertainty some farmers displayed about solar technology. Trust problems abound. Farmers said they do not think solar power will be as reliable as traditional energy sources even though it can have some benefits. One farmer openly said: I couldn't decide whether to use solar technology. I believed solar energy would not run as efficiently and economically as electricity" (F4). The challenge highlights the need for instructional programs that highlight successful implementation and show the dependability of the technology since it reflects one larger trend, which might prevent general acceptance among reluctant farmers.

This study found noticeable variation in regulatory experiences among producers. While some farmers found the procedure simple, others pointed out significant legal obstacles preventing solar acceptance. This clear difference suggests that operating scale or geographical location might affect the regulatory environment. Such differences can aggravate already existing disparities in the availability of solar technology.

Given this surprising result, it could be wise for legislators to seek a harmonized regulatory framework that guarantees fairness in solar energy access, thus enabling both larger and smaller farmers to negotiate.

4.5 Summary of results

4.5.1 Adoption of Solar Energy Technologies

Farmers had different experiences with solar energy systems, stressing both difficulties and achievements in acceptance. One farmer underlined the simplicity of adoption, while another said that solar energy is expensive and requires infrastructure for optimal use. Two advantages of solar energy are improved operational dependability and higher production. Adoption was driven in large part by the need to meet green sustainability targets, lower high electricity costs, and solve load shedding. Farmers report gains in cost savings from lower electricity bills, less environmental effect from less burning of fossil fuels, and more consistent operations.

4.5.2 Challenges and Obstacles

Solar technologies presented several difficulties for farmers. For small-scale businesses, especially, high initial installation costs presented major obstacles. Other challenges were reliance on low technical knowledge in rural locations lack of battery storage for cloudy days and delayed procurement of repairs or support. There were plenty of financial problems; farmers lacked subsidies or loans for investment. Although solar installations were prevalent in the past despite a clear ignorance of the rules influencing them, regulatory barriers have not been given much importance.

4.5.3 Impact and Sustainability

Solar energy's environmental advantages were well known; farmers noted lower pollution by less dependence on fossil fuel consumption. Many members said they saved a lot of money that allowed them to focus resources on other agricultural requirements. Farmers said they had hope about the ability of solar energy to promote long-term sustainability. The adoption is expected to result in even lower production costs and better operational efficiency.

4.5.4 Recommendations and Future Plans

Farmers recommended government assistance in addressing the difficulties through subsidies to small-scale farmers and better access to reasonably priced batteries and technical training. They also recommended setting up group meetings to assist in buying solar panels. The future called for increased capacity to sell extra energy produced and adding more battery storage to reduce the dependence on solar power on overcast days. The following subsequent chapter focuses on the discussion of the research results.

CHAPTER 5. DISCUSSION

5.1 Introduction

Based on the results, this chapter interprets these findings in the larger theoretical and contextual basis described in the literature review. This discussion will begin by restating the key findings and highlighting significant themes that emerged from the research, highlighting their relevance to the energy adoption dynamics in solar energy technologies. It then interprets these results and examines their broader implications and contributions to understanding the barriers and challenges in solar energy technology adoption.

5.2 Restate Key Findings

This study investigated the implementation of solar energy technology by subtropical fruit cultivators in Tzaneen Limpopo. The research was conducted the study highlighted numerous significant obstacles encountered by subtropical fruit farmers in the adoption of solar energy technology compared with substantial initial costs, inadequate technical support and the influence Although recognizing the enduring economic benefits of solar energy, there are numerous producers who continue to face financial obstacles and lack awareness of existing subsidies and support measures. This immediately applies to the principal research inquiry concerning the predominant obstacles faced by these producers.

The results relate to the topic of the research by defining important problems, advantages, and the wider implications of integrating solar energy into agriculture.

5.3 Interpretation of Findings

The results indicate that although solar energy offers significant cost savings and operational reliability, these advantages are often eclipsed by financial limitations. The recognition of substantial installation expenses corresponds with previous literature that documents analogous economic obstacles encountered by small-scale farmers in developing areas (Murombo et al. 2015). Furthermore, dependence on the national grid for energy presents a conundrum in which dependence obstructs the transition to renewable sources even after their benefits. Participants stressed the need for governmental assistance to render solar energy economically feasible and promote extensive adoption. This finding aligns with Technology Acceptance model (Venkatesh, Davis, & Morris, 2003), which suggest that perceived usefulness influences adoption.,

Results clarify the complex interplay between economic, technical, and environmental factors in the deployment of solar power sources. To adopt long-term saving and sustainable development, the potential for adoption encourages adoption. However, immediate barriers such as cost and technical competence block progress in developing countries. Economic disparity between small and large farm families illustrates systemic inequality. Larger-scale farmers experience difficulties related to initial costs and often lack access to financial instruments such as grants or loans, whereas larger farms benefit from established networks and resources. This corresponds with established beliefs that economic capacity significantly affects technology uptake.

Participants highlighted their dependence on urban specialists for technical support in rural areas is a challenge. Developing innovative strategies could address these challenges, given participants' recognition of solar energy's environmental advantages. This constraint not only delays maintenance but also diminishes the trust in solar technology. In this regard, it is appropriate to develop a new solar technique that can participants overwhelmingly recognized the environmental advantages of decreased dependence on fossil fuels consistent with global sustainability objectives.

5.3.1 Financial Barriers

A key finding was the emphasis on financial limitations. Producers stated that the substantial initial costs associated with solar installation dissuaded many from transitioning. This aligns with current evidence that regularly cites funding as a primary obstacle to renewable energy adoption because it can affect smallholder farmers (Murombo, 2015; Wüstenhagen et al.,2007). Participants noted the challenges in obtaining loan facilities and the lack of customized financial products that address the specific risks encountered by agricultural producers.

Moreover, some producers proposed that government subsidies and incentives might alleviate these financial difficulties. There was a widespread lack of understanding about current programs designed to facilitate solar energy adoption. A survey conducted last June highlighted the urgent need for better information dissemination. This disjunction between policy and practice underscores a systemic inadequacy in communication that politicians must rectify to facilitate the transition to renewable energy.

5.3.2 Technical Support Limitations

However, a predominant concern arises regarding the insufficient technical assistance available to producers. Significant numbers of respondents expressed their frustration over the arduous procedure of finding proficient specialists for installation and maintenance associated with solar systems. The geographical isolation of agricultural activities renders the availability of reliable professionals a crucial element in the decision-making about technology adoption. The participants' opinions indicate a lack of support for solar energy technologies at the global economic and technological level refining previous research that highlighted the need to utilize appropriate systems of training and support for effective technology deployment.

Furthermore, this technical support challenge is exacerbated by the complexity of solar systems and may deter producers from investing due to a lack of assurance in adequate assistance for system maintenance and troubleshooting. It constitutes a major barrier, as perceived ease of use and support directly affect adopted decision-making. Investing in training programs and setting a localized network of specialists across the country should help promote solar technology in all fields. With these measures, manufacturers can improve their confidence to use energy from renewable sources.

5.3.3 Regulatory Challenges

The interviews revealed diverse experiences with regulatory obstacles. Some producers faced difficult regulations regarding solar technology adoption, while others saw a relatively uncomplicated procedure. This discrepancy indicates a fluctuating regulatory environment that may result in disparities in access to solar technology. Participants observed that intricate laws and the requirement for distribution licenses impeded their ability to deploy solar systems efficiently, as expressed by one participant. The other participant commented:

In this context these discoveries highlight the need for regulations that enable more seamless transitions to renewable energy, especially in the agricultural sector. Harmonizing regulatory frameworks with farmers requirements could markedly decrease the perceived obstacles related to solar energy technologies. I am recommending that agricultural farmers support the adoption of renewable energy technologies for commercial farming and so further optimize policy processes and establish incentives for sustainable production.

5.3.4 Environmental Awareness and Motivations

An important feature of the research was the growing awareness of the environmental advantages linked to solar energy by participants. Although economic incentives are often recognised as the main catalyst to embrace renewable energy, qualitative data indicate a changing perspective among producers that emphasizes the need for sustainable practices. Participants expressed that the adoption of solar energy not only fulfilled their immediate energy needs but also enhanced their overall environmental impact.

This discovery corresponds with literature highlighting the dual significance of economic and environmental incentives in the adoption of renewable energy (Aroonsrimorakot & Laiphrakpam, 2019). The growing understanding of sustainability is a powerful method of convincing policymakers and agricultural stakeholders to act. Presenting solar energy adoption as an economic necessity and an environmental responsibility allows stakeholders to align more effectively with farmers' incentives.

5.4 Comparison with Existing Literature

The results predominantly validate previous research identifying economic considerations as major obstacles to solar adoption (Wüstenhagen et al., 2007; Timilsina et al., 2012). They dispute the idea that technological adoption is determined only by individual farmer preferences. Qualitative data suggests a more complex link shaped by systemic factors like regulatory frameworks and financial accessibility that prior research often has overlooked. Although there is consensus about restrictions many of them are still unresolved, emphasising socio-political frameworks provides a broader perspective to comprehend adoption processes.

The results of this study predominantly correspond with the current literature regarding obstacles to solar energy adoption, substantiating the established difficulties associated with technology transitions in agriculture (Timilsina et al., 2012; Wright et al., 2019). This research further contributes to the conversation by addressing the socio-political dynamics and contextual realities that influence producers' experiences in the Region of Tzaneen. Previous research often offers a broad summary, but the detailed results of this study highlight the necessity for tailored strategies that consider specific local circumstances and capabilities when confronting challenges to adoption.

The results corroborate previous research indicating that the substantial initial expenses of solar energy constitute a pervasive obstacle (Eberhard et al., 2014). The focus on the economic and environmental incentives corresponds with studies addressing the dual advantages of solar technologies (Timilsina et al., 2012).

This study, however, emphasizes distinct difficulties specific to South Africa. These are the effects of load shedding and regulatory anomalies. Although prior studies indicate that efficient regulatory frameworks are essential (Ferreira et al., 2018), this study uncovers diverse experiences among farmers, implying a disjointed policy landscape.

5.5. Comparative Case Studies in African Contexts

Comparison and Contrast of Kenya and Ghana with South African Findings

Across these cases, several similarities emerge:

- Social Influence: In Kenya and Ghana, peer and community leader endorsement significantly influenced adoption, aligning with the TPB's emphasis on subjective norms (Njoroge et al., 2019; Ansah et al., 2020).

- Perceived Benefits: Farmers perceive economic and environmental benefits as motivations, consistent with TAM predictions (Davis, 1989).

Differences include:

- Policy Support: Kenyan farmers received more substantial institutional backing, such as subsidies and awareness campaigns (Njoroge et al., 2019), whereas South African smallholder farmers face policy gaps and resource constraints (Fraser, 2021).

- Financial Barriers: Though financial constraints are universal, Ghanaian programs actively addressed these through donor funding and microfinancing, whereas in South Africa, these remain largely unaddressed, affecting adoption rates (Murombo, 2021).

Implications

These comparisons suggest that social factors underpin initial acceptance across contexts, yet institutional and financial support critically shape actual adoption rates. For South Africa, strengthening policies and community-based interventions could replicate successes observed elsewhere, leveraging social norms to overcome barriers (Wüstenhagen et al., 2007).

5.6 Theoretical Implications

Research highlights the importance of incorporating socio-economic elements into current theoretical models of technological adoption. The technological acceptance model could be improved by integrating factors that consider socio-economic limitations and governmental regulations that influence technological perceptions into the TAM. Future theoretical investigations may enhance frameworks to integrate external aspects much more effectively, integrating human decision-making with systemic impacts.

The findings enhance theoretical models of renewable energy adoption by highlighting the importance of localized obstacles, including technical support and regional regulatory discrepancies. These findings indicate that current models require modification when addressing the distinct socio-economic and infrastructure conditions of developing areas.

The statistics are needed to improve frameworks that include social equity considerations and address the disproportionate impact of economic and technical hurdles on small-scale farmers.

5.7 Practical Implications

The study indicates the immediate need for policymakers to develop specific financial support mechanisms and subsidies and low-interest loans targeting small farmers. The efficient distribution of information about these services must be prioritized. Numerous farmers are aware, in addition to the resources available to them. While the development of cooperations may reduce frustration at the intricacies and dependability of solar technology implementation, it is highly unclear whether the technical capabilities of CSOs will be fully supported in this new step.

The conclusions of this study have significant significance for policymakers and stakeholders involved in advancing solar energy use among subtropical fruit farmers. It is essential that governments establish methods to improve financial access, such as subsidization or low-interest loans, which are specifically designed for farmers. A coordinated initiative is essential for ensuring that producers are informed and capable of utilizing available resources.

A second step is implementing training programs that will cultivate local technical proficiency in fostering a positive ecosystem for the application of solar cells. Establishing collaborations between agricultural extension services and renewable energy specialists will provide farmers with the expertise and competencies required to implement and sustain solar solutions.

To address identified barriers, several practical recommendations emerge:

- Governments and stakeholders should provide targeted subsidies and low-interest loans to small-scale farmers to mitigate initial expenses.
- The establishment of local training centres for technicians will improve access to reliable maintenance services and hence promote pride in solar systems.
- Policy streamlining: Simplifying regulatory mandates and increasing communication regarding available incentives can promote broader adoption.
- Community-based initiatives: Establishing cooperatives for collectively generating solar installations may lower costs and enhance accessibility for little producers.

5.8 Unanticipated Findings

A surprising discovery was the significant knowledge among participants about environmental sustainability associated with solar energy. With the recent economic crisis, I had been able to leverage this awareness in lobbying and educational initiatives. This recently recognized recognition can be both a motivation and a catalyst for social action, encouraging policy reforms that integrate environmental advantages with economic incentives.

Interestingly the study revealed considerable heterogeneity in farmers' regulatory experiences. While some had no difficulty, others faced bureaucratic obstacles. This discrepancy suggests localized variations in policy execution.

One participant likewise exhibited trust issues with solar technology triggered by fears about its reliability. As a result of this issue, education is needed to increase awareness and confidence in others.

5.9 Limitations

The qualitative methodology of the study, characterized by a small sample size of eight individuals, restricts the generalizability of its results. Abstract: The geographical emphasis on Tzaneen may not be representative of experiences in other areas, but it does represent local cultural practices. These limitations may have affected both the scope and depth of findings. Future studies should aim to broaden the inquiry by including a bigger and more diverse participant pool, maybe utilizing a mixed-methods approach that integrates quantitative data for enhanced generalizability. These constraints may result in biases in interpretation and recommendations; therefore, the findings should be regarded as suggestive rather than universally applicable.

5.10 Future Research Directions

Subsequent studies should seek to increase sample size and include a broader population of producers and may employ a quantitative methodology to get statistically generalizable results. Further, a longitudinal analysis could assess the enduring effects of solar energy adoption on productivity, profitability, and environmental sustainability, giving a better understanding of its context in the Savannah socioeconomic and environmental conditions of South Africa. implications.

5.11 Contextualization of Results

The results are most effectively understood when placed within the economic context of the Tzaneen Regional Community, which is continuously subject to load shedding and inconsistent energy supply. The local context influences producers' views on energy reliability and financial viability. This highlights the need to tackle these regional energy issues in longer conversations over renewable energy implementation. Those who lack persistent support for policies hinder efforts to achieve widespread recognition of human rights.

Local socio-economic issues, including income gaps and infrastructure constraints, also affect solar energy adoption. Confronting these difficulties requires a comprehensive strategy that integrates financial, technical, and legislative measures.

5.12 Critical Reflection

The research process's strengths are found in the deep qualitative insights that illuminate participants' life experiences enriching the study of adoptability. However, biases stemming from the researcher's engagement with participants may have affected responses underscoring the necessity of reflexivity in qualitative research. Recognizing these factors improves the comprehensive discussion about the implementation of solar energy in agriculture.

The study process gained full qualitative insights but was restricted by its small sample size and geographic concentration. Reflexivity was defended throughout the study to mitigate biases. However, researcher's participation may affect participants responses for example data analysis from a survey conducted by a researcher who was not identified as indicating that he is a researcher.

This research leads to significant insights into the intricacies of the implementation of solar energy in agriculture and provides pragmatic recommendations for stakeholders incorporating solar power. The knowledge gained on this chapter sets the stage for the concluding chapter, which will bring together key points according to the research aim, research questions and objectives.

CHAPTER 6. CONCLUSION

The aim of this study was to investigate the factors influencing the adoption of solar energy technologies among subtropical fruit produces in Tzaneen area. Findings reveals that farmers in Tzaneen are looking at solar energy to deal with high electricity prices and power outages, aiming also for sustainable environmental goals. They see solar power as dependable, more affordable, and eco-friendly, which can boost how reliably they work and cut down on pollution. Therefore, answering sub research question 1.

Yet, there are hurdles that slow down its widespread use. The biggest issues include hefty upfront costs for installation and not enough technical know-how or assistance. There are also regulatory differences, lack of subsidies or financing options available, and limited infrastructure like battery storage for when it's cloudy. These economic and technical challenges make it tough for small farmers to invest in solar solutions. Therefore, answering sub research question 2 and objective 2.

When it comes to support systems sub research question 3 and addressing objective 3, farmers say they need government incentives, financial help through subsidies, training programs about technology use, and awareness initiatives to make adoption easier. Although some support efforts exist now, the report suggests they're either not enough or not easily reachable by all farmers especially those running smaller operations.

Sustainability plays a key role in why these farmers consider switching to solar energy. The draw is mainly due to its positive environmental impact less dependence on fossil fuels and reduced pollution which fits well with larger sustainability targets. This environmental awareness pushes adoption forward along with economic advantages; such considerations form a crucial part of how these farmers decide on adopting new technologies. Answering research question 4. While farmers see environmental gains, benefits like boosted reliability appeal to them too yet they lack complete understanding regarding its full impact alongside technical details still missing trust coupled inadequate info affects eagerness toward adoption negatively impacts openness this addresses objective 4.

Moving forward these findings suggest a solution to policy makers at the same time addressing objective 5. This can be done by introducing specific financial incentives such as subsidies or low-interest loans or grants might ease significant upfront investments burdening smallholder farms most notably so they can manage better financially speaking. Setting up regional training programs could boost local tech skills necessary for installations or maintenance thus lowering technical hurdles while building farmer confidence too. Streamlined regulatory procedures combined increased awareness about supports available should help promote wider use or adoption sustainable approaches toward employing solar technologies effectively!

In conclusion, subtropical fruit producers in Tzaneen area are turning to solar energy technology because of economic, environmental, and technical reasons. Though many farmers see the long-term gains like saving money and being eco-friendly, there are still obstacles. Financial limits, rules that get in the way, and not enough technical help slow down its broader adoption.

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APPENDICES

Appendices A: Ethics approval letter

UNIVERSITY OF CAPE TOWN

2024/06/21

EBE/00883/2024

RE: Research Ethics Committee Project Approved with Condition(s) Letter

Dear Hlulani Chauke,

Your application for ethics review of your project titled

Examining the Challenges to the Adoption of Solar Energy Technologies Among Subtropical Fruit Producers in the Tzaneen Region in Limpopo province.

has been reviewed and evaluated by the

Engineering & Built Environment Committee.

Based on the information supplied your application has been conditionally approved.

Please note the following additional conditions associated with this approval:

(i) The study is viewed as low risk in terms of the low vulnerability of the intended participants. However, there is some uncertainty as to the research instruments to be used. The impression is that both interviews and questionnaires are to be used, yet only the questionnaire is attached. Please discuss with your supervisor to ensure that all instruments to be used are checked and approved prior to fieldwork. The supervisor to please confirm to the Chair of the EBE REC that this requirement has been met.

Proof that you have met these conditions, in the form of letters of permission or other relevant documentation,

should be supplied to the REC, via the eRA system.

Once you have met with the above condition(s), you may proceed with your research project titled:

Examining the Challenges to the Adoption of Solar Energy Technologies Among Subtropical Fruit Producers in the Tzaneen Region in Limpopo province.

Please note that should:

(i) any serious or adverse effects to participants occur and/or,

(ii) aspect(s) of your current project change and/or

(iii) any unforeseen events that might affect continued ethical acceptability of the project occur then you should immediately report this to the approving REC. You may be required to submit an amendment to this application, in order to determine whether the changed aspects increase the ethical risks of your project.

Regards,

Engineering & Built Environment Committee.

Appendices B: Permission to conduct study.

subtrop
SA Subtropical Growers' Association
Tel: 015 307 3676/7
e-mail: info@subtrop.co.za
www.subtrop.co.za
P O Box 866
Tzaneen
0850
Subtrop manages the affairs of the SA Avocado, Litchi and Mango Growers' Associations

To: University of Cape Town

Department of Construction Economics and Management

Att: Research Division

CONFIRMATION ON AVAILABILITY OF THE POPULATION FOR THE STUDY

To whom it may concern

This communication serves to inform you that we have the population for the study "**Examining the Challenges to the Adoption of Solar Energy Technologies Among Subtropical Fruit Producers in the Tzaneen Region in Limpopo province**".

As the association we have on our database more than 500 registered farmers both in commercial and emerging. Therefore, our farmers are willing to help your student **Hlulani Chauke** with the information she might need.

For more information, please contact me on the details below.

Kind regards,

Stephen Mantsho
Transformation Coordinator
T + 27 15 307 3676/7
M + 27 81 724 5829
E stephen@subtrop.co.za
W www.subtrop.co.za
A 13 Peace Street | Arborpark | Tzaneen | 0850
P P.O. Box 866 | Tzaneen | 0850
subtrop SALGA SAMGA
Subtrop manages the affairs of the SA Avocado, Litchi, and Mango Growers' Associations

Appendices C: Consent letter

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

DATA COLLECTION CONSENT STATEMENT

Research Title: Examining the Challenges to the Adoption of Solar Energy Technologies Among Subtropical Fruit Producers in the Tzaneen Region

Introduction:

Before proceeding with the data collection process, it is important to ensure that you understand and agree to participate in this research study. Your participation is voluntary, and your responses will be kept confidential. By continuing with the data collection process, you are providing consent to participate in the study.

Data Collection Consent Statement:

I, (Name)____, acknowledge that I have read and understood the purpose of the research study titled "Examining the Challenges to the Adoption of Solar Energy Technologies Among Subtropical Fruit Producers in the Tzaneen Region." I agree to participate in this study voluntarily and I understand that my responses will be recorded.

I understand that my participation involves responding to a questionnaire related to the adoption of solar energy technologies in fruit production activities. I acknowledge that my responses will be used for research purposes only and will be kept confidential.

I am aware that my participation in this study is voluntary, and I have the right to withdraw at any time without providing a reason. I understand that my decision to participate or withdraw will not have any negative consequences for me.

1

I consent to the collection and use of the data provided by me for the purposes of this research study. I understand that the results of this study may be used for academic or publication purposes, ensuring that my identity remains anonymous.

By continuing with the data collection process, I confirm my consent to participate in the research study as outlined above.

Participant's signature:____________________________________

Date:____

Details of the researcher

Name	Hlulani Chauke
Position	Postgraduate student
Programme of the study	M Sc in Project Management
Email address	Chkhlu004@uct.ac.za
Contact	083 757 3045

Supervisor's Details

Name	Dr Rolien Terblanche
Email	rolien.terblanche@uct.ac.za

Appendices D: Research participants transcribe data collected.

FARMER 1: RESPONCES

I: Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

F1: - Solar energy is quite expensive and it needs a proper infrastructure for it to work efficiently. For instance, the solar panels must be facing the direction of the sun. the place must be secured due to theft. Incompatibility of infrastructure as well.

I: What factors influenced your decision to consider or adopt solar energy technologies in your operations?

F1: Loadshedding and high cost of Diesel

I: What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?

F1: The solar energy is new. However, the daily cost of electricity irrigation cost is eliminated as currently we use solar pumps to irrigate.

I: What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?

F1: Cost of solar and initial cost of installation. As a small-scale farmer its extreme expensive to install solar system. The smaller you are the more costly.

I: How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

F1: lack of funds and subsidy for small scale makes it difficult to adopt solar energy.

I: Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.

F1: technicians are limited, and the experienced ones are in big cities. So, if u face a challenge it gets to be expensive as well and sometimes you must wait for more than a day for someone to come.

F1: Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?

A: I don't know anything about regulations

I: In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?

F1: we using less electricity meaning that less coal or fossil fuel will be used. Less diesel use that can lead to less air pollution.

I: Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?

F1: yes. My daily production cost has been reduced.

I: How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?

F1: More and more farmers will adopt solar energy technologies in future.

I: What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?

F1: I suggest government intervene in a form of subsidy or grants for small scale farmers.

I: Do you have any future or strategies to further enhance the integration of solar energy technologies into your fruit production operations?

F1: incorporating batteries for energy storage will be beneficial in the future. Because when it rains there is no power.

I: How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?

F1: creating awareness and educate farmers about it. It's not all farmers who are comfortable to adopt solar energy as they are not sure about the negative impact of solar on the production land.

I: Is there any additional information, insights, or experiences you would like to share regarding the adoption of solar energy technologies in subtropical fruit production?

F1: if only solar was cheaper it would benefit many farmers.

FARMER 2: RESPONSES

I: Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

F2: So far, no problems are it's a good technology to work with.

I: What factors influenced your decision to consider or adopt solar energy technologies in your operations?

F2: Solar energy adoption was influenced by high cost of electricity and the loadshedding. We were not sure on when loadshedding will end.

I: What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?

F2: Electricity is very expensive. So solar energy you pay once and no monthly fees. So, cost wise its more beneficial to have solar than electricity.

I: What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?

F2: Implementation and the installing there were no problems. The guys were quick, and they finished in the short space of time. However, we do not have batteries, so when its cloudy we don't have power to irrigate. For example, two days we did not irrigate because it was cloudy. Reasons we don't have batteries yet, is that they are very expensive. They need big budget. For example, we needed R6 million to install batteries.

I: How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

F2: As for us we don't have power storage batteries as they are very expensive. We can't afford it now. Maybe in future. But operating cost is very low.

I: Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.

F2: At this stage no technical challenges as the solar energy are new. It just started working in December 2023. Were trained on how to operate solar energy from pump station to the functionality of it. We know how to fix it.

I: Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?

F2: No polices and regulations that we know of. Or came across with.

I: In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?

F2: We were focusing mostly on cost saving.

I: Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?

F2: We just started using solar, so we can't really tell the cost benefit yet. We just anticipate that its cheaper. Maybe in two years' time we will be able to see the difference.

I: How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?

F2: Its very sustainable because it's free. We bought it once. The sun its free. Initial cost is very high. But it can work.

I: What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?

F2: Tax incentive and subsidies will assist.

I: Do you have any future or strategies to further enhance the integration of solar energy technologies into your fruit production operations?

F2: Sustaining the operation with the batteries it's the future even though it's very expensive.

I: How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?

F2: subsidizing for installing and tax reduction.

I: Is there any additional information, insights, or experiences you would like to share regarding the adoption of solar energy technologies in subtropical fruit production?

F2: nothing that's all we got.

FARMER 3: RESPONSES

I: Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

F3: The adoption of the solar energy, facilitated for an uninterrupted farm activity, improved productivity amid the continued availability of electricity during the working hours. This also helped in accumulation savings for the farm due to reduction in cost of electricity, making it possible for reallocation of the resources to other important business requirements.

I: What factors influenced your decision to consider or adopt solar energy technologies in your operations?

F3: Frequent loadshedding and High electricity prices

I: What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?

F3: Reduced cost of production due to decline in energy cost. Improved business activity - no interruption of the business activity and processes due to continued electricity availability (no shocks and knocks due to loadshedding)

I: What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?

F3: Delay in implementation/ installations due to insufficient technical expertise in the region/area.

I: How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

F3: Adoption of the solar energy required a high initial investment at the star, but cheap to use through-out the lifespan and therefore a benefit to bring sustainability and savings.

I: Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.

F3: No very many because the installations a new and do not require a lot of attention. However, it becomes a bit challenging when there is a need for some technical support, since the expertise is mostly sourced from urban areas and far from the farms, making it expensive and with some delays in attending to the technical problems.

I: Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?

F3: Nil

I: In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?

F3: This has been a cost-saving measure because solar energy is cheaper compared to diesel and grid electricity. This also has an environmental benefit by reducing pollution caused by diesel generators and the use of fossil fuels.

I: Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?

F3: Yes. There is a significant amount of savings of resources that were previously used to pay electricity bills, due to a reduction in consumption of electricity from the national grid/ ESKOM.

I: How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?

F3: Positively. The implementation of the solar technology comes at an affordable cost to both the environment and the business. On the business side, the adoption reduces the operating cost (power cost), improves efficiency, and allows opportunity of reinvestment of the savings to expand the business portfolio.

I: What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?

F3: Recommend that farmers implement solar energy projects to save the environment, reduce energy costs and respond to the current electricity deficit in the country to boost their productivity.

I: Do you have any future or strategies to further enhance the integration of solar energy technologies into your fruit production operations?

F3: Yes. Looking into the opportunity of installing additional capacity, out of which the excess will be given out to the municipality/ESKOM at a cost.

I: How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?

F3: A need for a robust government intervention to support the implementation of solar energy in response to the national energy deficiency and to protect the environment. This will help the economic and productive sectors to perform efficiently and help the overall economic growth.

I: Is there any additional information, insights, or experiences you would like to share regarding the adoption of solar energy technologies in subtropical fruit production?

F3: Nil

FARMER 4: RESPONSES

I: Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

F4: I was hesitant to use solar. I didn't trust Solar. I thought solar power wouldn't operate as well as electricity. But later, I realized that solar was significantly superior to power. The availability of electricity has been continuous, allowing us to focus on other areas of the business.

I: What factors influenced your decision to consider or adopt solar energy technologies in your operations?

F4: Loadshedding and power cuts prompted the introduction of solar.

I: What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?

F4: Cost-effective. The initial expense is high, but the long-term benefits outweigh it.

I: What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?

F4: The first difficulty that prompted us to use solar energy was loadshedding and power reductions.

I: How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

F4: The electricity cost and the inconvenience of loadshedding led us to adopt.

I: Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.

F4: No issues

I: Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?

F4: I haven't faced any regulatory challenges; it seems straightforward for us.

I: In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?

F4: Solar is quite sustainable. We have a lot of sun in this location. We can pump as much water as we can. Unlike the usage of diesel and fossil fuels for energy, we do not emit any pollutants.

I: Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?

F4: Yes, electricity prices have been falling on a huge scale. It's a significant improvement.

I: How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?

F4: If all farmers use solar, we will be able to produce more reliably and at a cheaper cost.

I: What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?

F4: Government subsidy can go a long way for farmers. As it will assist in solar adoption.

I: Do you have any future or strategies to further enhance the integration of solar energy technologies into your fruit production operations?

F4: Addition for more solar panels and batteries installation for power storage

I: How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?

F4: If the government creates a fund for farmers, it will be good. If many farmers can use solar, production output will increase. Sustainability can be maintained as well.

I: Is there any additional information, insights, or experiences you would like to share regarding the adoption of solar energy technologies in subtropical fruit production?

F4: Ways to deal with theft and purchase additional batteries for storage.

FARMER 5: RESPONSES

I: Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

F5: The experience has been positive in the sense that it has contributed to the input cost savings, as well as promoting the goal of lessening the company and carbon footprint.

I: What factors influenced your decision to consider or adopt solar energy technologies in your operations?

F5: Availability of power purchase agreement, funding arrangements as well as environmental sustainability goals consideration.

I: What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?

F5: Electricity Cost savings

I: What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?

F5: mainly financial constraints. Consolidation of reasons to justify solar energy installation.

I: How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

F5: Conventionally, large solar installation requires a large initial capital outlay with savings only realizing over several years. From a budgeting point of view, it was difficult to justify these expenditures as opposed to the capital projects that had a more direct relation to the core business.

I: Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.

F5: our operations are dispersed over a large geographical area. Larger connection points create economies of scale. It is an ongoing challenge to consolidate smaller points and adapt the electrical grid to maximize the value created by adopting solar.

I: Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?

F5: Cumbersome legislation surrounding distribution licenses to supply bulk solar to own installation. SSEG requirements for small connection points makes them administratively unfeasible. Even though there are variables from on a technical point of view. Eskom pricing structure, specifically high fixed cost, makes modern farming practices, like crop rotation difficult.

I: In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?

F5: yes. Electricity supply is more independent, and activities pollute less.

I: Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?

F5: Yes, electricity cost has decreased.

I: How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?

F5: Businesses will move energy intensive activity to sunlight.

I: What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?

F5: If funding is a problem, consider Private partnership approach where a third party sees the initial capital outlay as an investment.

I: Do you have any future or strategies to further enhance the integration of solar energy technologies into your fruit production operations?

F5: Yes, large scale, battery integration is the current focus.

I: How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?

F5: Fixed costs should not be used to supplement for revenue losses through solar installation, this will only fuel the trend. Decrease the administrative lowers the burden surrounding micro distribution.

I: Is there any additional information, insights, or experiences you would like to share regarding the adoption of solar energy technologies in subtropical fruit production?

F5: Battery integration will become very important.

FARMER 6: RESPONSES

I: Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

F6: We hired a local contractor and renovated a machinery shed to give a roof with the best solar exposure. We rerouted the farm's cabling to increase the efficiency of the solar plant.

I: What factors influenced your decision to consider or adopt solar energy technologies in your operations?
F6: The purpose is to: 1) avoid loadshedding and 2) reduce CO_2 emissions. 3) Long-term cost reduction of power

I: What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?
F6: The security of the electrical supply results in lower electricity costs.

I: What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?
F6: We do not have access to any grants, subsidies, or loans.

I: How have financial considerations impacted your ability to adopt and utilize solar energy technology?
F6: High initial cost

I: Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.
F6: No

I: Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?
F6: No

I: In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?
F6: They are more sustainable because of the increased reliability of the electrical supply, which includes irrigation. Mains electricity reduces indirect CO_2 emissions, however reduced generator use causes direct emissions.

I: Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?
F6: Yes

I: How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?
F6:

I: What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?
F6: Access to grants, subsidies, or loans

I: Do you have any future or strategies to further enhance the integration of solar energy technologies into your fruit production operations?
F6: Yes, we intend to expand central generating and battery storage, as well as install solar pumping for new areas going into production, but we now lack the necessary financing.

I: How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?
F6: Smaller producers would benefit from technical advice. In our instance, it is solely a finance issue.

I: Is there any additional information, insights, or experiences you would like to share regarding the adoption of solar energy technologies in subtropical fruit production?
F6: No

FARMER 7: RESPONSES

I: Can you briefly describe your experience with adopting and using solar energy technologiesin your fruit production activities?

F7: Solar energy lowers the production cost. Reasons being that you are not using diesel and electricity. And electricity is very expensive. For instance, in the previous project where I was working, they are no longer using electricity they are fully using solar.

I: What factors influenced your decision to consider or adopt solar energy technologies in youroperations?

F7: Solar its very cheap and it does not need cables when you install solar. However, the initial cost is very high. However, in the long run its very cheap. Another reason is the current issue of loadshedding led farmers to adopt solar energy. And Solar cost is cheaper that diesel usage as well.

I: What are the primary benefits or advantages you have observed since implementing solarenergy technologies in your fruit production activities?

F7: Advantage is that your production cost will be reduced then realize higher profits. Youcan continue to work even when loadshedding kicks in.

I: What specific challenges have you faced in the adoption and implementation of solar energytechnologies on your farm?

F7: First challenge is that solar installation is very expensive, secondly batteries as well are very expensive, for instance if it can be hit by lightning, they can be burnt . Maintenance is very expensive. When lightning strike batteries dies. Thirdly proper technicians are needed. Currently technicians are outside of Limpopo, most technicians are in Gauteng province. And spares are sourced in Johannesburg. It times to fix or change batteries. Due to distance. U can take two to three days without working. Longer rain affects the energy to be stored.

I: How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

F7: Equipment's and installation are very expensive. We bought and installed so no loans used.

I: Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.

F7: There are few technicians working with solar. Most of the experience are based in Gauteng and spare parts are not available locally, one must find them in Gauteng.

I: Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?

F7: No policies that we know of. However, when you do global Gap there is a clause that states that you must at least have something that uses solar. To sustain environment. From government side no active regulation. Currently we do not have license to use solar. And noregulation that are currently on place. Lack of awareness as well.

I: In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?

F7: In terms of sustainability, solar energy assists us to continue with irrigation even if loadshedding kick in. No environmental pollution compared to generator and fossil fuel usagewhen you use electricity.

I: Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?

F7: Initial installation cost its extremely expensive, however in future cost of production decreases. And due to low or inactivity in electricity usage the electricity tariff gets to be loweredor reduced.

I: How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?

F7: Production cost will be lowered. The solar panels as they grow old you can take it backto the company for remanufacturing. There is that option, therefore I think environmental wise we are safe. As disposals is minimal or zero. It is very sustainable because it is free. We bought it once. The sun its free. Initial cost is remarkably high. But it can work.

I: What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?

F7: Solar panels must be cheaper. Farmers must be subsidized especially small-scale farmers.

I: Do you have any future or strategies to further enhance the integration of solar energy technologies into your fruit production operations?

F7: in future farmers must leave an open space specifically for future solar installation. Butthe challenge is theft as people can steal.

I: How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?

F7: Subsidizing farmers especially small-scale farmers for installing and tax reduction. For

bigger producers' subsidy is available as they pay less when they purchase the solar panels.

I: Is there any additional information, insights, or experiences you would like to share regarding the adoption of solar energy technologies in subtropical fruit production?

F7: Emphasis is the lack of solar technicians in rural farming area, as most are based in Johannesburg. And spares take long to be acquired as they must be sourced outside the provinceas well.

FARMER 8: RESPONCES

I: Can you briefly describe your experience with adopting and using solar energy technologies in your fruit production activities?

F8: We have solar on the farm to provide our employees with hot water, cooking and lighting due to the high cost of constructing Eskom line. We have not yet commissioned solar for production purposes.

I: What factors influenced your decision to consider or adopt solar energy technologies in your operations?

F8: The cost of commissioning solar can be capitalized and it is a saving long term.

I: What are the primary benefits or advantages you have observed since implementing solar energy technologies in your fruit production activities?

F8: We have solar in our other primary residences (Gauteng & Western Cape) and what we have observed over time is that our municipal bills have tumbled down to around 18% of the previous bills.

I: What specific challenges have you faced in the adoption and implementation of solar energy technologies on your farm?

F8: The cost is still high and there is a need for an incentive like we had in the recent past for domestic adoption - it should, however, be for a longer period (2 – 4 years period) to allow for phased – in approach.

I: How have financial considerations impacted your ability to adopt and utilize solar energy technologies?

F8: Financial consideration is the single most impactful outcome of the decision. The productivity level of the farm determines the developmental projects one can undertake on a farm. Own personal contribution does come into play, but the first consideration is to keep the productive means in-tact for one to realize the returns in the shortest period possible.

I: Have you encountered any technical difficulties or limitations in integrating solar energy technologies into your fruit production operations? If yes, please elaborate.

F8: Not applicable as we have not yet commissioned solar on our farm.

I: Are there any regulatory or policy-related hurdles that have affected your adoption of solar energy technologies?
F8: From our experience in commissioning solar in our two separate homes (Gauteng and Western Cape), there are no extra-ordinary regulatory requirements than using registered and qualified technicians.
I: In your opinion, how has the adoption of solar energy technologies influenced the sustainability and environmental impact of your fruit production activities?

F8: No idea as we have not adopted the technology yet.

I: Have you noticed any improvements in energy efficiency or cost savings since incorporating solar energy technologies?

F8: Yes, a lot of savings in our private homes.

I: How do you envision the long-term sustainability of fruit production in the region being influenced by the adoption of solar energy technologies?

F8: It's my considered opinion that the conventional electricity supply by Eskom directly and or the municipality is not sustainable long term. The tariff increases by Nersa is unaffordable while the produce of the farmers is squeezed by caring of orchards and many other hidden costs.

I: What suggestions or recommendations would you offer to address the challenges faced by fruit producers in adopting solar energy technologies?

F8: Depending on where they are, I would recommend that they form an association, equally contribute financially to building solar plants with sufficient battery storage. In this way, costs will be distributed evenly amongst the participants and thereby become affordable. Remember you could harvest as much energy as possible from the sun but if your storage capacity is limited, the efficiency will be lost!

I: Do you have any plans or strategies to further enhance the integration of solar energy technologies into your fruit production operations?

F8: Yes, now that we have harvested, we are waiting for the return on the yield and invest in solar energy.

I: How do you believe government policies or industry initiatives can better support fruit producers in adopting and utilizing solar energy technologies effectively?

F8: AgriSA and or Provincial Agriculture departments with the expert help of the Land Bank, DBSA and IDC should negotiate with the local manufacturers and put-up packages for the industry. A further tax rebate specific for the industry could also stimulate the up take.

I: Is there any additional information, insights, or experiences you would like to share regarding the adoption of solar energy technologies in subtropical fruit production?

F8: Energy needs differs from one operation to the next. It is critical that proper classification of subtropical fruit producers should be undertaken. The needs for a grower who is not involved in processing and the need of the next grower who participates in processing and one who is further involved in warehousing are very much different from each. Their energy needs and consumption are vastly different, and the capital required will also be different.

F8: One of my observations is that the uptake will always be an issue for as long as the market remain evasive for the small to medium size farmers. No one will be comfortable to lay too much capital in solar energy while it remains elusive to predict the prices of your produce in the market. In subtropical fruit farming, it is difficult to build a solid financial model due to many moving parts of the equation.