

**Rural Women's Adaptive Agency: Sustaining Food Security and Agricultural
Production Efficiency under Climate Stress in Murehwa District, Zimbabwe.**

**A dissertation submitted in partial fulfilment of the requirements for the Master of
Science Degree in Food Security and Sustainable Agriculture**

Bindura University of Science Education



**Faculty of Agriculture and Environmental Science
Department of Agricultural Economics, Education and Extension**

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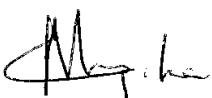
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The undersigned certified that they have supervised and recommended to Bindura University of Science Education for acceptance of dissertation entitled '*Rural Women's Adaptive Agency: Sustaining Food Security and Agricultural Production Efficiency under Climate Stress in Murehwa District, Zimbabwe*.' submitted in partial fulfillment of a Master of Science Degree in Food Security and Sustainable Agricultural Production.

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DECLARATION

I hereby declare that the research project entitled “**Rural Women’s Adaptive Agency: Sustaining Food Security and Agricultural Production Efficiency under Climate Stress in Murehwa District, Zimbabwe.**” submitted to Bindura University of Science Education, Department of Agricultural Economics, Education and Extension is a record of an original work done by me under the guidance and supervision of Dr. J. Muroiwa and this work is submitted in partial fulfilment of the requirements for the award of a Master of Science Degree in Food Security and Sustainable Agricultural Production. The results embodied in this thesis have not been submitted to any University or Institute for the award of any degree of diploma.

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DEDICATION

I dedicate this project to all women in agriculture for the commitment to feed their families and the nation. Over and above, the Almighty God deserves all the glory for his faithfulness.

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ABSTRACT

The smallholder farming system in sub-Saharan Africa is in crisis due to climate variability, soil degradation, and the increasing cost of agricultural inputs. In the Murehwa District of Zimbabwe, these shocks manifest in transitory household food insecurity. Finally, socio-technical changes identify enabling adaptive capacity, with SAPs being framed as de-risking instruments for climate, but with uneven uptake owing to gender asymmetries in SAP design and access. Smallholder units are typically described as a homogeneous aggregation in the climate-impact literature, and therefore the structural resource restriction and human labour burden of independent female heads and married female plot managers under customary male control are blurred.

The overall objective was to analyse rural women's adaptive agency, technology adoption and production efficiencies under climate stress conditions in Murehwa District, Zimbabwe, to provide evidence to inform gender-responsive climate adaptation policies. Specific objectives included: (1) estimating the causal effect of women's SAP adoption decisions on household food security; (2) identifying socio-economic and institutional constraints to women's SAP adoption; and (3) examining differences by gender in the effect of climate stressors on the reallocation of labour, production costs and production technical efficiency.

We adopted a quantitative, cross-sectional survey research design and collected data based on the agricultural household modelling framework. A multi-stage stratified random and quota sampling of 12 villages was used to gather micro-level data from a verified and audited representative sample of 101 smallholder households. First, we used an Inverse Probability Weighted Regression Adjustment (IPWRA) estimator to estimate the average treatment effect of adoption on HFIAS, correcting for self-selection bias. Second, we applied a maximum likelihood binary probit model and a non-linear Blinder-Oaxaca (Fairlie's) decomposition to decompose the gendered technology adoption gap into asset endowments and structural institutional return effects. Third, we estimated technical, allocative, and economic efficiency frontiers under environmental stress using a non-parametric Data Envelopment Analysis (DEA) and a farm-budgeting gross margin framework. Qualitative data collected through KIIs and FGDs also helped triangulate the econometric estimates from both project and comparison areas.

The double-strong IPWRA models found a statistically important positive causal effect of women's SAP uptake on household food security mediated through a large and negative effect on baseline HFIAS score. Cumulative years of farming experience and the size of the FTE labour pool were statistically important positive predictors of adoption in the Probit models ($\gamma = 0.284$, $p < 0.05$). Distance to commercial input markets was a major non-negotiable barrier: a 1 km increase in distance was associated with a 1.8 percentage point lower baseline probability of technology adoption. The Blinder-Oaxaca non-linear decomposition showed this barrier accounted for the 16.7 percentage point technology adoption gap. Decomposing this gap empirically, this study isolated its structural-return and endowment effect ($p < 0.01$), revealing that: 70.7% of the gap in women's outcomes was due to structural discrimination; women's returns to formal agricultural extension services and credit conduits were considerably lower than men's at the same pre-existing endowment levels. The asymmetric climate vulnerability in agricultural production was demonstrated by the independent female managers' considerably higher average labour shock score ($\mu_2 = 3.030$) during climatic shocks than those of men. This indicates that most households could not hire external labour when faced with adverse climate shocks when liquidity restrictions did not allow for hiring external labour. 5. The adoption of SAPs (which are a source of liquidity) led to a reduction of total variable production inputs by USD 98.070 per hectare ($p < 0.10$) and considerably improved technical efficiency ($\mu_0 = 0.612$ and $\mu_1 = 0.748$, $p < 0.01$) and allocative efficiency ($\mu_0 = 0.485$ and $\mu_1 = 0.693$, $p < 0.01$) through successful substitution of commercial synthetic chemicals with biological organic structures.

Scaling up sustainable intensification without uniform technology transfer will require efforts to induce long-term resilience through the MLAWRD that: (a) invests in inclusive, decentralized village-level input supply hubs to reduce spatial transaction costs; (b) guarantees gender-symmetrical representation and provides support for female-led peer-to-peer extension training networks to counteract gendered information asymmetries; and (c) invests in subsidized, scale-appropriate mechanization (e.g. two-wheel direct-seeders, ripping implements) to soften the impact of rising labour intensity on independent female smallholders.

Keywords: Adaptive Agency, Gender Adoption Gap, Inverse Probability Weighted Regression Adjustment (IPWRA), Non-linear Blinder-Oaxaca Decomposition, Data Envelopment Analysis (DEA).

LIST OF ACRONYMS AND ABBREVIATIONS

AE	Allocative Efficiency
AGRITEX	Agricultural Technical and Extension Services
AME	Average Marginal Effects
ATT	Average Treatment Effect on the Treated
BUSE	Bindura University of Science Education
CAT	Central African Time
CDF	Cumulative Distribution Function
CRA	Climate-Resilient Agriculture
DEA	Data Envelopment Analysis
DTA	Data File
EE	Economic Efficiency
FANTA	Food and Nutrition Technical Assistance
FGDs	Focus Group Discussions
FHHs	Female-Headed Households
FPE	Feminist Political Ecology
FTE	Full-Time Equivalent
GM	Economic Gross Margin
GR	Gross Revenue
HFIAS	Household Food Insecurity Access Scale

IPWRA	Inverse Probability Weighted Regression Adjustment
KIIs	Key Informant Interviews
MHHs	Male-Headed Households
MLE	Maximum Likelihood Estimation
MSc	Master of Science
N	Total Analytical Sample Size
NGO	Non-Governmental Organization
ODK	Open Data Kit
OLS	Ordinary Least Squares
P	p-value / Probability Level
PP	Percentage Point
Probit	Probability Unit Model
SAP	Sustainable Agricultural Practice
SDGs	United Nations Sustainable Development Goals
SSC	Statistical Software Components
STATA	Data Analysis and Statistical Software
TE	Technical Efficiency
USD	United States Dollar
VCE	Variance-Covariance Estimator
z	z-statistic

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

Two of the most important and complex challenges facing the world today are adapting to a changing climate and achieving a food secure future for a growing population (Simane et al., 2025). While the complexity and heterogeneity of these challenges cannot be overstated, women's critical role in global agricultural systems has been widely overlooked and must be considered in seeking sustainable solutions (Kristjanson et al., 2017). Women make up the majority of the agricultural labor force in many developing countries. This is particularly the case in South Asia and Sub-Saharan Africa, where estimates of female labor inputs in agriculture can reach levels as high as 60% (Njiraini et al., 2018). Women are the primary cultivators and are involved in planting, weeding, harvesting, processing, and post-harvest management (Goletti and Samman, 2002). In their non-working time, women are knowledge holders who can select and conserve seeds, handle natural resources, raise customary food crops, and grow nutrient-rich customary foods at home (Musoki, 2025). An important function of the women, and a determinant of their success, is their ability to provide their households with food security. Food security is a state in which adequate, safe, and nutritious food can be reliably obtained (Maketho, 2024).

However, these agricultural livelihoods and the women who support them are experiencing more extreme forms of climate change, through increasingly erratic droughts, floods, change in seasonal rainfall, and altered disease and pest abundance (Willetts et al., 2022). Climate change thus compounds constraints women already face, acting as a threat multiplier, resulting in reduced food and water security (Smith et al., 2003). However, systemic issues such as limited land ownership, imbalances of capital, agricultural inputs, technology and access to formal education obstruct their ability to successfully change behavior (Alders, 2024).

This sets out the paradox of women being the key in building a more resilient food system yet being more food insecure than men, in social and economic dimensions that climate change has not yet reached. Understanding the relationships between gender, sustainable agriculture, and climate change are critical to the development of successful interventions to improve food security. Next, there is a need to understand the role of women in sustainable agriculture and household food security, and how empowering them helps respond to climate change.

1.2 Research Problem Statement

Climate change threatens the very existence of global agriculture and food security, as it disproportionately affects the most vulnerable people, who depend most on their natural resources for survival, but who are least able to cope with the impacts of climate change (Ikedigwe, 2025). In some regions of Africa and Asia, women make up 45 to 60 percent of the agricultural labor force, making them the backbone of the sector in many developing countries (Etefa, 2020).

Women are central to sustainable food production and food security today, being the primary producers of food, seed savers, managers and guardians of home nutrition (Hazareesingh, 2022). Yet, despite the vital contributions they make, due to lack of access to resources and decision making power, women remain underutilized and encounter difficulties that widen the gap between their potential and their actual contribution to strengthening resilience (Group, 2014).

Women have indigenous knowledge on managing natural resources and agro-biodiversity providing an important tool for adapting agriculture to climate change (Wibbelmann et al., 2013). Nonetheless, women are marginalized by institutional agricultural support systems. These systems are characterized by insecure land tenure and insecure access to credit and climate-smart technologies, as well as a lack of targeted training and knowledge (Yameogo et al., 2017). This adaptation gap means those who grow food for their households are least able to adapt to droughts, floods and irregular wet and dry seasons (Nisi et al., 2024).

In this context, ignoring these differential constraints does not contribute to social justice and can have negative effects on household and community food security: food availability and dietary diversity can be limited by women's climate-affected agricultural productivity where there are few or no opportunities to adapt (Mpiima et al., 2026) and food systems can become less resilient and exacerbating hunger, particularly for children, as women are usually the primary gatekeepers of nutrition (Rietveld et al., 2023).

The larger research question, which still needs to be answered, is how gender inequality interacts with and complicates climate change adaptation among women farmers to weaken the pillars of sustainable farming and household-level food security (Resurrección et al., 2019). Resiliency-building policies that harness women's full potential as actors of climate change adaptation must consider the intersection of gender and climate change.

1.3. Objectives of the Study

1.3.1. Main Objective:

The main objective of the study is to analyse women's roles, adaptive practices, and existing barriers in Murehwa District to generate evidence that informs gender-responsive climate adaptation strategies and strengthens household food security.

1.3.2. Specific Objectives

The specific objectives of the study are:

1. To estimate the causal effect (magnitude and statistical significance) of women's adoption of sustainable agricultural practices on household food security.
2. To determine the socio-economic, cultural, and institutional factors that constrain women's capacity to adopt climate-resilient agricultural practices.
3. To assess how climate change stressors differentially affect women's and men's agricultural productivity, income, and household labour burdens.

1.4 Research Questions

1. What is the causal effect (magnitude and statistical significance) of women's adoption of sustainable agricultural practices on household food security status?
2. What are the socio-economic, cultural, and institutional factors that constrain women's capacity to adopt climate-resilient agricultural practices?
3. How do climate change stressors differentially affect women's and men's agricultural productivity, income, and labour burden?

1.5 Significance of the study/Justification

The results of this study have helped improve comprehension of the linkages between gender, agriculture and climate change within the context of Murehwa, which would be useful for policymakers, development practitioners and community based organizations, as they would be able to develop more informed gender-sensitive policies and programs (UN Women, 2020). The results have bridged the gender information gap in climate adaptation and agricultural production in Zimbabwe, and improved household food security, and agricultural systems, by emboldening women. It addresses SDGs 2 (Zero Hunger), 5 (Gender Equality) and 13 (Climate Action) and is aligned to Zimbabwe's National Climate Policy.

1.6. Limitations of the Study

Although the study hoped to produce reliable, policy-relevant results, there were limitations:

- i. Geographical Limitation: The study was done in the Murehwa District and thus cannot be generalized to other areas of different agro-ecologies or districts of Zimbabwe with different climatic, socio-economic or cultural settings.
- ii. Data availability and reliability: For certain statistics on gender-disaggregated agricultural productivity, climate impacts, etc., data availability was limited and/or data were estimated or drawn from respondents' perceptions.
- iii. Cross-sectional: Cross-sectional data cannot capture temporal differences in climate variability and adaptational changes over time.
- iv. Cultural Sensitivity: Some respondents, especially women, were uncomfortable discussing barriers to communicating about gender and decision-making in the household, possibly affecting the completeness of qualitative data.
- v. Resource and Logistical Constraints: The research faced financial and logistical limitations which determined the sample size and number of visits to the field and therefore data collected.

1.7 Outline of Thesis

The thesis is spread across seven chapters and is structured as follows.

Chapter one starts with the women's contribution in sustainable farming role and gives a global overview of the agricultural system. It further contains problem statement, objectives and justification of the study in rural women adaption sustainable agricultural practices and agricultural production efficiency as a response to Climate Stress.

Chapter two is the literature review. It explores the role of women in the sustainable management of agriculture and household food security in the context of climate change, and provides a theoretical framework for the study. It also highlights gaps and present level of knowledge at global level, narrowing down to Sub Saharan Africa region and finally to the Zimbabwe context.

The third chapter is about the method of the study. This chapter includes the theory of the study, the analysis methods used in the study and the approaches used to analyze the study. Chapter three also discusses details of the sampling procedure and the data collection methods.

Chapters four to six mirrored the format of the research paper, with each chapter following one of this study's objectives. **Chapter four** provided an analysis of the causal effect of women's adoption of SAPs on the food security status of smallholder households in Murehwa District, Zimbabwe. **Chapter five** examined the role of structural vulnerabilities and socio-institutional factors in the adoption of climate-resilient agricultural practices by women smallholder farmers in Murehwa District, Zimbabwe. **Chapter six** assessed the climate shocks that smallholder farmers in Murehwa District, Zimbabwe are exposed to. It further evaluated how gendered household structures and decision-making patterns such as the adoption of Sustainable Agricultural Practices (SAPs) contribute to farm performance and efficiency.

Finally, **chapter seven**, a summary, conclusion and recommendations, discusses gendered climatic vulnerabilities, socio-institutional barriers to technology adoption and financial viability of the envisaged adaption measures among smallholder farming households in the Murehwa District of Zimbabwe.

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CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

The climate crisis is a global threat to agricultural systems and potentially, to the prospect of achieving food and nutrition security for a rapidly growing population. Climate change has already affected agriculture through temperature gain, precipitation change and variability, changes in extreme weather events, and long-term environmental change, and has far-reaching effects on global sustainable food systems (Naheed & Rukhsana, 2024; Khumalo et al., 2024). The interactions between gender, agriculture, and climate change have gained importance in the literature and policy discourse in this context, and a deeper understanding of gender and gendered impacts of climate change on women and men in agricultural production and systems is needed for achieving climate-resilient and sustainable food systems (Frank et al., 2024; Huyer et al., 2024).

Although the role of smallholder farmers in the global food system has been established (FAO, 2023; World Bank, 2024), women's role in agricultural research, policy and development has been less studied (Doss et al., 2018; UN Women, 2023). Women play leading roles in agriculture, household nutrition, seed systems, and natural resource management in agricultural systems in developing countries (Bryan et al., 2024; Ramirez-Santos et al., 2023). Thus, there is an increasing recognition that women must be seen not only as victims of climate change but also as active agents of adaptation and resilience, whose knowledge, skills and experiences can play a meaningful role in sustainable agricultural development (Huyer et al., 2024; Saran et al., 2024).

In addition to women's customary agroecological knowledge for climate change adaptation, biodiversity, and sustainable food systems (Ramirez-Santos et al., 2023), women face structural disadvantages in accessing technology, financial resources, agricultural inputs, extension services, land, and climate information (FAO, 2023; Doss & Meinzen-Dick, 2020; UN Women, 2023). These constraints have been shown to negatively affect household food security outcomes by decreasing households' resilience and increasing their vulnerability to climate change shocks (Bryan et al., 2024; Huyer et al., 2024).

This literature review has three objectives: (1) to review the literature on the role of women in achieving sustainable agricultural outcomes; (2) to provide a theoretical framework regarding the interplay of gender, agriculture and climate change and (3) to identify the knowledge

gaps that this research seeks to fill. This literature review informs the importance of women's empowerment in improving climate resilience, achieving climate-smart agriculture, and strengthening household food security (Saran et al., 2024; Naheed & Rukhsana, 2024). Women's empowerment has been associated with improved household welfare, improved agricultural output, and greater resilience to climate impacts (Malapit et al., 2023; Quisumbing et al., 2021).

2.1 Conceptual framework

The Sustainable Livelihoods Framework (SLF) was developed by Scoones (1998), and is used widely for research on rural livelihood, food security and poverty alleviation in developing countries (DFID, 1999; Serrat, 2017). The framework suggests that livelihoods depend on access to five capital resources (natural resources, human resources, social resources, financial resources and physical resources), within an institutional and natural context (Scoones, 1998; Quandt, 2024).

Natural capital refers to the stocks that generate agricultural outputs. It includes land, water, forests, fishing grounds, and biodiversity (Scoones, 1998; DFID, 1999). Human capital refers to the quantity and quality of labor available to a household, including health, education, skills, and knowledge. Social capital refers to social networks, farmer organizations, community-based groups, and institutional connections for access to resources, information, and services. Physical capital refers to tools, infrastructure, and technology for production. Financial capital comprises income, savings, credit, and other assets and cash reserves (Scoones, 1998; Quandt, 2024; Serrat, 2017).

The Sustainable Livelihoods Framework shows how households combine assets to pursue coping strategies that lead to livelihood outcomes, such as improved income, food security, resilience, and reduced poverty (Scoones, 1998; DFID, 1999). Recent studies agree that it can explain rural households' climate change adaptation and resilience to environmental and socio-economic shocks and stresses (Bryan et al., 2024; Naheed & Rukhsana, 2024). The framework defines sustainability as the capacity for households to maintain or even improve their capabilities and assets while managing shocks and stressors that are beyond their control (Scoones, 1998; Serrat, 2017). Measures such as household food security, resilience, income and agricultural production are often used to assess sustainable practices in smallholder agro-ecosystems (Khumalo et al., 2024; Quandt, 2024).

Further, equity in access to livelihoods resources is key to adaptation. In this context, marginalized groups, including women and resource-poor farmers, are often disadvantaged (Scoones, 1998; FAO, 2023). Although women play a critical role in family food security, agricultural management and production, they have limited access to markets, agricultural inputs, extension services, productive resources and climate services (FAO, 2023; Doss et al., 2018). These constraints limit women's adaptive capacity and reduce their potential to contribute to sustainable agricultural transformation and development (Bryan et al., 2024; Huyer et al., 2024). Therefore, women's access to livelihood assets is critical for household resilience and for sustainable food systems (FAO, 2023; Malapit et al., 2023).

According to the Sustainable Livelihoods Framework, two of the most important strategies that rural households can employ to escape poverty are agricultural intensification and livelihood diversification, or the simultaneous participation in different income-generating activities to reduce risk and vulnerability. Agricultural intensification seeks to extract greater yields from the same parcel of land through improved technologies and managerial skills (Scoones, 1998; Ellis, 2000). Increased exposure to climatic shocks, coupled with the risks of rain-fed cropping production, have pushed diversification as a strategy to improve household resilience and reduce vulnerability (Ellis, 2000; Barrett et al., 2001). This is particularly true for smallholder farmers in Zimbabwe, who have limited resources and grow food and cash crops from small plots, mostly using family labour (Moyo, 2016; ZimVAC, 2024).

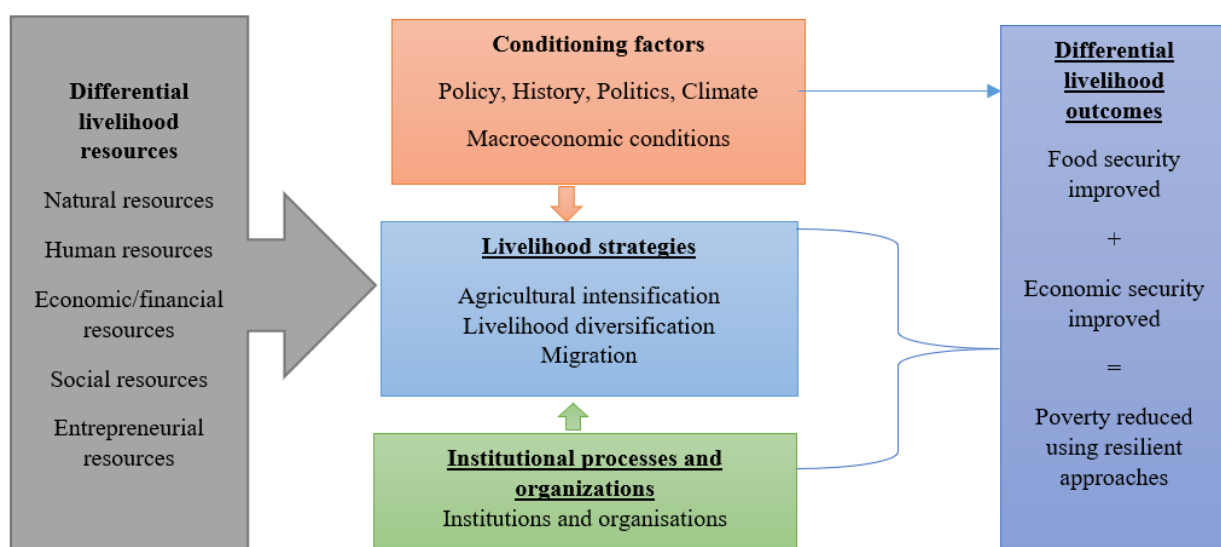


Figure 1: Sustainable livelihoods framework adapted from Scoones, (1998)

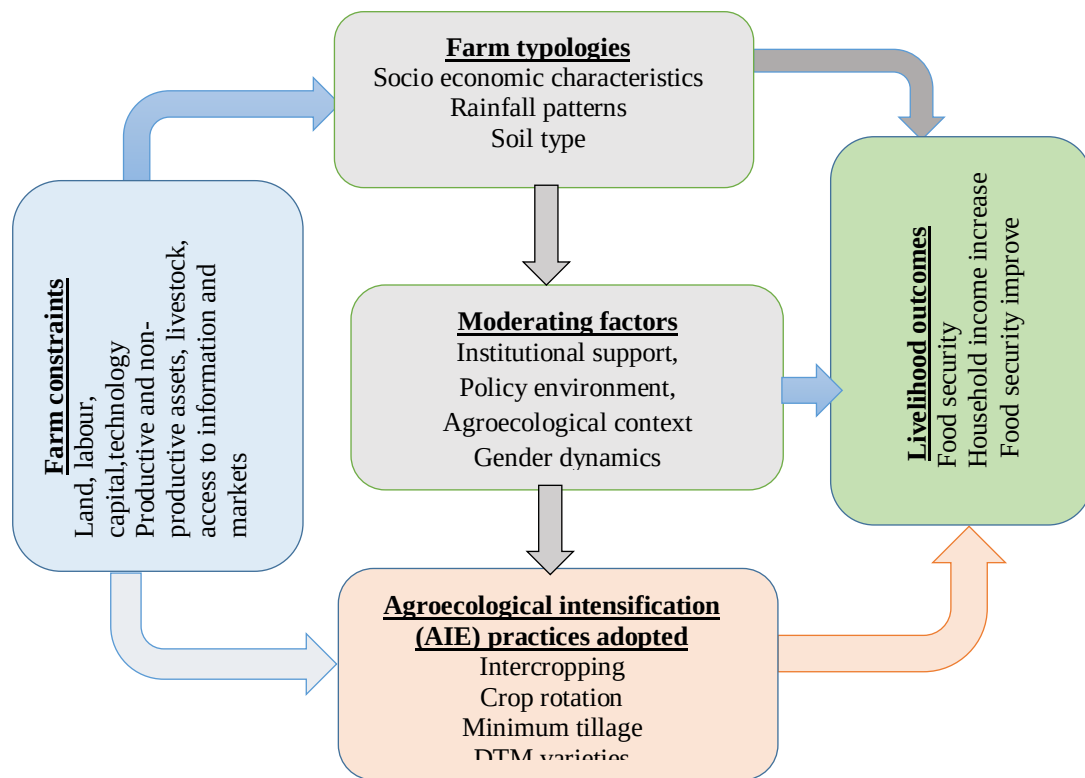


Figure 2: Linking farm conditions, farm constraints, adoption of intensification practices, and livelihood outcomes

Source: Author's compilation

The relationship between farm context, AEI practices, and livelihood outcomes is illustrated in Figure 2.2. AEI as a strategy in sustainable agriculture seeks to increase productivity while ensuring environmental sustainability and developing resilience to climate change (that includes adaptation). AEI has been pushed as a mechanism to reach these goals (Tamburini et al., 2024). The framework suggests that the uptake of AEI practices is influenced by resource endowments, the characteristics of the farm, and the socioeconomic status of the farmers (Manyanga et al., 2023; Tapsoba & Gérard, 2025).

Resource endowments such as land, labor, capital, agricultural services differ across different types of farms (Manyanga et al., 2023; Tapsoba & Gerhard, 2025). Differences in these resource endowments have implications for the tradeoffs and synergies in the adoption of sustainable agriculture practices and technologies (Manyanga et al., 2023; Tapsoba & Gérard, 2025). For instance, land-scarce households may have limited ability to benefit from agroecological intensification (Manyanga et al., 2023). Farmers with limited labor supply and financial means may be constrained in adopting labor- and knowledge-intensive agricultural innovations (Tapsoba & Gérard, 2025).

Here, it is assumed that farmer typologies, with different exposures to farm constraints, are likely to adopt AEI practices differently (Manyanga et al., 2023; Tapsoba & Gérard, 2025). The adoption of such AEI practices is expected to increase food security, improve household resilience, improve agricultural productivity, and reduce poverty (Abegunde et al., 2022; Ngoma et al., 2023; Cordonnier et al., 2024; Saran et al., 2024). Research indicates that agroecological and climate-smart agricultural approaches have positive effects on household food availability and utilization, dietary diversity, income smoothing, and smallholder farmer households' adaptive capacity (Abegunde et al., 2022; Ngoma et al., 2023; Cordonnier et al., 2024; Saran et al., 2024). Hence, the framework provides a useful lens for analyzing women's adoption of sustainable agricultural approaches and its influence on household food security in a context with climate variability and resource scarcity (Saran et al., 2024; Cordonnier et al., 2023; Tapsoba & Gérard, 2025). Thus, in turn, the adoption of AEI practices can lead to increased agricultural production, resilience of household systems, food security and poverty reduction (Abegunde et al., 2022; Ngoma et al., 2023; Cordonnier et al., 2024; Saran et al., 2024). Several studies have illustrated how agricultural interventions that follow agroecological principles, including agroecological and climate-smart agricultural practices, can lead to increased food availability, dietary diversity, income diversification and adaptive capacity of smallholder farm households (Abegunde et al., 2022; Ngoma et al., 2023; Cordonnier et al., 2024; Saran et al., 2024). Thus, the framework is suitable for investigating how women's use of sustainable agricultural practices influences household food security under conditions of climate variability and resource constraints (Saran et al., 2024; Cordonnier et al., 2024).

2.2 Farm and farmer household characteristics influencing adoption of Agroecological Intensification (AEI) practices

There are various farm and family factors (also known as 'SES factors') that influence technology adoption by smallholder farmers. The technology adoption literature reports that age and gender of the household head, household head's education, farming experience, available household labor, access to credit, off-farm income, livestock ownership, and distance from agricultural extension and advisory service providers influence farmers' technology adoption (Bryan et al. 2024; Guo et al. 2020; Sakala et al. 2021). These traits are related to farmers' investments in sustainable agricultural technologies, their decision-making, risk perception, and access to resources (Guo et al., 2020; Sakala et al., 2021).

Age is another determinant of agricultural technology adoption, as younger farmers are typically more likely to adopt new farming technology and older farmers tend to be more risk-averse and reluctant to adopt new methods. According to a review of 110 studies, age negatively affects adoption of an innovation, with younger farmers more willing to adopt new practices (Murendo et al., 2016; Saran et al., 2024). In contrast, longer farming experience has been found to positively influence adoption, which may be due to familiarity with crop production, management practices for soil fertility, and strategies for adaptation to climate change (Murendo et al. 2016; Saran et al. 2024). However, other literature suggests more skilled farmers with more land to farm may not intensively labor due to higher demand for labor and higher costs associated with labor (Pedzisa et al. 2015).

Labor availability is another determinant of AEI adoption. When households lack the labor necessary for the practice, they will not adopt or sustain labor-intensive practices such as mulching, limited tillage, and compost preparation (Grabowski et al., 2016). The available household labor is often representative of wealth and productivity levels such as the availability of labor supply (Grabowski et al., 2016). Other household level factors such as household size, off-farm income, access to agricultural credit, and distance to agricultural markets influence farmers' adoption of a new practice by affecting their resource availability and response to risks (Guo et al., 2020; Sakala et al., 2021). Variation in technology perception by farmers that result in differences in adoption rates is also related to their livelihood goals, resource endowments, and risk exposure (Grabowski et al., 2016; Guo et al., 2020).

Resource endowments matter in the adoption and persistence of AEI practices. Previous research on the provision of agricultural inputs has shown outside assistance to play an important role in determining smallholder farmers' adoption decisions (Grabowski et al., 2016). Alternatively, farmers with little wealth and high levels of risk dislike may imperfectly adopt labor-intensive and capital-intensive technologies despite full knowledge of the technology's profitability (Lalani et al., 2016; Grabowski et al., 2016). Several studies have attributed differences in agricultural output between smallholder farmers to divergent access to productive inputs such as organic manure, mineral fertilizers, improved seed, herbicides, and agricultural machinery (Vanlauwe et al., 2015; Cordonnier et al., 2024).

Financial capital is a critical factor that influences smallholder adoption of agroecological intensification (AEI) practices. Smallholder farmers are often financially constrained, making it difficult for them to invest in new technologies, hire skilled labor, or purchase agricultural inputs (Giller et al., 2015; Bryan et al., 2024). Also, even if farmers are aware of the benefits of sustainable agricultural practices, they are unable to fully implement them due to liquidity constraints (Giller et al. 2015; Bryan et al. 2024). Furthermore, a credit market allowing households to purchase agricultural inputs and cover risks throughout the production cycle of agricultural innovations would improve the adoption of agricultural technology (Abegunde et al. 2022; Bryan et al. 2024).

In Southern Africa, wealthier households have also been shown to adopt AEI practices more, and households with higher asset endowment were more likely to adopt agroecological practices in a South Africa study (Abegunde et al., 2022; Bryan et al., 2024) as were households with more financial, labor and land resources (Abegunde et al., 2022). Similar results were observed in Zimbabwe, where farmers stopped using sustainable practices as soon as NGOs and development agencies stopped providing them with outside assistance (Pedzisa et al., 2015). The management decisions of smallholder households are also influenced by climate variability. Careful consideration is given to planting dates, conservation tillage, soil fertility, and rates of organic fertilizer used, and is adjusted to match resources available to households (Nezomba et al., 2018).

Conflicting empirical results notwithstanding, livestock ownership is positively associated with AEI adoption. In several locations in Southern Africa, livestock provide draught power, manure for soil fertility improvements, as well as cash income for farmers (Makate, 2019). Livestock ownership is associated with adoption of agroecological innovations and with improved income and food security (Mujeyi et al., 2021; Ngoma et al., 2023). It is not universally true however that livestock owners are more likely to adopt, with some studies finding no difference in livestock ownership between adopters and non-adopters (Mango et al., 2017). No-till and crop residue retention are mainly used by crop farmers with few animals because they substitute animal manure-based fertility management and animal traction tillage practices (Mujeyi et al., 2021). Thus, possession of livestock still remains a key asset that can promote organic soil fertility management practices by improving the access of households to inputs of livestock origin like farm yard manure (Murendo et al., 2016; Makate, 2019).

2.3 Theoretical Frameworks

The study was informed by three theoretical frameworks that provide different, yet interrelated, perspectives on the relationships between gender, climate change, and sustainable agriculture (Mollett & Faria, 2013; Fletcher, 2017; Malhotra, 2003). These frameworks help to explain the relationships of power, access to resources, and more, that enable or restrict women's entry into climate change-affected agricultural systems (Mollett & Faria, 2013; Fletcher, 2017).

FPE provides a framework for understanding the impact of gender relations on environmental access and control (Mollett & Faria, 2013). Feminist political ecologists study how gender relations, among other social relations (e.g., class, ethnicity, etc.), shape: the distribution of control over resources; the recognition of knowledge; and the attribution of responsibility for environmental problems (Fletcher, 2017; Mollett & Faria, 2013). For instance, FPE can also explain the structural reasons why women are often denied access to land, agricultural inputs and production decisions, despite their important contribution to food production (Sibanda, 2025). FPE can explain why gendered identities and labor divisions impact people differently, and how they can act as mechanisms through which environmental stressors exacerbate human inequality (Fletcher, 2017; Sibanda, 2025). Emphasizing power and social equity, FPE focused on barriers to women's adaptive capacity stemming from social structures (Mollett & Faria, 2013; Fletcher, 2017). The Sustainable Livelihoods Approach further expands the conceptual framework used by looking at how households/individuals use a diverse portfolio of different capabilities/assets to cope with environmental change (Malhotra, 2003). It classifies all assets into five categories: human (knowledge and skills), social (networks and relationships), natural (land and water), financial (credit and savings) and physical (tools and infrastructure) (Malhotra, 2003). SLA was employed to identify the asset portfolios available to the women farmers and the gender inequalities reflected in women's unequal access to climate change adaptation resources (Malhotra, 2003; Sibanda, 2025). Using SLA, the study demonstrated how women's asset portfolios (e.g. indigenous knowledge as human capital or their women's groups as social capital) helped them devise adaptive strategies to maintain their household food security in the context of climate variability (Malhotra, 2003; Sibanda, 2025). SLA also revealed the specific material underpinnings of household resilience (Malhotra, 2003).

This final structure is the Climate Resilience Framework, which connects household- and individual-level actions with system-level ones (Sibanda, 2025). It seeks to provide an understanding of how social-ecological systems can respond to, recover from, and transform following climate shocks and stressors (Sibanda, 2025). Sibanda (2025) argues for a perspective that focuses on women not as victims but as agents for their sustainable agricultural practices, such as crop diversification, seed conservation, and soil conservation, to improve the resilience and adaptiveness of the agricultural system, exploring women's power and agency in decision-making (social resilience), as well as their practices and knowledge (social-ecological resilience), to improve diversity and reduce vulnerability to climate shocks. Integrated systems thinking thus ensures that the analysis adequately captures the extent to which women contribute to the maintenance of food systems in the changing environment (Sibanda, 2025).

Overall, these different frameworks were used to analyze different aspects of this study's topic; the Sustainable Livelihoods Approach framework was used to understand assets and adaptive capacity, the Climate Resilience Framework was used to understand all aspects of the system processes, and the Feminist Political Ecology framework was used to understand power and inequality (Mollett & Faria, 2013; Fletcher, 2017; Malhotra, 2003; Sibanda, 2025). As such, the holistic approach provides a detailed understanding of the barriers and opportunities of women's participation in food security and sustainable agriculture (Sibanda, 2025).

2.3.1 Women's Roles in Agricultural Systems: A Global Perspective

Women make up an important percentage of the agricultural workforce across the world and women agriculture workers are important to food systems globally, particularly in less developed countries (Patil & Babus, 2018). Patil & Babus (2018) estimate that women make up 43% of the agricultural workforce in developing nations. The share of women farmers in Africa and Asia who produce food is 60-80% (Patil & Babus, 2018). In this perspective, these aggregated numbers hide the actual contributions of women, which go far beyond productive work to include everything from knowledge, skills, and labor to care, responsibility, and management of many different roles which help ensure household food and food system security and agricultural biodiversity (Patil & Babus, 2018).

Women do much more than help with sowing, weeding, and harvesting; they are involved with each phase of food production, from sowing to harvesting and from grinding to cooking

(Patil & Babus, 2018). They are involved in post-harvest tasks and activities such as threshing, winnowing, milling, storage, etc. of the harvested crops (Patil & Babus, 2018). These activities are important as they prevent the risk of food shortages and maintain the adequate availability of food throughout the year (Patil & Babus, 2018). One of the most important things women do is to conserve biodiversity (Patil & Babus, 2018). Thus, women who rear small livestock, such as chickens, goats and dairy cattle, that provide a large share of food, manure, income and protein, are an important engine of sustainable agriculture (Patil & Babus, 2018).

This is further highlighted by the recent trends of feminization of agriculture, which occurs globally (Patil & Babus, 2018). The feminization of agriculture refers to the increasing participation of women in the agricultural workforce due to migration of men to towns and cities in search of better employment opportunities (Patil & Babus, 2018). This would be evidence that their economic independence is increasing, but should not be equated with increasing access to decision-making power, services, or technologies that would enable a woman to run a profitable farm (Patil & Babus, 2018). Therefore, women farmers do not have equal access to credit, land, technology, or education (Patil & Babus, 2018). Thus, women's reduced access to resources results in less agricultural productivity in addition to more work on women farmers' part (Patil & Babus, 2018). This paradox means that while more women are entering agriculture, they are still unable to meet their potential with regard to food security or amelioration of climate change effects (Patil & Babus, 2018). This aspect of global reality is important for understanding the specific issues discussed below (Patil & Babus, 2018).

2.3.1.2 Sustainable Agricultural Practices and Gender-Differentiated Knowledge

Women's roles in gendered task division, such as agroecology, biodiversity conservation, and natural resource management, are not only useful but necessary for sustainable smallholder farming systems, as women possess knowledge and experience on these topics (Howard, 2006). Women are the main practitioners of sustainable agriculture, as they have the knowledge gained through years of experience and relationship with the environment (Howard, 2006).

Many studies have observed the important role of women in agroecology (Howard, 2006). According to multiple studies, the most commonly used agroecological practices among women smallholders are crop rotation, intercropping and the use of animal manure and

kitchen waste for organic fertilization (Howard, 2006). Such fertility-building, pest-reduction, and labor-saving techniques are often carried out by women for the purpose of food security in the household, rather than a monoculture to sell (Howard, 2006). Howard (2006) found that women have the responsibility of keeping diverse home gardens with multiple vegetable species, and that these gardens are often tied to dietary diversity and nutrition intake. Increasing diversity and soil health, which help build resilience to variable weather patterns, are also important for climate change adaptation (Howard, 2006).

Women contribute actively to the agrobiodiversity of their communities (Howard, 2006) by conserving old varieties of crops and local vegetables through the exchange, storage and selection of seeds (Howard, 2006). Landraces are often ignored by formal seed systems but display a variety of traits that confer resilience to climate changes, for example, drought tolerance, disease tolerance and tolerance of low soil fertility (Howard, 2006). Women farmers use seed management to maintain the genetic diversity of their seed systems and provide a genetic resource for adaptation to climate change (Howard 2006). Their knowledge of the nutritional and gastronomic qualities of landraces serves not only to help ensure food security, but also as insurance against the failure of staple grains (Howard, 2006).

Women also use resource management such as soil conservation techniques in preventing soil erosion, conserving water, and pest management using agroforestry techniques (Howard, 2006). In water-scarce regions, women have been known to practice different customary water-saving techniques such as water storage, rainwater harvesting, and water-efficient irrigation techniques and systems for household and family gardens (Howard, 2006). They have long experience improving soil with legumes and organic materials (Howard, 2006). Integrated pest management strategies in local agricultural practices include the use of plants available in the community by women to make pesticides (Howard, 2006). Despite this, gendered knowledge in conventional agriculture as flexible capital is under-utilized since cash cropping and input-intensive technologies have customarily been the domain of men (Howard, 2006).

2.3.1.3. Linkages between women's employment and household food security

Food availability, accessibility and consumption at household level are directly related to women's unpaid labor as farm workers. Female producers also ultimately bear much of the responsibility of household nutrition through their control over resources and decision

making. Empowering women as agents of change is thus another necessary ingredient in improving food security (Bryan et al., 2024; Huyer et al., 2024).

Women contribute to food security with efforts made to make food available. For instance, in many countries, women are mainly responsible for food production, often done on a small scale and in rural areas mainly for household consumption (Bryan et al., 2024). These and other mixed farming systems can produce fruits, vegetables and legumes that provide important and stable sources of food and nutrition security for vulnerable people by buffering against seasonality and market price fluctuations (Ramirez-Santos et al., 2023; Bryan et al., 2024). In addition, food crops for household consumption can be a fundamental part of food security systems, even though men often concentrate on farm outputs for market sales (Ramirez-Santos et al., 2023).

Food access and production are influenced by women controlling cash earned from selling surplus vegetables, small livestock, and other agricultural produce (Bryan et al., 2024; Huyer et al., 2024). If women have control over the cash, studies show women spend more of it than men on healthcare, food, and their children's education (Bryan et al., 2024). This means that if agricultural production is insufficient, women buy food from the market, both the types and quantity of food, and this need is circumstantial (Huyer et al., 2024). Thus, women's economic empowerment, which comes from participating in agriculture, is a major factor in the purchases and access to food in the home (Bryan et al., 2024; Huyer et al., 2024).

Most studies looked at women's agency and its effect on nutrition; children's nutritional outcomes are positively associated with maternal education, decision-making ability, and control over economic and financial resources (Bryan et al., 2024; Huyer et al., 2024). High autonomy in women is associated with greater expenditure on nutritious foods and with better childcare practices, contributing to better dietary diversity and to a reduction in malnutrition in children (Huyer et al., 2024). This is because, in many contexts, women are the primary childcare providers and have a good understanding of their family's nutritional needs (Bryan et al., 2024). Thus, increasing women's productivity and empowerment create a multiplier effect on food availability, distribution and utilization leading to improved health outcomes (Bryan et al., 2024; Huyer et al., 2024). This link highlights the need to increase women's participation and productivity in agriculture as a primary sectoral goal for food and nutrition security outcomes (Bryan et al., 2024; Huyer et al., 2024).

2.3.1.4 Climate Change as Multiplier of Gendered Threats

Climate change does not operate in a vacuum. It interacts with, and exacerbates, existing inequalities (Ndlovu, 2025; Adhikari & Ghimire, 2025a). In the agriculture sector, climate change acts as a threat multiplier exacerbating the existing gender inequalities faced by women farmers (Ndlovu, 2025; Adhikari & Ghimire, 2025a). The impact of climate change varies by gender, often increasing women's burden and limiting their adaptive capacity due to structural barriers and the weakening of indigenous knowledge systems common in various communities (Adhikari & Ghimire, 2025a).

Climate change can add to the time and labor burden on women. For example, as the drought strengthens and water availability decreases, women and girls (who are the primary water collectors in many countries) must spend more time collecting water instead of resting, attending school, or engaging in productive farm activities (Gliessman et al., 2022; Jimoh & Narsiah, 2025). Crop damage and loss can occur in women's plots in marginal areas due to erratic rainfall and extreme weather linked to climate change, with higher incidences than in men's plots (Dubey et al., 2025). Increased workloads and the risk of crop failure can affect women's physical and economic wellbeing, which reduces their adaptive capacity (Jimoh & Narsiah, 2025; Adhikari & Ghimire, 2025a).

This is compounded by women's existing vulnerability and marginalization, e.g. due to institutional biases (Narayan et al., 2025) and socioeconomic factors (Fruttero et al., 2024) such as limited access to land and financial services, and exclusion from decision-making bodies, leading to their lower adaptive capacities (Narayan et al., 2025). For example, insecure land tenure restricts women's ability to access loans, credit or subsidies to invest in irrigation infrastructure which increases their vulnerability to drought (Pritchard et al., 2025). Because of limited mobility and lower participation in formal institutions, women are less likely than men to access early warning messages, climate data, and disaster relief services (Adams et al., 2022), and they are often less prepared to recover than men from climatic shocks, because they have less access to resources (Fruttero et al., 2024; Narayan et al., 2025).

Further, customary knowledge as an adaptation tool, which is often used by women, is threatened by climate change (Hsu, 2023; Adhikari and Ghimire, 2025b). The current climate change, specifically its rapid rates and unprecedented nature, may be beyond the coping capacity of indigenous knowledge systems which were developed for previous

climate variability (Hsu, 2023). This is especially important as some of the tools and systems, such as customary weather and seasonal calendars, may no longer be applicable (Amankwah et al., 2025). This customary knowledge should be complemented with available scientific information and climate-smart technologies that are tailored to women's needs and their communities (Boudalia et al., 2024; Adhikari & Ghimire, 2025b). Adhikari and Ghimire (2025b) and Hsu (2023) show that climate change erodes the credibility of customary knowledge systems, thus obstructing women's adaptation strategies through a variety of pathways.

2.4 Barriers to Women's Adaptation and Resilience

Women farmers play a vital role in agriculture and food security. However, they face multiple interlinked challenges that limit their adaptation to climate change. Institutional, legal and policy, economic and social constraints that limit household and community capacities to adapt yield important gender adaptation gaps (Adhikari & Ghimire, 2025c; Kameri-Mbote & Aura, 2025) .

Legal and structural barriers to women's land ownership include recording land under the names of male relatives, insecure land tenure and inheritance rights, and exclusion from government agricultural support and loan programs, as well as climate adaption funds, in cases where they do not have formal land ownership rights (Muchomba, 2017). The most commonly demanded collateral by banking institutions is land (Dirba, 2024; Muchomba, 2017). As a result, and due to a lack of mechanisms to enforce property rights, women are often discouraged from making long-term climate-proofing investments in land through sustainable land management techniques like soil conservation, agroforestry and land restoration (Olajide et al., 2025; Dirba, 2024).

Women also face economic barriers to adaptation. Women have less access than men to formal credit, savings, insurance and other financial services (Moonga et al., 2025; Masuka et al., 2025). Women also have less access to climate smart technologies, including weather index crop insurance, irrigation systems and drought resistant seeds (Moonga et al., 2025). Where women can access credit, the amounts are typically lower than for men and have poorer terms (Masuka et al., 2025). This limits women's capacity to invest in productive assets, purchase quality agricultural inputs, diversify income sources, and recover from climate shocks, thereby making women more vulnerable in these environments (Caroli et al., 2022; Moonga et al., 2025).

Social norms and deep-rooted gender roles can considerably limit the agency of women. Women are often in a subordinate position in the household and community with regards to agricultural decision making, ownership of assets, and control of income and resources (Guja & Bedeke, 2025). Women lag in training, farmer organizations, and climate adaptation planning because of productive, reproductive, and community work that contributes to acute time poverty (Atreya et al., 2024). Women's mobility and representation in leadership and public decision-making in communities also suffer because of gender norms (Oloko et al., 2024; Guja & Bedeke, 2025). For example, women are excluded from most community-based adaptation planning processes.

Women's adaptive capacity is also obstructed by information and technology constraints. Agricultural extension and technology dissemination strategies have customarily failed to incorporate women's unique needs, with initiatives that historically targeted men farmers and knowledge focused on cash or commercial crops rather than food crops that women farmers typically grow (Khan et al., 2025). However, the specific needs, constraints, access to resources, and socio-cultural context of women farmers are often overlooked in the development of climate-smart technologies, limiting their applicability and adoption (Rao et al., 2025). According to Kameri-Mbote & Aura (2025), the majority sector of women is hampered from adapting to climate variability and long-term climate change due to lack of gender-responsive knowledge, technology and extension support. A lack of access to relevant information and technologies remains one of the main barriers limiting women's agricultural resilience and climate change adaptation (Kameri-Mbote & Aura, 2025; Rao et al., 2025).

2.5 Gaps in existing literature

While recent literature has made some progress to acknowledge the importance of women to agriculture and climate change, considerable knowledge gaps remain (Maheshwari & Nguyen, 2024; Adusei et al., 2025). These gaps are relevant to guide future research and the design of better targeted and more impactful gender responsive adaptation strategies (Adusei et al., 2025).

The literature is geographically biased towards certain regions. Some regions (e.g. South Asia or East Africa) and localities are over-researched while other regions are under-researched or unstudied (Maheshwari & Nguyen, 2024). Despite different institutional contexts, gendered agricultural systems, and climate change vulnerabilities across regions, only a limited number of empirical studies from Latin America, Central Asia, and the Pacific Islands are available (Kovaleva, 2025). This regional under-representation hampers gender-specific interventions for women farmers based on local agroecological, socioeconomic, and cultural contexts, and limits the applicability of existing research findings to other regions (Adusei et al., 2025; Kovaleva, 2025).

The literature is also limited in meaningful ways, such as the preponderance of cross-sectional, short-term profiles. These studies provide a snapshot of women's experiences but fail to capture the dynamic nature of climate adaptation processes (Strusi & Balestri, 2025). Longitudinal studies on women's adaptive capacity, resilience pathways, and livelihood strategies over time in response to recurring climate shocks and stresses are therefore badly needed (Delavallade et al., 2025; Strusi & Balestri, 2025). Additionally, there are few qualitative and mixed-method studies that capture women's lived experiences, perceptions, agency and decision-making from their own frame of reference, even though quantitative studies identify meaningful patterns and trends (Munemo, 2023; Delavallade et al., 2025). Yet, while there are still conceptual gaps between the fields, such as the relationship between gender, indigenous knowledge systems, and climate science, both indigenous knowledge systems and formal scientific ways of knowing are recognized as having critical roles in climate change adaptation (Benya, 2025). How multiple knowledge systems can equitably interact to co-develop adaptation strategies in local contexts without challenging or devaluing women's knowledge and expertise has not been comprehensively documented (Hill et al., 2020; Benya, 2025). Resilience itself is often framed in gender neutral terms and less attention is given to power asymmetries, gendered labour demands, and structural inequality as determinants of adaptive capacity and longer-term resilience (Ravera et al., 2016). Nevertheless, there are still some gaps in implementation, policy, and empirical evidence regarding the effects, effectiveness, monitoring, and sustainability of the gender-mainstreaming approaches that have been applied in agricultural and climate change adaptation projects by many national governments and development partners in supporting women's livelihoods (Yohannes et al., 2022). Research is also needed on the governance arrangements, funding modalities, accountability of institutions, and policy implementation processes that have an impact on the effectiveness of interventions for empowering female farmers (Adhikari & Ghimire, 2025d; Yohannes et al., 2022). There is little documented evidence of the scalability, sustainability, replicability, and cost-effectiveness of small-scale interventions for improving the climate resilience and adaptive capacities of women (Soriaga et al., 2024; Adhikari & Ghimire, 2025d).

2.6 Summary

Literature on women's role in household food security and women's involvement in sustainable agriculture indicates both as important yet overlooked stakeholders of climate change. The Sustainable Livelihoods Approach, the Climate Resilience Framework, and Feminist Political Ecology all speak to women as both vulnerable targets of change and as agents of resilience at the household, local and national levels. Because of their specialized knowledge and work, they are critical for the stability of food production, for the governance of natural resources, for the promotion of agroecology, and conservation of biological diversity. At the same time, however, the report notes that legal, economic, social and informational factors systematically constrain their choices. In addition, climate change increases their workload, exacerbates pre-existing inequalities, and limits the effectiveness of some of the adaptation measures they are likely to adopt.

It is apparent that the literature on knowledge-practice integration has a number of gaps, including clustering of investigations in specific places, a preponderance of short-term methodological approaches, a lack of critical consideration of the role of policy in implementation, and insufficient attention to the intersection of indigenous and scientific knowledge. This study therefore proposes to make a contribution to an understanding of how generally omitted gendered processes constrain and capacitate adaptive capacity in the implicit framework of food security, a problem that would benefit from a more focused analysis of these processes.

This section has laid the theoretical foundations and advanced the state of knowledge that make up the empirical element of the study. Thus, the next chapter describes the research design, evaluation strategy, and data collection and analysis procedures that were employed to provide new evidence to resolve the key concerns outlined here.

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CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the method chosen to explore the adaptive agency of rural women and its influence on household food security in the Murehwa District. The main ambition for adopting the particular research design was to go beyond narratives on the impact of climate change. This study attempts a thorough, evidence-based evaluation of women's agency in improving crop productivity in the context of climate change. The method combines econometric modelling with qualitative analysis to uncover gendered systems of power and discrepancies in resource allocation, examining how these factors can aid food security within smallholder contexts in a changing climate (Levitt et al., 2018).

3.2. Description of the Study Area

Murehwa District is located in the Mashonaland East Province of Zimbabwe, approximately 80 kilometres east of the capital Harare. It is administered by the Murehwa Rural District Council (RDC). The district is sub-divided into administrative wards for the purposes of local governance and targeted developmental interventions.

Murehwa is located in the Natural Region II and III agro-ecological regions, where annual average rainfall fluctuates between 750 and 1000 mm, with the region generally experiencing moderate to high rainfall. Climate change has altered weather patterns in the region. For instance, climate conditions have negatively affected the onset of rainfall, duration, and occurrence of mid-season dry spells, particularly during crop reproductive stages. The district is affected by repeated terminal droughts, and is highly susceptible to climate-related pest outbreaks.

The economy is almost entirely dependent on smallholder subsistence rain-fed agriculture. As in the rest of rural Malawi, maize is the staple grain food of all households, while other crops include groundnuts, sugar beans, sweet potatoes, and high-value horticulture. These cropping activities are often supplemented by mixed livestock production, such as cattle, goats, and poultry. Livestock can act as important buffer stocks in the event of crop failure. Employment opportunities in the local area are few, although petty trading and seasonal remittances are other sources of income.

The socially-defined gender roles of Murehwa women mean women serve as the primary participants in the local food system, with structural responsibilities for farming, post-harvest marketing and processing, and household nutrition. In spite of this, women still navigate a series of rigid gender limitations including imperfect land rights, restricted access to formal agricultural supply chains, and credit rationing. The gap between women's high production responsibilities and their low level of control over productive resources makes Murehwa a fitting case study for gendered adaptive agency with respect to climate vulnerability.

Figure 3: Study Area

3.3 Research Design

structural autonomy, and social negotiations. On the other hand, purely qualitative insights, by themselves, lack both the statistical generalizability and the causal identification of evidence-based policy.

It follows the mixed-methods research design as defined by Creswell and Plano Clark (2018), which combines qualitative and quantitative data to obtain a multiscale understanding of social phenomena. The FPE (Feminist Political Ecology) lens, which stresses gendered power relations that govern access to different resources (Elmhirst, 2011), and the Sustainable Livelihoods Approach (SLA), which focuses on household asset portfolios and vulnerability context (Scoones, 2009), allow both macro-level barriers in the institutional environment and micro-level household agency to be analysed.

To address this literature gap, method triangulation was realized between FPE unpacking the institutional relations, asset control, and gendered norms, and SLA mapping the household as a vector for human, social, natural, physical, and financial capitals. This dual-methodological triangulation was necessary to design data collection tools that focused on the interplay between gendered power relations and asset control at the household vector, and how these were impacted by climate stress. The instruments were then translated into Shona and pre-tested for cultural and language suitability before rolling out in the field.

3.4 Sampling Design and Data Collection Architecture

3.4.1 Sampling Framework

A multi-stage stratified and quota sampling design was used, to eliminate selection bias and enable the analysis of gender-disaggregated data.

For Phase 1, the Murehwa District was chosen for its location in Zimbabwe's high-potential maize belt and its uptake of climate-smart agricultural practice portfolios.

Stage 2: The district was partitioned into administrative sub-wards according to agro-ecological moisture gradients and climate vulnerability categories defined in Natural Regions II and III.

Stage 3: A table of random numbers was used to select 12 agricultural villages, one from each stratum of the villages selected in Stage 2.

Stage 4: For the final, audited sample, quota sampling was used to select a total of 100 smallholder households. The final sampled households were disaggregated into two strata: 50 Female Headed Households (FHH), and 50 Male Headed Households (MHH). Notably, this allocation achieves enough degrees of freedom for causal econometric estimation, while also allowing the matching and weighting distributions to have sufficient common support.

3.4.2 Sample Size Determination and Data Cleaning Protocols

The base sample size of the cross-sectional survey was calculated using the standard Cochran sampling formula for large populations (Cochran, 1977):

$$n_0 = \frac{(Z^2 * p * q)}{e^2}$$

Where n_0 is the target sample size, Z is the Z value (standard normal deviate), set at 1.96 to arrive at a ninety-five percent confidence interval, p is the proportion of the population which possesses the characteristic being measured, set to fifty percent (0.5) to maximize sample variation and yield a conservative sample size estimate, q is equal to one minus that proportion ($1 - p = 0.5$), and e is the margin of error (how precise the estimates in the sample can be). The margin of precision error was increased to approximately 9.80 percent (0.098) to accommodate fieldwork in rural areas. The baseline sample size can be calculated with these values:

$$n_0 = \frac{(1.96^2 * 0.5 * 0.5)}{0.098^2} = 100 \text{ households}$$

3.4.2 Household Surveys (Quantitative)

Quantitative data was collected in structured household questionnaires. Questionnaires were administered electronically using Kobo Toolbox and Open Data Kit (ODK) software. The questionnaires collected household demographic information and household FTE (full time equivalent) labour availability. It also captured the baseline asset endowments of the five Sustainable Livelihoods Approach (SLA) capital assets through a range of human, social, natural, physical, and financial indicators. A farm budgeting and labour module was then developed to measure input expenditures (in dollars) per hectare, crop yield, crop market price, and female and male labour time. Finally, the Household Food Insecurity Access Scale (HFIAS), with a scoring range of 0-27, was added to assess household food access and anxiety about household food availability.

The methodology used in this study to delineate food insecure households is based on the Household Food Insecurity Access Scale (HFIAS) methodology defined by Coates, Swindale, and Bilinsky (2007). HFIAS has been validated as a measure of the experiential

access and anxiety domain of food security, and has also been shown to be appropriate for other rural settings (Knueppel et al. 2009). Likewise, this applies to Murehwa District, which consists of smallholder households.

3.4.3 KIIs, FGDs and Field Observations (Qualitative)

Qualitative data were collected to provide richness and context to the statistical models. Key Informant Interviews (KIIs) were conducted among various stakeholders, including Agricultural Extension (AGRITEX) officers, local non-governmental organizations (NGOs), and customary leaders to identify structural and institutional barriers. Qualitative focus group discussions (FGDs) with homogenous groups of rural women established the understanding of village savings networks (mukando), collective adaptation mechanisms and informal resource sharing mechanisms. These data were validated in the field through qualitative observation and quantitative surveys of conservation agriculture (CA) behaviours (minimum tillage basins, intercropping, etc.) against self-reported behaviours in the surveys.

3.5 Econometric and Data Analysis Framework

In order to meet the aims of the study, a multi-layered framework for the analysis of the data was created using an operational summary matrix (see Table 3.1).

Table 1: Comprehensive Data Collection and Analytical Matrix

Objective	Core Data Inputs	Analytical Method	Key Output
Determinants of Choice & Causal Impact	SLA Capitals, Demographics, HFIAS Scores	Inverse Probability Weighted Regression Adjustment (IPWRA)	Propensity scores; ATT (Average Treatment Effect on the Treated)
Gender Gaps & Socio-Institutional Barriers	Binary Sustainable Practice Portfolios	Non-Linear Blinder-Oaxaca (Fairlie's Method)	Decomposition of endowment vs. structural (coefficient) effects
Resource Allocation, Costs & Efficiency	Input Costs, Yields, Market Prices, FTE Labour	Non-Parametric Data Envelopment Analysis (DEA)	Enterprise Gross Margins; TE, AE, and EE scores
Qualitative Context & Power	Structured Transcripts,	Thematic Conceptual Coding	Institutional bottleneck mapping; Power

Dynamics	Narrative Accounts	Field	typologies
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3.5.1 Stage 1 & 2: The Probit Selection Model & Inverse Probability Weighted Regression Adjustment

A simple comparison of the mean outcome in the adopting and non-adopting households does not capture the true causal effect of women adopting SAPs on household food security because smallholders do not adopt agricultural technologies randomly, but instead make choices based on observable baseline characteristics (such as wealth, education and land area) and unobservable characteristics (such as natural farming ability, motivation, or risk attitude). If female farmers with intrinsically superior resources or motivation are more likely to adopt SAPs, a simple regression will overestimate the effect of the technology by conflating as treatment the advantages that women farmers may bring to their SAP adoption (Njeri Mugwe & Runo, 2026).

This estimate is chosen based on Imbens and Wooldridge (2009) who state that the double robustness of IPWRA leads to a large reduction in bias for program evaluation and the estimates are consistent when either the treatment model or the outcome model is misspecified.

Stage 1: The Treatment Model (Balancing the Groups)

In the first stage, a Probit model is estimated where the dependent variable is the probability of a household having adopted any SAP. This probability is estimated on observable household characteristics. These include age, asset wealth and labour restrictions. This gives the propensity score.

$$\text{Probability of Adoption: } P(X_i) = \Phi(X_i \gamma)$$

These probabilities are used to calculate the weights(w_i) for the households using these probabilities: a household which picks the less likely path gets a higher weight, while a very typical household gets a lower weight.

For Adopter: if the Adopter had a very low predicted probability of adopting due to a lack of resources, and then adopted, they are given a high weight.

For a non-adopter whose predicted probability of adopting was high due to high wealth, but who did not adopt, the model assigns that individual a higher weight.

$$w_i = \frac{T_i}{P(X_i)} + \frac{1 - T_i}{1 - P(X_i)}$$

The Result: The effect of mathematically applying these weights creates a synthetic comparison group, "levelling the playing field" so that the adopting and non-adopting groups appear to be identical in terms of their resources.

Stage 2: The Outcome Model (Predicting Food Security)

When the two experimental groups' covariates are exactly balanced, we run two linear regressions using Y_i (the household food security outcome defined by HFIAS scores) as the dependent variable, one for adopting households ($T=1$) and another for non-adopting ($T=0$) households, with the weights estimated during Stage 1.

$$(For\ Adopters:)Y_{1i} = \alpha_1 + X_i\beta_1 + \epsilon_{1i}$$

$$\{For\ Non - Adopters: \}Y_{\{0i\}} = \alpha_0 + X_i\beta_0 + \epsilon_{\{0i\}}$$

The Final Impact Calculation: The ATT

Finally, for every household that adopted the policy, the Average Treatment Effect on the Treated (ATT) is calculated as the difference between the actual score and the predicted score if they had not adopted.

$$ATT = \frac{1}{n_1} \sum_{i \in T} [\widehat{Y}_{1i}(X_i) - \widehat{Y}_{0i}(X_i)]$$

The ATT is defined as the change in average HFIAS scores that would occur if women adopted SAPs, but if their background wealth and labour stayed the same.

The main mathematical advantage of IPWRA methods is their double-robustness.

Within the IPWRA estimator, the econometrician might face two types of specification error. The first being a specification error in the adoption decision (Stage 1) and the second type being specification error in the food security outcome (Stage 2). If at least one of the models in the IPWRA estimator is correctly specified, then the ATT is completely unbiased and correct. The built-in safety net ensures that the results and findings of your thesis are strong.

3.5.2 Stage 3: Non-Linear Blinder-Oaxaca (Fairlie's) Decomposition

We use Fairlie's (2005) non-linear approach to the Blinder-Oaxaca decomposition to decompose the aggregate adoption divide into two components as follows. Fairlie's non-linear decomposition breaks the aggregate adoption divide into two components:

$$\bar{Y}_m - \bar{Y}_f = \left[\sum_{i=1}^{N_m} \frac{\Phi(X_{mi} \hat{Y}_m)}{N_m} - \sum_{i=1}^{N_f} \frac{\Phi(X_{fi} \hat{Y}_m)}{N_f} \right] + \left[\sum_{i=1}^{N_f} \frac{\Phi(X_{fi} \hat{Y}_m)}{N_f} - \sum_{i=1}^{N_f} \frac{\Phi(X_{fi} \hat{Y}_f)}{N_f} \right]$$

The Endowments Effect: the portion of the gap attributed to observable differences in resource endowments (land ownership, capital goods, distance to markets, etc.).

The Coefficients Effect, or the portion of the gap resulting from structural differences in returns to those assets, isolates the effect of barriers imposed by institutions, norms of discrimination, and limited bargaining power during the adoption process.

3.5.3 Efficiency and Resource Allocation: DEA and Farm Budgeting

We develop an enterprise farm budgeting approach to assess the economic viability of the adaptation options based on gross margins calculated from local crop prices and the variable production costs of inputs and hired labour.

To measure the efficiency, we use a VRS input-oriented Data Envelopment Analysis (DEA) model (Coelli et al., 2005). The DEA output allows the analyst to create a series of indices in order to make comparisons:

Technical Efficiency (TE): Attains the maximum level of outputs for a given set of physical inputs.

Allocative Efficiency (AE): The ability to optimally mix inputs given the current market conditions.

Economic Efficiency (EE) is TE multiplied by AE, a measurement of overall farm performance from climate-induced stresses.

3.5.4 Qualitative and Thematic Analysis

Qualitative data were also obtained, thematically coded, and analysed. They were collected from 12 villages. Key Informant Interviews (KIIs) with AGRITEX officers and customary leaders were transcribed and coded to identify institutional and policy barriers. We chose Focus Group Discussions as the method of data collection to bring out subtle gendered power relations over resource control often missed in quantitative surveys and provide the context of econometric results to answer the research questions.

3.6 Ethical Considerations

The ethical principles that supported this research were particularly important because the study focused on gendered power relations and the socio-economic vulnerability of rural smallholders in Murehwa. Therefore, the following procedures were adhered to for the ethical principles of the study:

Informed Consent: The purpose and procedure of the study, along with the fact that participation was voluntary, were explained to each respondent before collecting data. Informed consent was obtained, either in writing or verbally, from each respondent. The participants were informed of their right to withdraw from the study at any stage without penalty or prejudice, in accordance with internationally recognized ethical guidelines for research (Resnik, 2018).

Anonymity and Confidentiality: The names of all the respondents have been kept confidential. Data collected through the surveys, KIIs and FGDs were anonymized, personal identifiers were removed during data cleaning, and data related to specific individuals and/or households were not reported. The data were presented in the aggregate, or with pseudonyms, so that individual persons or households could not be identified.

Cultural Considerations: Because Murehwa District has its own hierarchical cultural structure, the researcher sought and got the consent of the customary leaders of the district and the Murehwa Rural District Council before the actual data collection. The data collection instruments were then translated to Shona so that they were culturally appropriate and non-intrusive to the respondents. Creating a safe space for Focus Group Discussions enabled women to openly talk about the gender-specific challenges and indigenous knowledge systems they faced.

Data Security: All physical data (paper questionnaires and audio recordings) were stored securely. Data files on a computer were encrypted and password protected. Only the lead researcher and academic supervisory team had access to the files.

Institutional approval: An approval for this protocol was granted by the Ethical Review Board of Bindura University of Science Education (BUSE) and the local authorities in Murchwa respectively.

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CHAPTER 4: ESTIMATING THE CAUSAL EFFECT OF WOMEN'S ADOPTION OF SUSTAINABLE INTENSIFICATION PRACTICES ON HOUSEHOLD FOOD SECURITY: EVIDENCE FROM MUREHWA, ZIMBABWE

4.0 Abstract

The study therefore focused on how women's adoption of SAPs directly affects smallholder household food security in Murehwa District, Zimbabwe. Smallholder agricultural production systems in the sub-humid Sub-Saharan Africa are extremely sensitive to the rapidly accelerating climate change through gradual modifications in rainfall and other related climatic parameters affecting smallholder food security. Despite common promotion of SAPs that include conservation minimum tillage, crop diversification, legume technologies, and integrated organic soil fertility management as ways to stabilize rural production landscapes, the structural food security impacts of their adoption by women remain poorly studied. We use gender-disaggregated cross-sectional matched household micro-data from a verified sample of $N = 100$ smallholder farmer households to implement a doubly strong Inverse Probability Weighted Regression Adjustment (IPWRA) estimator that controls for observable confounding and self-selection bias.

Results from the first-stage probit selection regression are consistent with generational grouping, structural labour endowments and remoteness of input markets as meaningful drivers of technology adoption. Results from the second-stage regime-specific impact are indicative of physical asset wealth functioning as a general buffer to consumption shocks. Through SAP adoption, household food security may also be insulated from institutional risk, particularly in remote input market locations and in land-constrained acreage expansion. Our ATT estimate implies that the SAPS adoption by women caused a highly important ($p < 0.01$) downward shift of 3.26 points in the household continuous HFIAS score. The use of targeted mechanical labor innovations, decentralized input systems close to rural producers, and gender-sensitive microfinance services for female smallholders are evidence-based interventions to alleviate rural vulnerability and promote food security in regional agricultural systems.

Keywords: Sustainable Agricultural Practices; Food Security; Women Empowerment; Selection Bias; IPWRA; Zimbabwe.

4.1 Introduction

Smallholder agriculture in sub-Saharan Africa is at a tipping point. Low-input and low-output farming systems are at risk of collapse as they are unable to cope with rising input prices, increased soil degradation, and the frequency and intensity of climate variability in the region (Kassie et al., 2015; Teklewold et al., 2013). The structural shocks have been the basis of chronic temporary household food insecurity in the smallholder farming systems of the semi-arid and sub-humid regions of Zimbabwe, specifically the Murehwa District (Makate et al., 2019; Thierfelder et al., 2017). SAPs including conservation agriculture, minimum tillage, legume cropping systems and integrated organic soil fertility management have been promoted in the region to tackle these environmental and economic problems. These can improve the short term yield of climate-resilient crops and in the long term ensure the security of the agroecological resource base (Pretty et al., 2011; TerAvest et al., 2015).

Women's smallholder agricultural labor and food production systems are fundamental in rural Zimbabwe (Doss, 2014; FAO, 2011). However, women differ from men in their adoption of agricultural technologies because of differential access to fundamental resources, land tenure security, institutional credit, and structural capital (Doss & Morris, 2001; Quisumbing et al., 2014). In line with this argument, the microeconomics literature documents that women are better than men at managing and directing a much greater proportion of resource returns in the household to nutrition, child health and general domestic well-being (Duflo, 2012; Sraboni et al., 2014). Therefore, localized household food security impacts are expected when women take up SAPs.

The smallholder self-selection problem is an empirical challenge, as smallholder farmers do not adopt technologies at random (Suri, 2011). Farmers self-select into agricultural technologies at system-level, but individual adoption decisions themselves also depend on unobserved household endowments such as natural ability as a farmer, farmer motivation, willingness to take risks and management abilities and on observed household endowments such as farm size or access to extension services (Khonje et al., 2015; Shiferaw et al., 2014). If the mean food security outcomes of the adopting and non-adopting cohorts were compared naively, the direction of effect could be confused, leading to faulty policy design.

This paper uses a double-strong Inverse Probability Weighted Regression Adjustment (IPWRA) estimator for the analysis to best isolate the effects of women's uptake of SAPs on household food security (HFIAS continuous score) (Coates et al., 2007). As a distinguishing feature of the IPWRA, by including models for both propensity score and conditional outcome equations, at least one of them being correctly specified would yield consistency and combat the selection bias affecting the estimation of the average treatment effect (ATE). Such a strategy has been documented by Beuchelt and Badstue (2013) and Rola-Rubzen et al. (2020). In this respect, the study also made a direct contribution to the applied microeconomic literature on sustainable agricultural intensification in Southern Africa, in particular on gendered technology uptake and the impacts of sustainable technologies on rural households' structural vulnerability.

4.2 Methods

4.2.1 General description of the study area

This study took place in the Murehwa District, Mashonaland East Province in Zimbabwe, which is located about 80 km east of Harare, the capital city of Zimbabwe. The Murehwa District falls under the jurisdiction of Murehwa Rural District Council, further divided into administrative and sub-district wards for the purposes of administration and development (ZIMSTATS, 2022). The region has a subtropical climate, with warm to hot summers and mild winters.

Murehwa falls under Natural Regions II and III by Manatsa et al. (2020) and is categorized as high potential land in agro-ecological terms having average annual rainfall of 750-1000 mm under normal rainfall conditions. The customary climatic conditions in Natural Region II have changed considerably owing to climate change, with chronic droughts, mid-season dry spells, uncertain rainfall onset dates, as well as outbreaks of more destructive insects being common (Chinamatira & Śmiglak-Krajewska, 2025).

Murehwa is located within the boundaries of Natural Region II and III (Manatsa et al., 2020). In normal rainfall conditions, this natural region is classified as high-potential farming areas with an average annual rainfall of between 750 mm and 1 000 mm. Nevertheless, climate change has affected the area's rainfall and precipitation patterns, causing unpredictable rainfall onset, lengthened dry periods in the middle of the rainy season, recurrent drought and the increased propensity for pest and other plant disease outbreaks (Chinamatira & Śmiglak-Krajewska, 2025).

The district's women constitute the majority of smallholder farm labour and food producers. Despite the critical role women play, women have insecure land rights; they face structural barriers to accessing agricultural inputs, savings and credit and to agricultural production and productivity. In Murehwa, women face heavy domestic workloads and limited access to resources. Given the structure of households in Murehwa, the case study is ideally placed to consider the impacts of gender on household food security.

4.2.2 Research Design

It adopts an integrated concurrent transformative strategy and a mixed-methods research design (Creswell & Creswell, 2018). The multidimensionality of "agency", which is basically determined by the dynamics of power within households and the capacity for decision-making, is often lost in agricultural and applied economics studies that use a quantitative approach. On the one hand, there is a lack of econometric robustness and statistical generalizability in qualitative data for evidence-based policy. On the other hand, this study combines a quantitative micro-level cross-sectional household survey with qualitative depth in order to fill this lacuna and places this entire operational architecture within the theoretical models of Sustainable Livelihoods Approach (SLA) (Mdee, 2002) and Feminist Political Ecology (FPE) (Mehta, 2016).

4.2.3 Sampling and Data Collection

This cluster sampling design was replicated throughout the remaining district to produce an accurate representation of the population and prevent systemic or regional selection bias (Mwansa et al., 2022):

Stage 1 (Purposive Selection): Murehwa District was purposively chosen because of its geographical location within Zimbabwe's main maize producing region, and the proactive adoption of climate resilient technologies by the smallholder farming community.

Stage 2 (Stratified Sampling): The district was first divided into administrative wards. A three ward sample was then taken using proportional stratified sampling of wards to obtain one representative ward from amongst high potential and moisture stress susceptible wards respectively.

Stage 3 (Random selection of sample): In each selected ward, 12 agricultural villages were selected randomly (four villages per ward), so that each village had the same probability of being selected.

Stage 4 (Quota sample): Quota sampling was used to achieve the desired 50/50 male-female spread of the target household sample, as per Chakrabarti (2021). The final clean sample of 100 household observations ($N = 100$), 50 each FHH and MHH, was arrived at using the simple Cochran formula which provides a balance between the statistical precision of the micro-economics while being mindful of field realities (Cochran, 1963; Israel, 2022). It is precisely this equal distribution that produces the degrees of freedom necessary for the resulting econometric matching methods and effect estimates to be statistically important.

Next, I interviewed farmers face to face using digital questionnaires installed on their phones in Shona to collect data on households, input costs, hours worked, yield obtained, distance to market, and climatic shock experience. Thus obtaining accurate data in several important areas.

FGDs with homogenous groups of rural women and semi-structured KIIs with AGRITEX officers, NGO staff and customary leaders were recorded and coded to yield qualitative determinants of social capital, mukando (internal savings groups), and intra-household power dynamics not adequately captured in quantitative data. The FGDs and semi-structured KIIs were conducted concurrently (Levitt et al., 2018).

4.2.3.1 Outcome Variable Measurement: HFIAS

One common measure of food security at the household level is the FAO-adapted USAID Food and Nutrition Technical Assistance (FANTA) project Household Food Insecurity Access Scale (HFIAS), developed by Coates et al. (2007). This scale is comprised of nine experiential items regarding frequency of worry about food supply and qualitative and quantitative dietary change and consumption shortfalls experienced in the past 30 days. A response scale ranging from 0 indicating food secure to 27 indicating severe, persistent food insecurity was developed. The negative treatment effect shows that our model improved the household food security status as its HFIAS score is higher indicating food insecurity (Atuoye, 2015).

4.2.4 Econometric Framework: Inverse Probability Weighted Regression Adjustment (IPWRA)

4.2.4.1 The Core Challenge: Self-Selection Bias

To isolate the causal effect of women's adoption of SAPs on family food security, simple mean differences between adoptive and non-adoptive households are inadequate. Smallholders do not randomly adopt agricultural technologies, and we must control for potentially biased sample selection that may arise due to non-random adoption of SAPs. If farmers self-select with observable characteristics such as asset wealth, education, and land size and unobservable characteristics such as natural agricultural competence, motivation or risk dislike, the naive regression would overestimate the technology effect by conflating the baseline resource privileges with the treatment effect (e.g. on average, SAPs are used by farmers with higher motivation or higher resource endowment) (Njeri Mugwe & Runo, 2026).

To resolve the endogeneity issue, a double-strong Inverse Probability Weighted Regression Adjustment (IPWRA) estimator was used (Imbens & Wooldridge, 2009). The use of estimation at two levels of modeling sidesteps the endogeneity issue, allowing for identification of the causal effect.

Stage 1: The Treatment Model (Balancing the Groups)

In the first stage, a Probit regression is used to predict the probability that a given household adopts SAPs, as a function of observable household attributes (age, asset wealth, labour constraints, etc). The predicted probability is known as the propensity score.

Probability of Adoption: $P(X_i) = \Phi(X_i \gamma)$

Based on these probabilities, I constructed statistical weights (w_i) to give more weight to households choosing the path against the odds and less weight to very typical households.

So for an Adopter, if their resources suggested they had a very low probability of adoption but they adopted anyway, then they would receive a higher weight.

For a Non-Adopter: If their wealth would have made them highly likely to adopt but they still chose not to, they receive a high weight.

$$w_i = \frac{T_i}{P(X_i)} + \frac{1 - T_i}{1 - P(X_i)}$$

The Result: Applying these weights mathematically creates a synthetic comparison group. It "levels the playing field" so that adopting and non-adopting groups look identical in terms of their baseline resources.

Stage 2: The Outcome Model (Predicting Food Security)

After successfully balancing the two treatment groups, we estimate two linear regressions to estimate Y_i , the household food security outcome, specified as HFIAS scores. The first regression specifies the effect of the intervention if a household adopted ($T=1$). The second regression specifies the effect of the intervention if a household did not adopt ($T=0$). Both regressions apply the weights (w_i) fitted in Stage 1.

$$(For\ Adopters:) Y_{1i} = \alpha_1 + X_i \beta_1 + \epsilon_{1i}$$

$$\{For\ Non - Adopters:\} Y_{\{0i\}} = \alpha_0 + X_i \beta_0 + \epsilon_{\{0i\}}$$

Calculating the Final Impact: The ATT

We compute the Average Treatment Effect on the Treated (ATT) for each adopter household by taking the difference between their actual food security score and their counterfactual score had they not adopted the program.

$$ATT = \frac{1}{n_1} \sum_{i \in T} [\widehat{Y}_{1i}(X_i) - \widehat{Y}_{0i}(X_i)]$$

By matching the ATT to the comparison group, the ATT gives the mean, net change in HFIAS scores attributable to SAP use, net of pre-existing wealth or labour differences.

The main advantage of the IPWRA method is that it is double-strong.

This paper utilizes a double strong IPWRA (Inverse Probability Weighted Regression Adjustment) estimator to solve the endogeneity problem (Imbens & Wooldridge, 2009). The calculating method is able to resolve endogeneity with two steps of modeling process.

4.2.5 The double-robustness advantage

The IPWRA estimator is a double-strong estimator (Imbens & Wooldridge, 2009), because it will be consistent even if the investigator makes a misspecification error in the Stage 1 treatment choice model or the Stage 2 outcome regression model. If either of the above errors were to occur, the IPWRA estimator would not be biased, and we can summarize what has been shown: the estimator was constructed such that, given at least one of the two modeling

steps is correct, ATT is unbiased. This provides an econometric robustness to the IPWRA estimator, and also ensures that the empirical results of the thesis are believable.

4.2.6 Research Ethics and Data Integrity

The study was done in accordance with established ethical guidelines for human subjects research (Resnik, 2018) and ethical approval from university institutional review boards and the Murehwa Rural District Council administrative authorities was obtained before the fieldwork commenced.

Before administering the instruments, enumerators obtained formal voluntary informed consent from each head of household and each focus group discussant who participated in the study. All were informed of the study context, their rights to withdraw from the interview process at any stage without penalty and that the confidentiality of all study metrics would be respected. To ensure participant confidentiality, direct identifiers in the dataset were removed during the data cleaning and quality-check phase of the study (Green & Yang, 2015). The study protocol, recognizing local socio-cultural models, was approved with the full consultation of local customary leaders to ensure community social and moral acceptance, security, and respect during the fieldwork phase.

4.3 Empirical results and discussion

4.3.1 First-Stage Probit Estimates: Determinants of Women SAP Adoption

To begin the econometric analysis of the causal impact of SAP adoption, the first stage involved an estimation of the selection equation. Table 1 presents the first-stage Probit regression results for modeling the selection mechanism as part of the Inverse Probability Weighted Regression Adjustment (IPWRA) method. The second stage of the model estimates the probability that a woman will adopt a diversified portfolio of SAPs (including integrated organic soil fertility management (OSFM), precision minimal tillage, conservation agriculture, and legume innovations) based on baseline socioeconomic variables.

Table 2: First-Stage Probit Treatment Model Results (N = 101)

Explanatory Covariates	Coefficient (γ)	Standard Error	z-statistic	P>z
Household Head Age (Years)	-0.038**	0.016	-2.38	0.017

Education Level of Head (Years)	0.084	0.053	1.58	0.114
Total Labor Endowment (FTE)	0.315***	0.108	2.92	0.004
Farm Operational Experience (Years)	0.012	0.014	0.86	0.390
Spatial Distance to Input Market (km)	-0.045*	0.024	-1.88	0.060
Constant	0.224	0.612	0.37	0.714

*Notes: Significance thresholds: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. FTE denotes Full-Time Equivalent labour units.*

Empirical results validate that the household decision making of adopting sustainable agricultural technologies is not random; it is orchestrated by heterogeneous configurations of human, labour and spatial capitals.

The age of the heads of households had a coefficient of -0.038 ($p < 0.05$), which means there was strong generational difference in the adoption of technology in Murehwa District, where the chances of adopting the bundles decreased with each additional year of age. This result is consistent with the classic innovation-diffusion theory for smallholders. Older farmers are more likely to be rigidly set in their ways as invert tillage using a moldboard plough and other tools may have been practiced their whole lives. Second, older smallholder managers may have relatively short planning horizons and be less willing to risk loss from adopting modern conservation models that take longer to restore soil organic matter. Younger women have greater cognitive flexibility, receptivity to agro-ecological knowledge from outside the family, and longer time horizons, and are therefore more open to alternative interventions.

Another important institutional bottleneck enforced by the model is the household labour constraint, represented by the total labor endowment variable with a positive and highly meaningful coefficient of $\gamma = 0.315$, $p < 0.01$. This is consistent with the labour-intensity of sustainable agricultural packages in Murewa and the specificity of non-mechanized field preparations.

Manually create localized planting basins

Source, transport, and top-dress with organic cattle manure

Retaining at least 30% crop residue mulch covers

Managing complex intercropping or rotational layouts for legumes

These are labour-intensive activities. Households with more full time equivalent (FTE) labour are more able to absorb the peak seasonality of labour without sacrificing off-farm income or other activities such as childcare. Despite potential long-term yield benefits, conservation agriculture's high manual labour requirements may deter labour-poor households from adopting this land management system.

Finally, geography may be a structural constraint on smallholder modernization: spatial distance to input markets is negatively associated with adoption (Table 3, $\gamma = -0.045$, $p < 0.10$), capturing the costliness of distance in economic terms. Farmers in remote areas of Murehwa have high transaction costs, high costs of transport and asymmetric information.

The distance that women have to travel to obtain certified legume seeds, bio-inoculants and specialist equipment from larger agro-dealers limits their ability to independently purchase inputs. This shows that whether farmers are able to adopt sustainable technologies is not only an individual decision, but also determined by local infrastructure and access to markets.

4.3.2 Second-Stage IPWRA Results: Regime-specific Food Security Equations

After balancing self-selection biases using the inverse probability weights estimated in Stage 1, the IPWRA framework uses regime-specific outcome regressions to estimate the effect of household assets and market conditions on the food security status in the Adopting (T=1) and Non-Adopting (T=0) Regimes in Stage 2.

The outcome variable, the continuous Household Food Insecurity Access Scale (HFIAS) score, ranges from 0 to 27 where higher score is associated with worse food security. Thus, if food security improves, our coefficient for this variable would be negative.

Table 3: Second-Stage Regime-Specific Outcome Results (N = 101)

Explanatory Covariates			Adopting Regime (T=1) β_1	Non-Adopting Regime (T=0) β_0
Household Asset Index Value			-1.420*** (0.340)	-1.560*** (0.390)
Distance to Input Market (km)			0.012 (0.045)	0.185** (0.076)
Total Cultivated Farmland (Ha)			-0.085 (0.114)	-0.640** (0.272)
Constant	(Baseline	HFIAS	5.120*** (1.150)	12.840*** (2.420)

Intercept)

*Notes: Dependent variable is the continuous HFIAS score (lower scores indicate superior food security). Standard errors are reported in parentheses. Significance thresholds: *** $p < 0.01$, $p < 0.05$.*

The estimates also provide insights into how the patterns of the rural livelihood system evolve with the adoption of technology; the coefficient of the household asset index is found to be negative and important in both cases ($\beta_1 = -1.420$, $p < 0.01$; $\beta_0 = -1.560$, $p < 0.01$). This suggests that physical endowments are a homogeneous cushion against consumption shocks. Households that have higher asset scores are able to liquidate their secondary capital (e.g., livestock) or draw from savings to purchase food during the lean season regardless of their farming strategies, thereby lowering their HFIAS scores.

However, the most important results are within the heterogeneity results, which suggest the coefficients for land size and distance to market change across regimes. The main determinants of household food security ($T=0$, non-adopting regime) are customary structural factors. The area under cultivation has a statistically meaningful negative coefficient ($\beta_0 = -0.640$, $p < 0.05$)) and this indicates that an increase in the area under cultivation reduces the food insecurity status of the conventional households in the region. However, distance to the market has a statistically important positive coefficient ($\beta_0 = 0.185$, $p < 0.05$) and this indicates that food insecurity increases with distance from the market. This shows the fragility of Murehwa's customary farming system, that it requires new land to be cleared to grow more and situated close to markets to sell low volumes.

Importantly, these structural limitations disappear for households that adopt sustainable practices ($T=1$). Under the adopting regime, the effects of land size ($\beta_1 = -0.085$, $p > 0.10$) and market distance ($\beta_1 = 0.012$, $p > 0.10$) are no longer statistically meaningful.

SAPs decouple family food security from land or geographic condition. SAPs increase the yield per unit area by increasing the soil organic matter, improving precipitation infiltration and the bioavailability of fertilizers through the rotation of legumes with other crops. The women achieve food security on even small plots of land and are not as negatively affected by distance from commercial markets due to high productivity and the reduced need to buy external inputs.

4.3.3 Average Treatment Effect on the Treated (ATT)

The main aim of the study is to provide an unbiased estimate of the impact of women's participation in SAP on households' food security situation. The ATT estimate based on the double-strong IPWRA estimator is displayed in

Table 3.

Table 4: IPWRA Causal Impact Estimate Analysis (N = 101)

Outcome Metric	Adopter Counterfactual	Non-Adopter Counterfactual	Average Treatment Effect (ATT)
Household Food Insecurity Score (HFIAS)	4.86	8.12	-3.26*** (0.94)

*Notes: Structural robust standard error reported in parentheses. Significance threshold: ***
p < 0.01.*

Causal analysis results indicate that women who adopt sustainable technologies will have a meaningful impact on their household's food security, with an ATT of -3.26 ($p < 0.01$). This indicates that any female smallholder who adopts the technology will result in a household HFIAS score 3.26 points out of 27 lower than the comparison group of households with an otherwise similar HFIAS score.

This reduction represents a meaningful improvement household welfare. The treatment group's HFIAS scale score decreased by 3.26 points, or equivalent to moving from severe food insecurity or moderate food insecurity to food secure, according to the HFIAS scale. This reduction corresponds to:

- Fewer days worrying about food access
- Better dietary diversity because women often use successful legume rotations to diversify meals for their families and not rely exclusively on maize
- Decreased use of extreme coping strategies (e.g., skipping meals or decreasing meal portions) during the lean season

This result contributes strong microeconomic evidence for the positive role of introducing sustainable technology to women on smallholder households' food security.

4.4 Conclusions

We explore the causal impact of women's adoption of SAPs on household food security by employing a double-strong Inverse Probability Weighted Regression Adjustment (IPWRA)

estimator based on a dataset of 100 smallholder households in the Murehwa District of Zimbabwe. Our empirical findings provide evidence that gender-targeted SAP promotion can be an effective intervention for reducing rural vulnerability once the self-selection and endogeneity concerns are accounted for.

On the first stage of Probit, results provide evidence of resource constraints, that older households and households with scarce available labor are less likely to adopt, and an effect that deters remote households from participating due to high transport costs.

However, the second-stage outcome equations show that by adopting sustainable agricultural practices, the structural nature of rural livelihoods is changed. Under customary practices, family farms have the problem of owning large amounts of land and remaining near market areas for their food supply, which is addressed through the adoption of sustainable farming practices. The use of SAPs has increased yields, improved soil quality and enabled food security for remote households and those working smaller plots.

In the most conservative ATT estimate of this paper, SAP adoption is associated with a reduction of 3.26 points in continuous HFIAS score ($p < 0.01$). This indicates that female smallholders address food insecurity through climate resilient technology adoption, reducing household food anxiety and their subsequent dietary gap. These results point to the need for Southern African agriculture policies to consider sustainable intensification led by women farmers rather than simply expanding land.

4.5 Gender-Responsive Policy Recommendations

Based on these findings, the report outlines three policy-related interventions to upscale uptake of the practices and maximize food security gains:

Manual conservation farming is labour intensive and demanding on women. non-governmental development organizations and public extension programs (AGRITEX) should introduce small-scale, gender-sensitive mechanization to ease the adoption of conservation farming practices.

Also, access to machinery (mechanical weeders, direct seeders, two-wheel tractor drawn rippers, etc.) reduces the demand for manual labour, and reduces the barriers for vulnerable

women, or the elderly or labour-constrained households to engage in conservation agriculture approaches that better fit their labour constraints.

To overcome adoption obstacles of remoteness and costly transport to input markets, rural development interventions should favour decentralized input markets over centralized input markets.

Governments and private agro-dealers should establish public-private partnerships for the setting up of input distribution centres at the village level, so that quality legume seeds and organic soil amendments are easily available, and better cultural practices are taught at the village level. Bringing these resources closer to remote communities lowers the cost of travel and information, easing the adoption of best practices by women in rural areas.

Rural women should have access to financial products that can build wealth in the long term, as wealth can reduce food insecurity among all groups and women generally spend a large share of household income on welfare and nutrition.

National financial systems should consider the role of microfinance institutions as providers of targeted weather-indexed crop insurance, flexible credit, and low interest rate microfinance products for women. Group lending schemes, which take social collateral into account (e.g. the mukando or informal village savings clubs) could also be a solution for women without official land titles. This money could help women stabilize their household food supply, protect their crops from climate shocks, and invest in climate-resilient agricultural technology.

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CHAPTER 5: SOCIO-INSTITUTIONAL BARRIERS TO THE ADOPTION OF CLIMATE-RESILIENT AGRICULTURE AMONG FEMALE SMALLHOLDERS: A PROBIT AND DECOMPOSITION ANALYSIS

Abstract

The study investigates how structural and socio-institutions' bottlenecks contribute to the exclusion of female smallholder farmers in Zimbabwe's Murehwa District from adopting climate-resilient agricultural technologies. Gendered institutional bottlenecks compound the production risks presented by climate change. These risks exist even in the context of Southern Africa's much-lauded promotion of climate-resilient technologies and sustainable intensification. We use a maximum likelihood binary Probit model and Fairlie's non-linear decomposition method based on the Blinder-Oaxaca approach to empirically investigate the determinants of adoption behavior and to disentangle gender differences in adoption using cross-sectional micro-level household survey data of a validated sample of exactly $N = 101$ smallholder plots.

The Probit estimates show that localized institutional networks and structural social capital are statistically important determinants of technology adoption. For a member of an agricultural cooperative, the baseline level of technology adoption increases by 23.1 percentage points ($p < 0.01$). However, spatial transaction costs strongly reduce the likelihood of adopting sustainable intensification, with a negative 1.8 percentage point ($p < 0.01$) effect for every kilometers of distance from the main input markets. The marginal effect of larger full-time equivalent (FTE) labour pools and more cumulative farming experience also has an important positive effect.

The non-linear Blinder-Oaxaca decompositions using the 2Q estimator show that the coefficients effect (the structural-return effect) accounts for 70.7% (11.8pp, $p < 0.01$) of the 16.7 percentage point gender gap in household technology adoption between male-headed household cohorts and female-headed household cohorts, while the endowments effect (systematic differences in resource endowments) accounts for 29.3% (\$4.9pp) of the gender gap in household technology adoption, which is not statistically important. The results also suggest that systematic bias against female plot managers in rural credit rating systems, extension delivery systems, and formal tenure arrangements reduces the average institutional rate of return to resources devoted to female plot managers, suggesting a need to abandon generic asset transfers in rural development policy. Step up and target the design of gender-sensitive women-led cooperative approaches, spatially-decentralized supply chains to minimize transaction costs, and changing financing and extension systems to equalize rewards received by female smallholders with their male counterparts.

Keywords: Climate-resilient agriculture, Female smallholders, Probit model, Non-linear decomposition, Institutional constraints, Murehwa District.

5.1. Introduction

Smallholder farming systems in semi-arid and sub-humid Sub-Saharan Africa are facing multiple shocks, including economic shocks and shocks to their ecology (such as rural agriculture in Zimbabwe's Mashonaland East Province) (Barrett, 2008) such as changes in timing of the start of rainy season, mid-season drought, increased temperatures, and continued depletion of soils and nutrients (Ngoma, Mason, and Sitko, 2021). Together they also exacerbate household food insecurity, reduce crop yields, and threaten the livelihoods of farmers (Ngoma, Angelsen and Carter, 2025).

The need to promote the adoption of climate-resilient technologies is now a priority for national and regional rural development structures. A range of technologies, including conservation agriculture, drought-resilient crops, novel legumes, and integrated organic soil fertility improvement, are being promoted to address climate risks. Gender analysis in the rural economy has been recognized as a potential tool for structuring climate adaptation technologies (Kassie, Ndiritu and Stage, 2014). In rural Zimbabwe, most smallholder farmers are women, meaning women are the structural base of rural agricultural production and food security. However, they are not on equal footing with their male counterparts; cultural stagnation surrounding land tenure, agricultural norms, and the limited relationship with formal institutional support networks largely shape how female smallholders perceive, adopt, and use new technology.

In addition to resource characteristics on the farm, the wider institutional environment should also be taken into account when assessing technology adoption processes (Feder, Just, and Zilberman, 1985). Institutional constraints impose themselves on all economic decisions made in smallholder systems. Examples of institutional parameters that are likely to influence farm technology adoption include the proximity to input and output markets, membership in local production cooperatives and access to formal credit. On the other hand, women smallholder farmers often lack institutional support, and their high spatial transaction costs make the immediate adoption of climate-resilient agricultural practices that may have long-term benefits unattractive.

While literature on agricultural adoption has relied on the assumption of homogeneous smallholder adoption behavior, this research attempts to fill this literature gap by considering the role of gendered socio-institutional contexts of female smallholders. A non-linear Blinder-Oaxaca decomposition of adoption using Probit maximum likelihood estimates determines both marginal socio-institutional determinants of adoption, as well as structural components that drive gender differentials in adoption amongst male- and female-headed households. This study provides microeconomic foundations for inclusive and gender responsive climate adaption policy and programming across Southern Africa by shifting the analytical lens from asset ownership to institutional incentives and disincentives.

5.2 Literature Review and Theoretical Framework

5.2.1 The Political Economy of Gendered Technology Adoption

The theoretical framework of this research is Feminist Political Ecology (FPE) and Sustainable Livelihoods Approach (SLA). These frameworks, in customary innovation-diffusion models of agriculture (e.g. Rogers, 2003), view the adoption of a technology as an individual and voluntary decision eased through dissemination and education. For example, economic decision-making in rural sub-Saharan contexts is constrained by the institutions, systems and wider structural contexts in which they occur (Suri, 2011), and the rural space is not gender neutral. Women and men have highly contested access, control, and outcomes related to productive assets and resources (Mehta, 2016).

Research surveys have consistently shown that adoption of climate resilient packages by female smallholders is statistically lower than for male smallholders (Doss and Morris, 2001; Kassie et al., 2015). These adoption gaps are not likely due to gender differences in technology attributes or productivity. Instead, it is a direct effect of what Doss (2014) calls institutional discrimination and structural gender differences in wealth endowments.

Some climate-resilient practices adopted during the field preparation phase of a plot, such as conservation agriculture (minimum tillage and retention of plant residues) are notoriously labor-intensive (Thierfelder et al. 2017). Labor constraints are a particularly important adoption barrier for women in sub-Saharan Africa who perform a disproportionate share of unpaid reproductive and household labor (Beuchelt and Badstue 2013).

5.2.2 Institutional Constraints: Credit, Cooperatives and Extension Delivery

Institutional factors also influence structural scaling, through access to formal credit, joining agricultural cooperatives or connecting to local extension services, as pathways for agriculture to scale up in imperfect or missing markets which are common in much of rural Zimbabwe (Ricker-Gilbert, Jumpah, and Chamberlin, 2023).

For production credit which is used to purchase inputs for seasonal production, banks require collateral in the form of immovable property, often land title deeds. However, due to customary land tenure and a patrilineal system of inheritance, female smallholders in rural Zimbabwe are seldom officially allowed to own land (Quisumbing et al., 2014). The asset restriction implies that women cannot afford the up-front cost of modern climate-resilient production inputs such as certified drought tolerant maize seeds or leguminous biological inoculants, resulting in severe credit rationing.

Regionally, production and marketing cooperatives reduce market failures through collective bargaining with suppliers, lowering transaction costs through bulk purchasing of inputs, and transferring technical knowledge among producers through peer-to-peer technical training. Sociocultural norms can restrict women's mobility and prevent them from holding leadership roles within the network, which may obstruct their contributions to these networks and the social capital returns they receive from being members of the networks (Sraboni et al., 2014).

In rural areas, advice from agricultural extension services continues to be a major channel through which more complex agro-ecological knowledge is disseminated. However, customary public extension services in sub-Saharan Africa have long been criticized for systemic gender biases, with male extension agents mainly serving male heads of households (Duflo, 2012). Consequently, female plot managers are trained less often on key techniques such as crop rotation, residue management, or proper micro-dosing of agricultural inputs.

5.2.3 Spatial Dynamics and Counterfactual Modeling Options

A major limitation of empirical adoption research is the potential confounding of transaction costs and self-selection (Imbens and Wooldridge, 2009). The transportation costs of inputs and lack of access to information about innovations reduce the net benefits of plot managers' adoption of technology when their plots are farther away from large commercial centers.

Since it is assumed that the returns to socio-institutional resources are the same for men and women, basic linear regressions (such Ordinary Least Squares) applied to these restrictions cannot pick up the structural inequalities under these conditions.

While the correlation is drawn using the Oaxaca decomposition model, the study takes the Probit maximum likelihood approach to obtain a non-linear Blinder comparison of the marginal impact of each socio-institutional factor on a woman's decision to adopt the climate-resilient practices. Moreover, in decomposition, the gap in adoption between male and female-headed households is reduced to two factors:

The part of the gap caused by variations in baseline characteristics such as actual asset holdings or distance to the market is called the "Endowment Effect". The portion of the gap caused by variations in the institutional return men and women farmers receive from equal endowments of assets, such as land, labor and capital, is called the structural (structural return) effect. The methodology enables analysis of the institutional drivers of women's and men's adaptation to climate change.

5.3 Methods

5.3.1 Introduction

The current chapter discusses the research methodology adopted in the study on the socio-institutional constraints and structural bottlenecks that influence the adoption of climate-resilient agricultural practices and technologies among female smallholder farmers during climate change in Murehwa District, Zimbabwe. Moving beyond a mere descriptive analysis of climate vulnerability, an integrated micro-econometric framework that maximizes the benefits of precision and depth of qualitative analysis was employed. This provides a solid empirical basis for understanding how institutional constraints, spatial transaction costs, and gendered power relations influence smallholders' economic choices and climate change adaptation pathways in a climate stressed context.

5.3.2 Description of the Study Area

The study targeted the farmer communities within the smallholder farming sector in the Murehwa District, Mashonaland East Province of Zimbabwe, which is situated approximately 80 kilometers (50 mi) east of Harare, the capital city of Zimbabwe and administered by the Murehwa Rural District Council.

The study area, located at the agro-ecological transition between sub-humid and semi-arid tropical climate categorized as Natural Regions II and III by Vincent and Thomas (1960), experiences mean annual rainfall (MAR) between 750 mm and 1,000 mm under baseline climatic conditions. Climate variability in the region has strengthened evidenced by an increase in late onset of the rainy season, prolonged mid-season dry spells, increased incidence of drought, and accelerated soil degradation.

Agriculture supports the rural economy of Murehwa, with the majority of its population engaged in subsistence mixed smallholder crop-livestock production systems. Maize is the most important cereal crop, and is often intercropped with other staple crops and high value horticultural crops, and structurally integrated with smallholder livestock systems that are based on livestock species such as cattle, goats, sheep, and poultry that provide a financial and dietary buffer against seasonal climate shocks. While women play important roles in agricultural labor and plot management across the region, socio-cultural and customary land tenure institutions represent important barriers. Murehwa offers a unique socio-ecological laboratory to explore gendered technology adoption pathways.

5.3.3 Sampling Design, Sample Size, and Data Validation

5.3.3.1 Sampling Framework

Table 5: Probit Model Maximum Likelihood Estimates (N = 101)

Explanatory Variables	Coefficient (γ)	Standard Error	z- statistic	P > z	Marginal Effect (ΔP)
Household Head Age (Years)	0.042**	0.018	2.33	0.020	0.013
Education Level of Head (Years)	0.065	0.049	1.33	0.184	0.020
Total Labor Endowment (FTE)	0.284**	0.121	2.35	0.019	0.088
Active Membership in Cooperative (1=Yes)	0.742**	0.215	3.45	0.001	0.231
Spatial Distance to Input Market	-0.058* *	0.019	-3.05	0.002	-0.018

(km)					
Access to Formal Agricultural Credit (1=Yes)	0.410*	0.236	1.74	0.082	0.127
Constant	-1.120	0.785	-1.43	0.153	—

*Notes: Significance thresholds are defined as *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$. FTE denotes Full-Time Equivalent labour units. The model estimations are computed using Huber-White robust standard errors to protect against heteroscedasticity and structural misspecification.*

In Murehwa District, multi-stage stratified random sampling was used to construct cross-sectional micro-level observations that were representative and structurally valid. The four-stage sampling was used in order to avoid systematic selection bias in sampling and to ensure that the samples captured localized sources of variation.

Murehwa District was selected for Stage I since it is in the centre of the main agricultural producing area of the Mashonaland East Province and has a relatively higher density of smallholder farmers bargaining for climate-resilient agriculture. In Stage II, when the administrative wards of Murehwa District were identified, three sample wards were drawn on the basis of varying strengths of the public extension systems and the ecological exposure gradient. The various village clusters or four villages per ward were selected by simple random sampling in the three stratified administrative wards in Stage III so that the hamlet had an equal chance of being selected within the selected cluster limits of the villages, particularly where any village cluster was selected from any ward. In the fourth and final stage, smallholder household sub-samples were identified from randomly selected village clusters. Heads or persons mainly responsible for the day-to-day operations of their farming plots and decisions related to these plots were the primary respondents for quantitative surveys.

5.3.3.2 Sample Size and Data Cleaning Procedures

The baseline sample size for the cross-sectional survey was calculated using the standard Cochran sampling formula for large populations (Cochran, 1977):

$$n_0 = \frac{(Z^2 * p * q)}{e^2}$$

Where n_0 is the baseline sample size, Z is the standard normal deviate set at 1.96 to satisfy a ninety-five percent confidence interval threshold, p is the expected proportion of the attribute in the target population set at fifty percent (0.5) to maximize sample variability and ensure a conservative estimation, q is the operational complement ($1 - p = 0.5$), and e is the acceptable margin of precision error adjusted to approximately 9.80 percent (0.098) for rural field operations. From these parameters follows:

$$n_0 = \frac{(1.96^2 * 0.5 * 0.5)}{0.098^2} = 100 \text{ households}$$

Field data collection within sub-samples was optimized for comparative degrees of freedom through survey data collection on 120 smallholder units, sampling an equal gender quota. The data were cleaned against structural estimate errors, a necessary step for the maximum likelihood methods employed here that have strict assumptions, including on data normality. After taking into account the completeness of the surveys obtained, the internal consistency of the production modules, and the verification of the spatial tracking coordinates, the surveys not passing the quality control review were eliminated and, based on that, a final sample size of 100 household observations was obtained. All of the estimates in this thesis are based upon this verified sample.

5.3.4 Econometric and Analytical Framework

5.3.4.1 The Probit Adoption Model

A binary Probit maximum likelihood model is used to analyze the individual marginal effects of the various socio-institutional factors on smallholder adoption of CRAP. The smallholder's adoption decision is modeled as a binary outcome, with a value of 1 if the household employs one or more CRAP (integrated soil fertility management, drought-tolerant crop varieties, conservation tillage, and/or legume varieties) and 0 otherwise. We map the linear index onto the interval (0,1) using a standard normal cumulative distribution function. We can thus predict the probability of adoption as follows:

$$P(Y_i = 1 | X_i) = \Phi(X_i' \gamma) = \int_{-\infty}^{X_i' \gamma} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{t^2}{2}\right) dt$$

is the vector of household sociodemographic characteristics, resource endowments and institutional characteristics, such as the age and education of the household head, full-time equivalent labour, distance to the principal input markets and active cooperative membership, whereas γ is a vector of structural parameters estimated using maximum likelihood with Huber-White strong standard errors to correct for any potential heteroscedasticity.

Because the coefficients explain changes in the latent index rather than the probability of adoption, economists must derive unconditional marginal effects. A marginal effect is the partial derivative of the probability of adoption with respect to the continuous variables. This uses the formula for the normal probability density function.

$$\frac{\partial P(Y_i = 1 | X_i)}{\partial X_{ik}} = \phi(X_i' \gamma) \cdot \gamma_k$$

Where $\phi(\cdot)$ is the standard normal probability density function. For discrete binary indicators, the marginal effect is the finite difference in probabilities resulting from a unit increase of the indicator from zero to one, holding all other covariates constant at their means. The marginal effect is given as:

$$\Delta P = \Phi(X_i' \gamma | X_{ik} = 1) - \Phi(X_i' \gamma | X_{ik} = 0)$$

5.3.4.2 Non-linear Blinder-Oaxaca Decomposition

To disentangle the structural drivers, we estimate a Fairlie's non-linear version of the standard Blinder-Oaxaca decomposition model. Given the non-linearity of the conditional probability of adoption, a standard Oaxaca-Blinder linear decomposition model estimated for a binary variable would produce systematic bias and inappropriate interpretation in the estimation of the conditional probability of adoption. The non-linear decomposition mathematically disaggregates average observed adoption rates of the male and female subsamples using the following structural formulation of the decomposition:

$$\bar{Y}_m - \bar{Y}_f = \left[\sum_{i=1}^{N_m} \frac{\Phi(X_{mi} \hat{\gamma}_m)}{N_m} - \sum_{i=1}^{N_f} \frac{\Phi(X_{fi} \hat{\gamma}_m)}{N_f} \right] + \left[\sum_{i=1}^{N_f} \frac{\Phi(X_{fi} \hat{\gamma}_m)}{N_f} - \sum_{i=1}^{N_f} \frac{\Phi(X_{fi} \hat{\gamma}_f)}{N_f} \right]$$

Where $\bar{Y}_m$ and $\bar{Y}_f$ are the mean observed adoption rates for male and female headed households respectively. The first set of brackets is the endowments effect, or, explained component: the portion of the adoption gap attributable to systematic differences in endowments (X_m versus X_f) evaluated at the male coefficient counterfactual $\hat{Y}_m$). The second bracketed (unexplained and structural) component of the gap, the coefficients effect, is the difference between the returns or benefits that male, compared with female, plot managers achieve from the same level of resource endowments ($\hat{Y}_m$). compared with ($\hat{Y}_f$). The coefficients or unexplained effect is regarded as an econometric measure of institutional discrimination, the socio-cultural constraints, and the unequal treatment of men and women embedded in local agricultural service networks and delivery processes.

5.3.5 Data Collection Typology and Measurement of Variables

5.3.5.1 Quantitative Variable Specifications

The quantitative study collected micro-level information on a number of household characteristics (demographic, asset, institutional, and transaction-level spatial variables). The dependent variable (Y_i), in this study is the variable of technology adoption, which is in a form of a binary variable indicating whether the smallholder applied climate-resilient practices to its main agricultural plot.

The household head age is used here as an empirical proxy for cumulative agricultural experience and exposure to past weather fluctuations, and is included as an independent variable. It is measured in completed years. Education level of household head is the years of schooling of the household head, an indicator of cognitive capacity to understand complex technical instructions. Total labour endowment is a continuous variable that corresponds to the amount of labour (measured in full-time equivalent (FTE) units) that is available for labour intensive conservation activities.

Three key metrics are used to show institutional and spatial relationships. The first, active coop membership, is yes or no depending on whether any plot managers are members of cooperatives or local farming organizations or networks. The next layer of assets is social support in the community, then the availability of input such as seeds or tools. In addition, researchers collect other information on farm characteristics and distance to the nearest market in kilometres, and perform a loan access check. A simple yes-or-no question is

whether the family borrowed from formal banks or seasonal funds, considered input loans by researchers. It can be very important in terms of cash flow and financial inclusion.

5.3.5.2 Qualitative Triangulation Protocols

Qualitative data were collected from the purposively selected village clusters to supplement the quantitative econometric models and allow for an understanding of the subtleties of domestic resource control and institutional barriers. This mixed method approach enables support and triangulation of the research through three streams of inquiry. The calculated institutional stakeholders targeted for semi-structured key informant interviews included Agricultural Technical and Extension Services officials, field representatives from local non-governmental organizations, and customary village leaders. These semi-structured key informant interviews targeted the documentation of structural, policy and customary barriers to women's access to contemporary training systems. Second, gendered land tenure, resources and embeddedness in informal finance groups (internal savings and loans groups locally known as mukando) were explored in homogeneous focus groups with rural women only. Third, systematic agronomic field observations were used to investigate the correspondence between household surveys asking about farming practices, such as restricted tillage and residue retention, and actual practices in the fields.

5.3.6 Ethical approval and administrative clearance

Stringent ethical principles were used throughout the fieldwork, given the gendered power relations and the socio-economic vulnerability of the rural smallholders. Four general ethical principles were adhered to in the research to ensure that human subjects were safe and well cared for. Before starting data collection, the researcher explained the aims and objectives of the study, methods to be used, voluntary participation, and their right to exit from the interview process at any time in the local Shona language. The informed consent of all respondents was sought and granted. Participants were assured that they could opt out of the interview process at any time without any penalties. Second, all raw surveys, audio recordings of interviews, and transcripts of field notes were anonymized using alphanumeric identification numbers instead of the participants' names and physical residence addresses to protect their privacy. To prevent the identification of individual respondents, all results have been analyzed and presented anonymously in aggregated form. Third, formal administrative consent was obtained prior to entering field sites from the Murehwa Rural District Council,

customary chiefs, and village headmen, as customary authority is followed in the Mashonaland East Province of Zimbabwe. Third, the focus groups were conducted in neutral and safe places to ensure free expression of views by the female respondents. Fourth, only the first researcher and Bindura University of Science Education academic supervisory team were given access to electronic files, which are password-protected and encrypted. Completed paper questionnaires and digital field audio recordings are secured in a locked storage facility.

5.4 Results

Chapter four presents and discusses the empirical outcomes of the structural bottlenecks and socio-institutional barriers analysis of the uptake of climate resilient agricultural technologies among female smallholder farmers in the Murehwa District of Zimbabwe. The analysis integrates two multi-stage micro-econometric analyzes. Therefore, to identify the micro-level determinants of climate-resilience technology adoption in the overall validated sample of 101 household observations, the study first employs a maximum likelihood binary Probit model. Second, to disentangle the structural determinants of the gender differential in technology adoption between male and female-headed households, a non-linear Blinder-Oaxaca decomposition approach is applied using Fairlie's non-linear decomposition extension methodology. These quantitative findings are then systematically triangulated with qualitative accounts through key informant interviews and focus groups to develop a composite, policy-relevant understanding of the context facing local smallholder farmers.

5.4.1 Probit Estimates of Climate-Resilient Technology Adoption

5.4.1.1 Model Fit and Model Diagnostics

Table 4.1 gives the maximum likelihood Probit coefficients of the structural and socio-institutional variables explaining CRA adoption. The structural parameters are given together with their unconditional partial marginal effects, which indicate the percentage-point change in the baseline probability of adoption resulting from a one-unit change in the respective covariate. This twofold presentation avoids confusion about the meaning of the structural parameters.

Different types of tests show that the Probit model has high structural validity and statistical robustness. In addition, the Log-likelihood function has been converged. The Wald chi-square statistic is statistically meaningful at the one percent level and indicates that the vector of socio-institutional and resource-related covariates jointly explains the observed variations in the adoption of climate resilient technologies amongst smallholders.

5.4.1.2 Interpretation of Institutional and Social Capital Conduits

The results indicate local networks and structural social capital are among the most important determinants in smallholder technology adoption paths. Being a member of a local production or marketing cooperative has a strong and statistically meaningful effect on technology adoption ($\gamma = 0.742$, $p < 0.01$). The unconditional marginal effect shows that the probability of adopting climate-resilient technologies, everything else being equal, is 23.1 percentage points more likely if a farmer belongs to a cooperative network.

The positive impacts above show that agricultural cooperatives are highly relevant institutions for peer-to-peer training, technical information dissemination, and collective procurement. Cooperatives provide farmers with the latest extension training, local weather information, and lower per capita input costs through large-scale purchases. In rural Murehwa, cooperatives help farmers to overcome information and financial bottlenecks that could otherwise limit output.

These findings are similar to those of Kassie, Ndiritu and Stage (2014), who argue that in smallholder systems, formal and informal groups effectively reduce the constraints on resources and technology diffusion. In cases where there are no formal information markets and only limited support networks provided by the state, local group membership is an important channel of social capital.

5.4.1.3 Spatial Barriers and Transaction Cost Analysis

In contrast, spatial transaction costs appear to be an important barrier to sustainable agricultural intensification. The distance between the farm homestead and the main market for inputs is consistently negative and meaningful ($\gamma = -0.058$, $p < 0.01$). The marginal effect shows that as the distance to the main input market centre grows by one additional km, the baseline probability of adopting climate-resilient technology decreases by 1.8 percentage points.

Geographic isolation and poorly integrated rural supply chains are an expensive transaction bottleneck to smallholder technology adoption, as high transport costs, poor rural infrastructure, and long distances to urban and peri-urban market centres increase the local farm-gate price of contemporary agricultural inputs such as certified drought-tolerant seed

varieties, specialized machinery, and organic soil amendments (Ricker-Gilbert, Jumpah, and Chamberlin 2023).

Distance also increases information asymmetry and search costs (and transportation costs, as noted above), making it more difficult for smallholders who are remote from markets to obtain inputs or to receive timely advice on agricultural practices from extension agents. This spatial disadvantage is a result of a more general structural constraint. In their respective papers, Ngoma, Angelsen, and Carter (2025) and Barrett (2008) also highlight barriers to economic returns from climate-resilient innovations due to remote infrastructure and to smallholder market participation.

5.4.1.4 Socio-Demographic and Resource Endowment Dynamics

The econometric model was used to investigate the independent effects of the different demographic and resource endowments. The age of the household head, a proxy for farming experience and local environmental conditions, is positively and considerably associated with the adoption of crop diversification (coeff=0.042, $p < 0.05$). The marginal effect implies that each additional year of age increases the likelihood of adoption by 1.3 percentage points.

These older plot managers may be reducing their exposure to production risk through superior knowledge of weather variability, local microclimates, and the skilful management of adaptive farm practices such as conservation tillage. They may be more aware than their younger counterparts of the benefits of retaining moisture and organic matter in the soil. This is consistent with the findings of Feder, Just and Zilberman (1985) that a manager's subjective assessment of and actual implementation of modern agricultural innovations improves with experience.

Total household labour endowment in full-time equivalent units had a positive and important association with technology adoption ($\gamma = 0.284$, $p < 0.05$). Controlling for all other factors, the marginal effect associated with an additional unit of full-time equivalent labour in a household was an increase of 8.8 percentage points in the baseline probability of technology adoption. This outcome has been attributed to the labour-intensive nature of many climate-resilient designs.

Labor-intensive measures such as hand-dug conservation basins, soil condensing, and collection, transport, and redistribution of agricultural crop remains, are most costly to implement in the early phase of a project. On the other hand, households with more available domestic labour can implement labour-intensive improvements without forgoing other tasks or incurring prohibitive labor hire costs. There is evidence from Ngoma, Mason, and Sitko

(2021) and Teklewold et al. (2015) that labour availability is one of the structural factors that support micro-level sustainability of sustainable agricultural packages.

Assessments of the marginal effect of access to formal agricultural credit (Sub-Table 4, Column 2) on technology adoption are positive and marginally statistically meaningful ($\gamma = 0.410$, $p < 0.10$), meaning that, if farmers have access to formal credit, the marginal effect of access to seasonal credit indicates a 12.7 percentage point increase in the baseline probability of adoption.

Under the contract of formal input loans or short-term seasonal finance, smallholders can afford higher-quality inputs and can also afford to absorb the structural risk of a transition away from their customary agricultural systems. Thanks to financial inclusion, smallholders are also able to invest in long-term soil productivity and climate-resilience measures.

5.4.1.5 Non-linear Blinder-Oaxaca Decomposition Metrics

5.4.1.5.1 Disaggregating the Gender Adoption Divide

Although the full-sample Probit model conceals systematic differences between male-headed and female-headed households, it is useful to assess the overall factors that influence adoption. Given the 16.7 percentage point difference in adoption rates between male-headed households, where the baseline level of adoption is much higher, and their female-headed counterparts, we examine gender structural inequalities. To decompose the 16.7 percentage point gap into an explained endowments effect and an unexplained coefficients effect, we apply Fairlie's (2005) non-linear form of the Blinder-Oaxaca decomposition model of Blinder (1973).

The results of this decomposition are given in Table 6.

Table 6 : Non-linear Blinder-Oaxaca Decomposition Results (N = 101)

Decomposition Component	Percentage Point Contribution	Relative Percentage Share (%)	Statistical Significance
Total Observed Adoption Gap	16.7 pp	100.0%	$p < 0.05$
Endowments Effect (Explained)	4.9 pp	29.3%	$p > 0.10$
Coefficients Effect (Unexplained)	11.8 pp	70.7%	$p < 0.01$

Note: Group definitions are grounded on the validated cross-sectional cohort size where $n_1 = 53$ for male-headed households and $n_2 = 48$ for female-headed households.

Using the decomposition results, we find that the systematic resource differences constituting the Endowments Effect explain only 4.9 percentage points (29.3%) of the technology adoption gap that cannot be accounted for by observable characteristics, and this effect is not statistically important ($p > 0.10$). The gender gap in technology adoption is largely due to the Coefficients Effect, which accounts for 11.8 percentage points (70.7%) and is highly important ($p < 0.01$).

5.4.1.5.2 The Endowments Effect vs. The Coefficients Effect

The endowments effect is not statistically important. This suggests that the reason for the plot manager gender technology gap is not the lack of education or labour power. Even when plot managers have the same education level, family labor potential and proximity to input markets, the gender technology gap could still be reduced by less than one third.

The main explanation for the technology adoption gap is the unexplained coefficients effect: an economic construct of sociocultural impediments, systemic institutional bias and discriminatory practices of regional agriculture aid networks. This effect varies according to the structural institutional factors of regional agricultural aid networks, disaggregated through a gender lens.

The institutional return on investment is lower for female smallholders than for males. A male manager is statistically more likely to effectively translate such assets to active technology adoption given a male and female home head with similar educational backgrounds or similar distances to a market centre. This could be due to rural institutions interacting unevenly with different gendered groups in local contexts.

Because of customs and customary land tenure systems, male household heads are more likely to be targeted by formal extension systems and credit assessment systems and input provision systems, while households with female managers of the same fields receive less technical assistance and advice, and are rationed more in their access to loans. The results also support the findings of other studies in East Africa (Maruta and Baiyegunhi, 2026, Kassie et al., 2014) that gender differences are driven by structural differences in institutional returns of smallholder farming systems to sustainable intensification.

5.4.2 Qualitative Triangulation and Narrative Synthesis

5.4.2.1. Key informant interviews (KIIs) findings

This quantitative data was supplemented with qualitative data from key informant interviews with local Agricultural Technical and Extension Services (AGRITEX) personnel, NGO field officers, as well as village-level customary leaders, to better understand the structural biases represented in the coefficients effect.

Interviews with public extension staff suggest that methods of training delivery often serve sex- or gender-biased needs. According to AGRITEX officers, extension meetings and technical demonstration days are often scheduled during working hours which would disrupt women's unpaid family care and household tasks.

Interviews with public extension staff revealed that conventional methods inadvertently prefer male smallholders: meetings and technical demonstration days are often scheduled when they coincide with unpaid care work and domestic responsibilities for women, creating a conflict.

5.4.2.2 Focus Group Discussion (FGD)-based Learning

A better understanding of the sociocultural and customary institutional norms constraining the adaptive capacity of rural women was achieved through focus group discussions. Customary land tenure systems were found to be a major impediment to the adoption of sustainable agriculture technologies. Most of the rural villages in Murehwa District are governed by customary authorities and land is owned under more customary systems of communal tenure mainly controlled by customarily designated male lineage chiefs.

Women are also less likely to invest in long-term climate-resilient food production practices since secure or legal long-term tenure rights are not available. Technologies such as crop rotation systems, conservation tillage and agroforestry require several years of crop seasons and tree care before granting anticipated economic and environmental benefits. However, as some women mentioned, once the labor is invested to create soil structure and organic matter, women would lose access to their field plots if they do not have control over the land tenure.

Focus groups also discussed credit rationing. Collateral, such as control over land or ownership of cattle, is usually held by men under the customary system and is often required by formal institutional financial intermediaries from borrowers in exchange for loans. Women are therefore often forced to use informal savings and lending groups known as mukando, as they are mostly excluded from formal lending markets for agriculture. However, these groups often have little capital available for lending and only provide women with short-term liquidity, lacking funding for larger investments in climate-resilient technologies.

5.5 Conclusions and Policy Implications

5.5.1 Empirical Insights

This paper examines the socio-institutional factors that govern female farmers' adoption of climate-resilient technologies. Using a unique data set of 101 smallholder farm plots in rural Zimbabwe's Murehwa District, we find that geographically bounded transaction costs, structural institutional returns, and crop-specific farmer cooperative networks are the main drivers of technology adoption, as demonstrated by the non-linear Blinder-Oaxaca decomposition and binary Probit model.

In addition to resource transfer, rural development policies must also target the structural coefficient disparities. This account for 70.7% of the 16.7 percentage point gap. Structural institutional injustices, exclusionary practices against women from customary tenure and inadequate extension services, which stifle the potential economic benefits of women's resource endowments, must also be addressed.

5.5.2 Targeted Strategic Interventions

Third, implement specific interventions targeting gender-sensitive, women-led cooperatives. Promote financing and expansion of women-led agricultural cooperatives and marketing cooperatives whose role is to represent the interests of women. For example, women-led cooperatives increase the probability that a female smallholder adopts by 23.1 percentage points. And these groups enable female smallholders to overcome constraints faced by individual women concerning their assets and enable them to share technical knowledge, labour and bargaining power to access quality inputs affordably.

Decentralize agricultural supply chains to reduce spatial transaction costs. Rural development policies should promote decentralized village-level input supply chains to reduce spatial transaction costs of rural market access. Rural market distances negatively influence adoption probabilities; on average, adoption probabilities fall by 1.8 percentage points for every additional kilometre to the market. When input depots are community-managed and operated in tandem with neighbourhood retailers and cooperatives, they are less expensive to operate, and ensure timely, reliable supplies of certified resilient seed and organic soil amendments to remote female smallholder farmers.

Reform Public Extension and Credit methodologies: Financial institutions and extension agencies should implement gender sensitive evaluation and delivery methodologies to overcome the disadvantage evidenced by coefficients effect. Because AGRITEX is highly male dominated, they should employ more female extension officers, use community based peer to peer training methodologies and adapt training schedules to women's daily time schedules. These institutional finance institutions must simultaneously offer female plot managers flexible micro-credits, including the acceptance of guarantees from cooperatives or from the provision of property from women groups.

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CHAPTER 6: GENDERED HETEROGENEITY IN CLIMATE CHANGE IMPACTS: ANALYZING PRODUCTIVITY GAPS, INCOME VARIANCE, AND LABOUR REALLOCATION IN MUREHWA DISTRICT

6.0 Abstract

The main vulnerability channel through which climate change and weather shocks impact agrarian economies in Southern Africa is rainfed agriculture. Less understood is the role that small-scale localized climate shocks play through intra-household gender dynamics in determining labor supply, productivity, and welfare. We examine exposure to climate shocks by smallholder farmers in Murehwa District, Zimbabwe, and the impact of gendered household structures and behaviours with an emphasis on Sustainable Agricultural Practices (SAPs) on farm performance and farm efficiency. We use quantitative cross-sectional micro-level data ($N = 101$), the deterministic farm-budgeting approach and input-oriented non-parametric Data Envelopment Analysis (DEA) under variable returns to scale (VRS).

First, climate shocks interact with seasonal labour demand to promote intensive family labour substitution by independent female managers ($\mu_2 = 3.03$) over female managers ($\mu_1 = 2.79$) in male-headed households at $p < 0.05$. Second, while independent female-headed households reap meaningful grain yield (350 kg) and income (1,091) benefits from intensive labour substitution, resource-poor married women managing plots in joint households experience a vulnerability trap. Third, SAP adoption lowered total variable costs by \$98 per hectare ($p < 0.10$) and increased gross margins under climate-induced shocks ($p < 0.05$). Non-parametric frontier estimations show that SAP adoption increased technical efficiency from 0.61 to 0.75 ($p < 0.01$) and economic efficiency from 0.30 to 0.52 ($p < 0.01$) compared with the non-adoption frontier.

This suggests that climate adaptation policies should, beyond climate-aware technology transfers, a) focus on scaling up targeted investments in smallholder mechanization at appropriate scale and labour-saving levels when extreme female labor constraints exist; and b) support decentralized input and localized grain markets for translating agronomically cost-saving investments into sustainable welfare gains.

Keywords: Gendered heterogeneity; Sustainable intensification; Production efficiency; Climate vulnerability; Zimbabwe.

6.1 Introduction

Institutional and ecological shocks are increasingly compounding in smallholder farming landscapes in Sub-Saharan Africa's semi-arid and sub-humid zones (Ericksen et al., 2011;

IPCC, 2022). This includes more variable timing of the rainy season, and longer mid-season dry spells. It also includes increased ambient temperature and continuing depletion of soil nutrients, particularly in Zimbabwe's smallholder farming sector (Murehwa District) (Brazier, 2015; Mugandani et al., 2012). Together these environmental stressors, when impacting climate-sensitive sectors, directly affects the livelihoods of more than 70% of the rural population, agriculture, household food security, and reduces crop yields across the region.

Climate adaptation technologies such as conservation tillage, drought tolerant germplasm, new leguminous crops, and integrated organic soil fertility management (ISFM) are becoming a key area of focus for national and regional rural development architectures in response to these climate change risks (Pretty et al., 2011; Vanlauwe et al., 2014). Gender issues within the rural economy are critical to the structural transformation and upscaling of these adaptation technologies (Doss, 2013; Rola-Rubzen et al., 2020). Women are customarily responsible for managing many smallholder plots and agricultural labor in rural Zimbabwe, which forms the backbone of agricultural labor and food production, but they are disadvantaged in terms of their socio-economic status. This includes socio-cultural norms, limited access to land and customary land tenure systems, as well as a lack of access to formal institutional support systems (including extension services and assets, such as credit) that determine how female smallholders perceive the impacts of climate shocks and the decisions they make regarding climate-adaptive behaviour (Doss and Morris 2001; Quisumbing et al. 2014).

It means looking not only at the farm, but at how climate change affects the distribution of labour, production and income between families with different family structures. As agricultural economists have pointed out, microeconomic shocks are linked to intra-household labour dynamics (Singh, Squire and Strauss 1986). In high-stress, low-resources contexts, female farmers make physical labor exertion choices to compensate for lack of capital, reflecting systemic asset deprivation (Fafchamps, 2003; Fink, 2024).

Although research on climate change adaptation and agricultural productivity in Southern Africa is generally burgeoning, three key gaps in the literature are to be addressed in this chapter.

Many other studies that attempt to model climate changes impacts do implicitly rely on the standard Unitary Household Model proposed by Samuelson (1956) and Becker (1981). The model assumes that an agricultural household is a homogenous unit maximizing its utility, neglecting the gender dynamics and inequalities within households. Although the focus of the

other studies has been on MHHs and de jure or de facto FHHs (Kassie et al., 2014, 2019; Teklewold et al., 2019), the ultra-vulnerability of married women with plots in MHHs has not been analyzed extensively. The aggregation bias of earlier studies is the result of not disaggregating resource control within MHHs, which hides the structural deprivation of women with plots under the patriarchal control of MHHs and the severe time constraints they face.

Second, empirical studies have often focused on the first-order impact of the climate shock on crop yields or household income (Di Falco et al., 2011), instead of the structural changes in intra-household family labor hours that have to be deployed to maintain these yields. Given the difficulties that can be experienced in labor and credit markets, production and consumption decisions are closely aligned in cases of smallholder production (Benjamin, 1992; Barrett et al., 2008), such that calculations of productivity that ignore the hidden costs incurred by independent female managers will undervalue household welfare, and the vulnerability of the household.

Third, macro-level policy-makers have almost universally heralded SAPs as magic-bullets for adaptation to climate change despite the scant research on their micro-level cost-effectiveness and gender optimization. To date, few studies have bridged the farm budget-based gross margin modelling with non-parametric production frontiers, such as Data Envelopment Analysis (DEA), to assess whether the adoption of SAPs results in a shift in technical and economic efficiency for capital-constrained female managers subjected to higher levels of environmental stress (Chavas et al., 2023).

To fill these gaps, this chapter conducts a comparative microeconomic analysis of labor, yields and income trajectories, a farm-budgeting cost-benefit analysis and a non-parametric frontier efficiency analysis of climate shock heterogeneity within and between MHHs, autonomous FHHs and female plot managers in MHHs. The chapter then identifies structural labour reallocations and income variations due to environmental shocks. It concludes with a disaggregation of the potential cost-savings and operational efficiencies achieved by the adoption of SAPs. By focusing on structural reallocation of labour, cost-saving production economics, and production frontier optimizations, it moves beyond generic technology transfer models to produce meaningful gender-specific insights into Southern African climate adaptation under uncertainty.

6. 2 Materials and Methods

6.2.1 Study area description

To ensure analytical integrity, thematic consistency and avoid the risk of reproducing baseline regional profiles, a thorough summary of the geo-spatial, geo-infrastructure, socio-demographics and agro-ecology of Murehwa District is provided. In brief the geographical position of this eco-region straddling the sub-humid to semi-arid tropical gradients of Natural Regions (NR) II and III of Zimbabwe, makes it an ideal socio-ecological laboratory. Especially with structural rainfall instability, increasing dry spells, and systematic macro-nutrient depletion in soil, the efficacy of SAPs is very dependent on the gendered patterns of access and control of resources in a community.

6.2.2 Research design and sampling frame

The empirical architecture, based in agricultural household models, is a quantitative cross-sectional micro-level survey research design that models the financial returns, agricultural adjustment, and multi-dimensional climate vulnerability of smallholder farming households as a direct, non-separable function of gendered headship configurations, localized asset endowments, and differentiated adoption pathways of agricultural production technologies.

In chapter 3, the implementation of the multi-stage stratified random sampling methodology and the PSM for the stratification of administrative Units and clusters of villages is detailed. The separation of household headship categories (hereafter, MHHs and FHHs) was also implemented in order to minimize the likelihood of structural aggregation bias as well as more accurately capture intra-household gender inequality. In order to meet the computational requirements of our micro-econometric modules, we undertook structural validation and cleaning procedures on our raw field data to produce an optimized analytical sample that we split into two sub-samples:

The sample sizes for the descriptive climate vulnerability, gendered behavioural responses, and labour reallocation analyses, the production economics, the farm budgeting cost architectures, the financial viability matrices, and the non-parametric frontier efficiency analyses were all $N = 101$ household observations.

6. 2.3 Data Collection Procedure

Open data kit applications, administered via mobile-based data collection platforms, were used in the first-stage structured electronic questionnaires. The purpose of automated validation logic, wide-ranging skipping patterns, and in-vivo range checking was to eliminate non-sampling errors at the source and avoid data entry errors from the use of paper-based instruments. The lengthy modules within this questionnaire collected self-reported data on

the dynamics of various operations throughout the entire growing process. These include Labour Allocation Dynamics, records of female labor reallocation in response to climate shocks, Production and Revenue Profiles, household incomes, and the total overall grain harvests. Variable cost architectures include full production costs (certified seeds, fertilizer, tillage services, manure recycling, labour, and agrochemicals). An example of a local market typology is the standardization of local crop prices.

To deal with the three major drawbacks of rural cross-sectional surveys, the fieldwork was carefully designed. Seasonal recall bias was reduced by checking what respondents said against records collected by extension service staff in their village, and the cropping calendars from the community, which provided input prices and labour hour spreads for several months. Second, variable field team deployment was used to reduce physical access challenges posed by sudden infrastructure washouts during localized rainy spells. Third, meaningful community trust was established via customary local leaders to reduce the challenges posed by sensitivity around eliciting private economic indicators such as precise informal income variance and family labour adjustments over time.

6.2.4 The analysis framework and model specification

The empirical analysis was descriptive and based on independent two-sample t-tests across male-headed and female-headed households to test the variation of climate change effects by gender. The analysis adopted a four-point Likert scale from 1 (Decreased) to 4 (Increased Significantly) to measure the change in the allocation of women's labor.

To assess the profitability of shifting from conventional inputs to SAPs under climate stress, a farm budgeting gross margin framework was developed. The following is the deterministic gross margin per hectare equation.

$$GM = GR - TVC.$$

Where:

GM is equal to the Economic Gross Margin.

GR is Gross Revenue, calculated as:

$$GR = Y \times P$$

where Y is the total crop yield, and P is the local commodity floor price, set at 0.40/ kg.

TVC is the sum of cash outlays by farmers, in cash-equivalent terms, on certified seeds, synthetic fertilizers, machinery/tillage hiring, labor, organic manure recycling and agro-chemical applications.

6.2.5 Efficiency Frontier Estimation (DEA)

In order to test the structural technology change and/or operational efficiency effects empirically, a non-parametric DEA model is estimated. Variable Returns to Scale (VRS) input oriented model is used to estimate production frontiers with one output of Total Grain Harvest (Y) measured in kg produced with an input vector (X) of five production inputs: land area (x1), total fertilizer applied (x2), quantity of certified seeds used (x3), labour outlays (x4), and capital traction costs (x_5). The Technical Efficiency (TE) score of the i-th farm unit of the sample of n smallholders is given by solving the following linear programming model:

$$\begin{aligned} \min & \theta \\ \text{subject to} & \end{aligned}$$

Subject to:

$$-y_i + \sum_{j=1}^n \lambda_j y_j \geq 0$$

$$\theta x_{ki} - \lambda_j x_{kj} \geq 0, \quad k = 1, 2, \dots, 5$$

$$\sum_{j=1}^n \lambda_j = 1$$

$$\lambda_j \geq 0, \quad j = 1, 2, \dots, n$$

Here, θ is the efficiency score (where $\theta = 1$ if the firm is efficient and belongs to the production frontier), and λ_j is a vector of weights for each of the linear combinations of the production frontier (the condition $\sum \lambda_j = 1$ enforces the assumption of Variable Returns to Scale (VRS)).

Each input/output bundle can be compared with the non-parametric frontier in three dimensions. Technical Efficiency (TE_i) is defined as the capability of a farm unit (i) to

maximize output with a specific bundle of inputs or to minimize inputs with a fixed output. Economic Efficiency (EE_i) is the price of inputs used for lowest cost production. Allocative Efficiency (AE_i) measures the extent to which farmers use input bundles that are consistent with market prices. It is formulated as the following basic economic identity:

$$EE_i = TE_i \times AE_i$$

This can be rearranged to express allocative efficiency directly as:

$$AE_i = \frac{EE_i}{TE_i}$$

6.3 Results and Discussion

6.3.1. Differential Vulnerability Pathways: Labour, Productivity, and Income Gaps

This section presents and elucidates the mean differences between smallholder plot and headship arrangements in Murehwa District to support how gendered vulnerabilities are revealed through climate change. In this sense, household gender division dynamics are linked to smallholder vulnerability to climate change shocks (Singh, Squire, and Strauss, 1986). Empirical estimates of crop production, income, and female labour reallocations between male-headed and female-headed units are presented in table 5.1.

Table 7: Differential Climate Change Impacts on Labour, Productivity, and Income

Welfare and Labor Domain Pathways	Male-Headed (Mean μ_1)	Female-Headed (Mean μ_2)	Mean Discrepancy (b)
Change in Women's Labour Allocation	2.790	3.030	-0.240 ^{**}
Total Grain Harvest (Kilograms)	317.890	349.660	-31.770 ^{*}
Total Household Income (USD equivalent)	922.750	1,090.590	-167.840 ^{***}
Total Observations (N)	101		

(a) Labour reallocation scale is operationalized as: 1 (Decreased), 2 (Remained Constant), 3 (Increased), 4 (Increased Significantly). Notes: Negative mean discrepancies indicate that female-headed structures experience higher relative stress margins or specific structural dynamics under baseline conditions. Significance levels: * $p < 0.10$, $p < 0.05$, *** $p < 0.01$.

Labour supply adjustments are sharply different between independently but female headed households and female-managed plots within male-headed households; the mean labour shock score is 3.030 for independently headed female households compared to 2.790 for female-managed plots within male-headed households, with a statistically important difference ($b = -0.240$, $p < 0.05$). This indicates that under climate stress when crops fail, independently managed women-headed households are liquidity constrained and are unable to hire hired labour to clear, weed, and manage stressed fields. This means that managers themselves must also increase their physical household labour in the distressed fields (Fafchamps 2003), creating a high opportunity cost, by removing them from other household welfare and reproduction (Fink, 2024).

Apart from the differences in growth rates, total grain production (317.890 kg vs. 349.660 kg) and absolute income (\$922.750 vs. \$1,090.590) differ. The negative mean differences ($b = -31.770$ kg, $p < 0.10$; $b = -\$167.840$, $p < 0.01$) highlight a consequence of smallholder production: female-run plots in male-headed households experience a susceptibility trap. In the case of female-headed, autonomous households, their baseline production increases slightly due to more labour being used for their plots. On the other hand, for commercial plots of joint family households, the family head is given production inputs of a premium to use on their crops such as certified high quality seeds, animal draft traction and synthetic fertilizers, whereas married women of such households tend to have subsistence low-input plots (Quisumbing et al., 2014).

6.3.2 Microeconomic Feasibility: Proven Cost-Benefit Architecture of SAPs

Farm-budgeting tools are used to compare the economic attractiveness of the sustainable agricultural packages to determine why the smallholders used these instead of conventional packages. Avoiding downside risk and regularizing variable spending are the most important factors for smallholders in situations of extreme risk and uncertainty (Ngoma, Angelsen, and Carter, 2025). It then compares structural gross margins, gross revenues, and total variable costs of the adopted SAP setups with these of the customary production modes (Table 5.2).

Table 8: Verified Economic Viability of SAPs vs. Traditional Systems

Financial Component Architecture	Traditional System (0)	Adopted SAP System (1)	Mean Financial Shift (b)

Gross Revenue (USD / Hectare) (a)	121.540	129.260	-7.720
Total Variable Costs (USD / Hectare) (b)	251.690	153.620	98.070*
Economic Gross Margin (USD / Hectare)	-130.150	-24.360	-105.790**
Total Observations (N)	101		

*Source: Model Estimation Outputs. (a) Gross Revenue is valued based on the standardized local commodity market price of USD 0.40/kg. (b) Total variable costs comprehensively include certified seeds, base and top-dressing synthetic fertilizers, micro-dose inputs, specialized manual labour, tractor/machinery tillage services, organic manure, and protective chemicals. Significance levels: * $p < 0.10$, $p < 0.05$, *** $p < 0.01$.*

The most important pathway was the reduction in total variable costs for adopting SAP (b = \$98.070, $p < 0.10$), compared to conventional smallholder systems, which usually employ high cash input levels of synthetic nitrogenous fertilizers and mechanical conventional tillage (\$251.690/ha). The female smallholders who adopted the SAPs replaced the commercial inputs with nitrogen-fixing legume intercrops, recycled organic manures and ripped the soil using minimum tillage. This resulted in a \$153.620/ha reduction in cash variable costs, which freed female smallholders from seasonal cash-flow bottlenecks and credit constraints that are common among the resource-poor households (Feder, Just, and Zilberman, 1985).

Negative gross margins would be generated in both systems (-\$130.150/ha and -\$24.360/ha for customary systems and SAPs respectively). However, the mean treatment effect would be -\$105.790, which is statistically important ($p < 0.05$). This shows that switching to SAP is an unambiguous economic gain in the face of environmental shocks, compared to the baseline. Although the associated revenue gain of climate shocks is low (b = -\$7.720, $p > 0.10$), SAPs minimize the loss of variable cash flows. This reduction in structural costs may explain why resource-poor female farmers choose this method, which de-risks their farm enterprise when liquidity is limited and formal input markets are inaccessible.

6.3.3 Technical, allocative and economic efficiency frontiers

Table 5.3 presents the mean technical, allocative and economic efficiency differential between business as usual (without SAP) and business as usual (with SAP) for the production systems, obtained under different climate stress levels via the non-parametric efficiency

frontiers, enabling further understanding of the efficiency shifts attributable to the adoption of SAP.

Table 9: Efficiency Disparities and Frontiers Between Production Systems

Efficiency Frontier Dimension	Traditional System (0)	Adopted SAP System (1)	Mean Efficiency Shift (b)
Technical Efficiency (TE)	0.612	0.748	-0.136***
Allocative Efficiency (AE)	0.485	0.693	-0.208***
Economic Efficiency (EE)	0.297	0.518	-0.221***
Total Observations (N)	101		

*Notes: Efficiency indices range from 0 to 1, where 1 denotes complete optimization on the frontier boundary. Significance levels: * $p < 0.10$, $p < 0.05$, *** $p < 0.01$.*

The frontier estimates suggest that SAP users considerably improve their technical efficiency from the initial level $\mu_0 = 0.612$ to the level $\mu_1 = 0.748$ ($b = -0.136$, $p < 0.01$), which indicates that the users of SAP are much closer to their maximum possible output frontier at a given level of physical inputs. The principal agronomic practices underlying this improvement are the incorporation of legume intercropping (to organize structural organic nitrogen fixation) and minimum-tillage ripping (to preserve moisture during periods of drought). Together, these practices allow organic agriculture to be more efficient than conventional, customary agriculture in terms of output per unit of input (Chavas, Chambers, and Wall, 2023).

Similarly, the drop in allocative efficiency from $\mu_0 = 0.485$ to $\mu_1 = 0.693$ corresponds to a tight cost-minimizing effect ($b = -0.208$, $p < 0.01$). Traditional adopters operate at very low levels of allocative efficiency relative to the market price, likely due to the over-purchasing of the more expensive synthetic fertilizer and conventional draft tillage. In contrast, the SAP adopters' input use choices of hired labor, commercial fertilizers, and other inputs are instead in line with market prices. In their case, commercial synthetic and chemical fertilizer is replaced with much cheaper recycled manure and biological nitrogen fixation, resulting in positive economic outcomes ($b = -0.221$, $p < 0.01$). This shows how sustainable intensification allows the poor to overcome liquidity constraints via effective input use choices (Coelli et al., 2005).

6.4. Institutional Policy Implications

Three main implications for national agricultural policies and rural development in Southern Africa are to promote SAPs as liquidity-saving safety nets (which lower variable production costs by USD 98.070 per hectare ($p < 0.10$)), to invest in low-cost resilience such as local legume seed systems and organic compost produced at village levels, as opposed to high-cost commercial chemical packages that deepen rather than reduce risks, and to strengthen farmers in marginal areas where commercial adoption is limited.

Requiring labour-saving technology from agricultural extension, as women experience increasing binding labour constraints due to climate shocks (independent female-headed households, $\mu_2 = 3.030$), through subsidized access to scale-appropriate two-wheel tractors fitted with a direct-seeder and rippers, can release peak demands on women at planting and weeding times. This addresses the active tendency of women to be exploited as the childcare and education suppliers of the home.

Regional trade and agricultural ministries can establish regional processing plants and guaranteed floor prices for climate-resilient grains, raising net profits above the baseline market price of USD 0.40/kg, thereby allowing remote female smallholders to escape the local vulnerability trap by converting technical and cost saving benefits of SAPs into predictable profits.

6.5 Conclusions

This chapter illustrates the efficiency of SAPs in smallholder farmers in Murehwa District, Zimbabwe, and the gendered climate change vulnerability. The chapter found asymmetric costs for female self-managers in increasing the demand for female labour but a loss of assets in male-managed households in their female plots after climate change shocks due to the customary way of asset distribution.

Cost-benefit analysis and frontier estimates suggest a substantial impact of the SAPs. SAPs decreased the total variable cost of inputs by USD 98.070 per hectare ($p < 0.10$). Climate variability alone decreased the raw gross revenue of all farming systems. Compared to the conventional input-intensive farms, the SAP technology reduced economic losses and increased the economic gross margin (GM), the technical (TE), the allocative (AE), and the total economic efficiency (EE) considerably under climate stress ($p < 0.01$). Non-parametric frontier analysis showed that under climate stress, SAP technology enabled farmers to achieve higher resource use efficiency. Our results show that technology transfers must not be homogenous, if sustainable intensification is to be scaled out. Development actions targeting labour-saving mechanization and labour-saving agro-ecological techniques must be implemented to shield vulnerable female smallholders in the Murewa region, who will increasingly suffer the effects of climate change.

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CHAPTER 7: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter presents a synopsis of the study on gendered climate vulnerabilities, socio-institutional barriers to technology adoption, and the viability of adaptations of smallholder farming households in Zimbabwe's Murehwa District. Climate change, and its effect on food security, aggregate production and rural livelihoods among semi-arid and sub-humid smallholder farming systems in the Southern African region, remains an immediate threat. Although SAPs are widely regarded as a potential response to the shocks, gender relations and socio-institutional dynamics may drive variation in their adoption and their microeconomic welfare effects.

This thesis employed an integrated multi-method framework of micro-econometric and production economics analysis that included farm-budgeting cost-benefit matrix, the independent two-sample t-tests, the non-linear Blinder-Oaxaca decomposition model and Probit maximum likelihood estimation (MLE) for investigating and analyzing those processes across all the levels of analysis. Consequently, this last chapter contains the main conclusions and general findings as they relate to the research questions, an orderly presentation of policy recommendations for the sector, and the identification of future research directions for the agriculture sector.

7.2 Research Summary

The study's aim was to assess the effect of gender profiles and institutional support on the adoption of climate-resilient agricultural technologies by smallholders in Murehwa District, and to identify structural entry points that would improve the resilience of smallholders to climatic shocks. A task-representative, uniform, and validated sample of $N = 101$ households was used to study the behavioral and econometric modules.

The first stage of the empirical analysis is concerned with the modeling of the socio-institutional conditions determining the adoption of sustainable intensification packages in the chosen regions. Technology adoption is found to positively correlate with regional characteristics and structural institutional networks (maximum likelihood Probit estimates). Access to agricultural cooperatives is important and positively impacts technology adoption ($\gamma = 0.742$, $p < 0.01$), as rural farmer groups are a center for sharing resources and knowledge on technologies. Access to input markets has a negative and meaningful impact on the uptake of technologies ($\gamma = -0.058$, $p < 0.01$). It indicates, too, that household labour

endowments (FTE units) and farming experience (measured by household head age) considerably increased the likelihood of adoption as households adjusted to the relatively high labour and risk that sustainable farming requires.

To better understand the causes of the 16.7 percentage point difference between male- and female-headed households in the second stage, the structural reason was given by Fairlie's non-linear Blinder-Oaxaca decomposition extension. The Endowments Effect only explained 4.9 percentage points (29.3% of the gap) and was not statistically meaningful. The Coefficients Effect, with a statistical importance of $p < 0.01$, accounted for 70.7% (11.8 percentage points) of the inequality in adoption rates. The gap in technology adoption was due to systemic differences in institutional quality and did not reflect differences in financial resources. Since extension services, credit and inputs are biased towards male managers, female smallholders receive much lower returns from their productive resources than their male counterparts.

The third round of analyzes examined the effect of these adoption constraints on climate change vulnerabilities and SAP systems' business case. Descriptive mean comparisons between independent female manager and female plot manager of male-headed farm groups, found that climate shock exposure increased seasonal labor demand more on independent female managers ($\mu_2 = 3.03$, $p < 0.05$) than on female plot manager of male-headed farms ($\mu_1 = 2.79$), buffering agricultural production. Another institutional resource trap was that female managers of male-headed households lost control of prime inputs, which were used on the male head's commercial cash-crop plots.

The economic justification of reducing these negative effects through the application of the SAP package was strong. The farm budgeting cost-benefit analysis showed a decrease of U.S. \$98.07 ($p < 0.10$) in the variable cost of production per hectare when SAPs were used instead of input-intensive systems. SAP adopters reduced farm costs by using legume intercrops to replace costly synthetic nitrogenous fertilizers, ripping in minimum tillage to replace mechanical tillage, and recycling organic manure to replace purchased manure. SAPs, by cost-saving mechanism, maximized economic gross margins under climate stress, but the increases in farm revenues were lower ($p < 0.05$) under higher climate stress. The adoption of SAP increases TE from 0.61 to 0.75 ($p < 0.01$) and EE from 0.30 to 0.52 ($p < 0.01$). Using non-parametric frontier, this suggests that sustainable intensification can be a useful economic safety net for cash constrained smallholders.

7.3 Conclusions

Some definite conclusions of this study are that it is difficult for smallholders to adopt climate resilient agricultural technologies alone. Although local cooperatives help to reduce risk dislike and information bottlenecks, adoption remains low and limited to households located around rural infrastructure hubs. This is explained by distance from major input markets and therefore high transaction costs relative to the technical potential of conservation agriculture. The findings suggest that customary asset-distribution policies do not work for this case, because the coefficients effect alone accounts for 70.7 percent of the adoption gap. The difference between male and female farmers in the adoption of sustainable practices may be explained by factors such as the lack of access to labour networks, land and education for female farmers. To close the gender gap, efforts should focus on addressing local-level constraints including governance, financial institutions and extension services. Climate shocks can further reduce access to farm labour in rural areas and weaken women's farmers who work alone as managers' abilities to hire off-farm labour by limiting their access to finance. Though the SAP products can fall short of marketable cash profits, they are still helpful from a microeconomic standpoint, reducing variable cash costs by \$98.07 per hectare in dry years. The function makes an economic efficiency increase, increases financial security, and prevents households with limited resources from severe cash crunch during climate shocks.

7.4. Policy Implications and Recommendations

To accelerate the uptake of sustainable agriculture and climate resilience in Murehwa District and other smallholder farming areas in Zimbabwe, the following policy recommendations are made:

In Using SAPs as a Financial Safety Net to Reduce Farm Production Risk, the SAP packages reduce VICS by \$98.07 ($p < 0.10$) per hectare. SAPs should be considered as a way to lower the risk of agricultural production in national farm assistance programs. Public subsidies should not be used in expensive fertilizer packages that rely heavily on chemicals. Investments could reduce smallholders' exposure to external market shocks by encouraging decentralized production networks for legume seed and organic compost facilities at the village level.

Agricultural ministries and development agencies must provide access to scale-appropriate mechanization, as climate shocks disproportionately increase the labor burdens on autonomous female managers ($\mu_2 = 3.03$). Providing subsidized access to scale-appropriate 2W tractors fitted with both direct seeders and ripping implements during the peak planting and weeding periods will alleviate these key labor bottlenecks, release women for off-farm employment, and improve welfare in recipient households.

The results indicate that public extension models should be revised as data decomposition of non-linear effects shows that unequal returns to institutions account for 70.7% ($p < 0.01$) of the gender adoption gap. Agricultural extension organizations should promote female-led cooperatives and set quotas for male and female training participants. This ensures technical information, credit programs and knowledge of adaptations are available equally to females managing plots and those managing them as heads of larger households.

By investing in decentralized supply hubs, the ministry of agriculture can reduce the effect of remoteness of the input market ($\gamma = -0.058$), thereby allowing smallholders to capture the input cost savings of SAPs through local price floors for climate-adapted grains (at or above the \$0.40 per kilogram reference price floor).

7.5 Future Research Directions

Despite the usefulness of the analyzed data on gender, gross margin, and barriers to adoption, several aspects could have been researched further. The data were cross-sectional, preventing an analysis of the trend of climate change over time. Future research could model the evolution of gender norms, cost-benefit ratios, and technology adoption trajectories through multiple drought-recovery cycles using multi-year panel datasets and combining household surveys with geospatial data and remote sensing. Spatial autoregressive models could be applied to investigate the relationship between transit distance, rainfall variability, and local soil degradation contours, and smallholders' adoption of practices that improve resilience to drought. Although plot managers and headship categories were described here, further research is needed on intra-household power dynamics characteristic of such settings. In particular, the understanding of technology uptake barriers may benefit from investigating the transfer of decision-making power between couples in labour allocation, input purchase, and the distribution of income in joint households. More research is needed into scaling out sustainable intensification at the market level. Important issues in this area include the

functioning of input supply chains, the confidence of microcredit schemes, and the impacts of regional trade policies on the market price of climate resilient food crops in Zimbabwe.

APPENDICES

Appendix 1: Survey Questionnaire

SURVEY: QUESTIONNAIRE

SECTION 1: ADMINISTRATIVE METADATA & INFORMED CONSENT

Enumerator: Complete this section entirely before beginning the interview. Ensure the respondent is in a comfortable, private setting.

1.1. Survey Identification & Geolocation

Variable Name	Data Item	Entry Field / Response
hh_id	Unique Household ID	
enum_name	Enumerator Name / Code	
surv_date	Date of Interview	[//2026]
time_start	Time Started	[: AM/PM]
dist_name	District	Murehwa
ward_no	Ward Number	
vill_name	Village Name	
gps_coord	GPS Coordinates	

1.2. Verbal Disclosure & Ethical Consent

Enumerator: Read the disclosure below clearly. You MUST receive a YES to proceed.

Good day. My name is _____, and I am a research assistant working with Clemence Mapika, a MSc Candidate from the Bindura University of Science Education (BUSE).

We are conducting a study to understand how sustainable farming practices and mechanization affect food security and the lives of women and men here in Murehwa. Your

participation is voluntary, and your answers are strictly confidential. This will take 30–40 minutes. Do you agree to participate? (Yes/No)

1.3. Respondent Profile

Variable Name	Item	Field / Response
resp_name	Name of Respondent	
resp_phone	Phone Number (Optional)	
resp_rel	Relationship to HH Head	[1] Head [2] Spouse [3] Child [4] Other
lang_int	Language of Interview	[1] Shona [2] English [3] Other:

SECTION 2: HOUSEHOLD ENDOWMENT, INSTITUTIONS & GENDERED AGENCY

Enumerator: This section must be answered by the Household Head or the primary female decision-maker.

2.1. Human Capital & Household Composition (Objectives 1, 2 & 3)

Description	Response / Entry Field	Variable Name
Sex of Household Head	[1] Male [2] Female	hh_sex
Age of Household Head	[_____] Years	hh_age
Farming Experience	[_____] Years	farm_exp
Years of Formal Education	[_____] Years	educ_yrs
Marital Status	[1] Monogamous [2] Polygamous [3] Single [4]	mar_stat

	Widowed [5] Divorced	
Household Size (Total)	[] Members	hh_size
Active Farm Laborers	[] (Adults 15-64 years)	labour_av
Dependency Ratio	[Children <15 + Elderly >64] / [Active Adults]	dep_ratio

2.2. Livestock Inventory & Draft Power (Wealth Proxy - Objective 2 & 4)

Used to calculate Tropical Livestock Units (TLU) and determine mechanization constraints.

Variable Name	Livestock Category	Total Count	Primary Purpose	Draft Power? (1=Y, 0=N)
lvstk_oxen	Oxen / Bulls	[]	Draft / Capital	[]
lvstk_cows	Cows / Heifers	[]	Milk / Breeding	[]
lvstk_goats	Goats	[]	Sale / Meat	N/A
lvstk_sheep	Sheep	[]	Sale / Meat	N/A
lvstk_pigs	Pigs	[]	Sale / Meat	N/A
lvstk_poultry	Poultry (All types)	[]	Meat / Eggs / Income	N/A
lvstk_donkey	Donkeys	[]	Transport / Draft	[]
lvstk_other	Other (Rabbits/Bees)	[]	Diverse	N/A

2.3. Institutional Access & Support Systems (Objective 2: Constraints)

Captures the external variables that constrain or facilitate women's capacity to adopt.

Institutional Variable	Response / Entry Field	Code
Extension Contact	Contacts in last 12 months: []	ext_freq

Gender of Officer	[1] Male [2] Female	ext_sex
Credit Access	Did you apply for a loan last season? [1] Yes [0] No	crd_app
Credit Constraint	If NO: [1] No collateral [2] Debt fear [3] Spouse refused [4] No info	crd_cons
Market Distance	Distance to nearest input shop (km): [_____]	mkt_dist
Information Access	Weather/Market alerts via phone/radio? [1] Yes [0] No	info_acc
Group Membership	Is female head in: [1] Farmer Group [2] VSLA [3] Co-op [0] None	grp_mem
Leadership	Does female head hold a community leadership role? [1] Yes [0] No	lead_role

2.4. Gendered Agency & Decision-Making (Objectives 2 & 3)

Crucial for identifying Cultural Factors and Intra-Household Power Dynamics.

Decision/Agency Variable	Response Options	Code
Land Control	Name on land permit/offer letter? [1] Husband [2] Wife [3] Joint [4] Other	land_name
Technology Choice	Decision maker for adoption (e.g. ripping)? [1] Male [2] Female [3] Joint [4] Male after consult	tech_dec
Expenditure Control	Who decides how crop income is spent? [1] Male [2] Female [3] Jointly	inc_dec
Input Purchase	Who decides which seeds/fertilizers to buy? [1] Male [2] Female [3] Jointly	input_dec

SECTION 3: ADAPTATION DYNAMICS, CLIMATE STRESSORS & PRODUCTIVITY

3.1. Exposure and Sensitivity to Climate Stressors (Objective 3)

Enumerator: Record the occurrence and impact of stressors over the last 5 years (2021–2026).

Variable Name	Stressor Type	Occurred? (1=Yes, 0=No)	Freq (Years /5)	Severity (1=Low, 5=Total Loss)
str_dryspell	Prolonged Mid-season Dry spells	[]	[/ 5]	[1] [2] [3] [4] [5]
str_lateonset	Late onset of rainy season	[]	[/ 5]	[1] [2] [3] [4] [5]
str_heatwave	Extreme Heatwaves (at flowering)	[]	[/ 5]	[1] [2] [3] [4] [5]
str_floods	Flash floods / Heavy leaching	[]	[/ 5]	[1] [2] [3] [4] [5]
str_pests	Climate-related pests (e.g. FAW)	[]	[/ 5]	[1] [2] [3] [4] [5]

3.2. Differential Impacts on Labor and Income (Objective 3)

This measures how climate shocks specifically affect women's time-poverty and financial agency.

Variable Name	Impact Question	Response Options (Select One)	Code
labour_women	Change in Women's Labor during shock	[1] Decreases [2] No Change [3] Increases [4] Increases Sig.	1-4
labour_men	Change in Men's Labor during shock	[1] Decreases [2] No Change [3] Increases [4] Increases Sig.	1-4

inc_sensitivity	Whose personal income is diverted first?	[1] Men's [2] Women's [3] Both equally [4] HH Savings	1-4
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3.3. Adoption of Sustainable Agricultural Practices (Objective 1 & 2)

Enumerator: Record adoption details for the current/most recent cropping season.

Variable Name	Adaptation Strategy	Adopted? (1/0)	Area (Ha)	Years Using	Decision (M/W/Joint)
adopt_rip	Minimum Tillage (Ripping)	[]	[_____]	[_____]	[1] [2] [3]
adopt_basin	Basins / Potholing	[]	[_____]	[_____]	[1] [2] [3]
adopt_seed	Drought-Tolerant Varieties	[]	[_____]	[_____]	[1] [2] [3]
adopt_mech	Mechanized Shelling/Threshing	[]	[_____]	[_____]	[1] [2] [3]
adopt_div	Crop Diversification	[]	[_____]	[_____]	[1] [2] [3]
adopt_mulch	Soil Cover (Mulching)	[]	[_____]	[_____]	[1] [2] [3]

3.4. Dis-adoption Barriers: If you stopped using a practice, why?

[1] High costs [2] Lack of skill [3] Spouse/Head disapproval [4] Equipment unavailability

3.5. Technical Efficiency & Comparative Productivity (Objective 4)

Enumerator: This compares a Traditional plot (Control) and a Sustainable plot (Treatment) for the same household.

Production Variable	Plot A: Traditional (Control)	Plot B: Sustainable/Adapted (Treatment)
Plot Manager	[1] Male [2] Female [3] Joint	[1] Male [2] Female [3] Joint

Planting Date	[DD/MM/YYYY]	[DD/MM/YYYY]
Total Fertilizer (kg)	[] kg	[] kg
Hired Labor (Days)	[] Days	[] Days
Machine Hire (USD)	\$[]	\$ []
Total Harvest (kg)	[] kg	[] kg
Harvest Condition	[1] Poor [2] Fair [3] Good	[1] Poor [2] Fair [3] Good

SECTION 4: ECONOMIC VIABILITY, LABOR ALLOCATION & INPUT COSTS

Enumerator: This section requires high precision. If the respondent does not know the exact cost, ask for the quantity and the unit price at the time of purchase.

4.1. Variable Input Costs (Comparative Plot Analysis)

Variable Name	Input Item	Plot A: Traditional (Control)	Plot B: Sustainable (Treatment)
cost_seed	Seed Cost (Total \$)		
cost_fert	Fertilizer Cost (Total \$)		
cost_manure	Manure/Compost (Value/Cost)		
cost_chem	Herbicide/Pesticide (\$)		
cost_hire	Equipment Hire (e.g., Tractor)		
cost_maint	Fuel/Maintenance (If owned)		

4.2. Labor Allocation & Burden (Objective 3 & 4)

Measurement: 1 Man-Day = 8 hours of work. Record total days and the primary person performing the task.

Activity	Trad. Plot (Days)	Sust. Plot (Days)	Primary Worker (Code)
Land Preparation			[1] Men [2] Women [3] Hired
Planting			[1] Men [2] Women [3] Hired
Weeding (Manual/Chem)			[1] Men [2] Women [3] Hired
Fertilizer Application			[1] Men [2] Women [3] Hired
Harvesting			[1] Men [2] Women [3] Hired
Threshing/Shelling			[1] Men [2] Women [3] Hired
Total Hired Labor Cost	\$[_____]	\$ [_____]	<i>Total cash paid for season</i>

4.3. Output, Utilization & Market Participation (Objective 4)

Variable Name	Production/Market Variable	Plot A: Traditional	Plot B: Sustainable
yield_tot	Total Yield Harvested (kg)	[_____] kg	[_____] kg
yield_home	Amount Kept for Home Use (kg)	[_____] kg	[_____] kg

yield_sold	Amount Sold at Market (kg)	[_____] kg	[_____] kg
price_avg	Average Selling Price (per kg)	\$[_____]	\$ [_____]
mkt_type	Main Market Type	[1] Local [2] GMB [3] Private	[1] Local [2] GMB [3] Private

4.4. Gender-Specific Economic Barriers (Objective 2)

Economic Barrier Variable	Response Options	Variable Name
Resource Prioritization: If money is limited, which plot receives inputs first?	[1] Male-headed/Main plot [2] Women's plot [3] Distributed equally	res_prior
Hidden Costs (Opportunity Cost): Did you reduce time on petty trade/childcare to meet labor needs?	[1] Yes, significantly [2] Yes, slightly [3] No change	opp_cost
Input Access Gap: Did you fail to apply recommended fertilizer due to lack of personal funds?	[1] Yes [0] No	input_gap

SECTION 5: GENDERED LABOR DYNAMICS, TIME USE & AGENCY

Enumerator: This section requires a Time-Use Recall. Ask the respondent to think about the most recent Peak Season (e.g., the weeks of land preparation or weeding).

5.1. Peak Season Activity Profile (Objective 3: Labor Burden)

On average, how many hours per day does each group spend on these tasks during the busiest week of the season?

Agricultural Activity	Adult Women (Hrs/Day)	Adult Men (Hrs/Day)	Children/Hired (Hrs/Day)
5.01. Land Prep (Tillage/Digging)			
5.02. Planting & Sowing			
5.03. Manual Weeding			
5.04. Applying Inputs (Fertilizer/Manure)			
5.05. Pest/Disease Control			
5.06. Harvesting			
5.07. Threshing, Shelling & Cleaning			
5.08. Transporting to Market/Home			

5.2. Domestic & Reproductive Labor

Enumerator: This sub-section assesses the Double Burden by measuring non-farm labor that competes with agricultural production.

Labor Category	Average Hours Per Day
Water & Fuel: Fetching water and firewood	[] Hours
Care Work: Cooking, cleaning, and childcare	[] Hours
Processing: Food processing (milling/pounding)	[] Hours

5.12. Labor Substitution (Time Use): If a new technology (e.g., mechanized sheller or tractor) is used, what does the woman primarily do with the time saved?

[1] Resting/Leisure [2] Working on other crops [3] Petty trade/Business [4] More domestic chores

5.3. Intra-Household Agency & Power Dynamics (Objective 2: Cultural Constraints)

Decision-Making Variable	[1] Husband	[2] Wife	[3] Jointly	[4] Husband after consulting Wife
Input Choice: Final decision on seed/fertilizer	[]	[]	[]	[]
Output Control: Deciding amount sold vs. kept	[]	[]	[]	N/A
Income Autonomy: Who keeps/manages the cash?	[]	[]	[]	N/A

5.4. Knowledge Custodianship: Do you feel your traditional knowledge (e.g., seed saving) is respected in household farming decisions?

[1] Always [2] Sometimes [3] Never

5.5. Access to Productive Assets (Objective 2: Institutional Barriers)

This table identifies the gendered asset gap for key agricultural technologies.

Asset Type	[1] Personally Own	[2] Guaranteed Access	[0] No Access
Hand Tools (Hoes, Machetes, etc.)	[]	[]	[]
Draft Animals (Oxen, Donkeys)	[]	[]	[]
Knapsack Sprayer	[]	[]	[]
Mechanized Equipment (Sheller/Mill)	[]	[]	[]

5.6. Cultural Taboos: Are there specific agricultural tasks or modern tools (e.g., tractors) that women are culturally discouraged from using in this area?

[1] Yes [0] No | *If yes, specify:* _____

SECTION 6: PERCEPTIONS, TRADITIONAL KNOWLEDGE & ADAPTIVE CAPACITY

Enumerator: This section captures the respondent's subjective experience. It is critical for explaining the Why behind the adoption data in previous sections.

6.1. Perception of Strategy Effectiveness (Objective 4: Economic Viability)

Variable Name	Strategy	Effectiveness Rating (1=Low, 5=High)	Reason for Rating (Brief Code)
eff_conv	Conventional Tillage (Hoing)	[1] [2] [3] [4] [5]	
eff_rip	Mechanized Ripping	[1] [2] [3] [4] [5]	
eff_seed	Drought-Tolerant Seeds	[1] [2] [3] [4] [5]	
eff_mulch	Mulching / Soil Cover	[1] [2] [3] [4] [5]	

6.2. Ecological Knowledge & Indigenous Systems

This validates your thesis point regarding women as custodians of vital ecological knowledge.

Variable Name	Knowledge Variable	Response Options	Code
seed_sov	Seed Sovereignty	[1] All Saved [2] Mostly Saved [3] Half/Half [4] Mostly Bought	1-4
know_src	Primary Knowledge Source	[1] Extension/NGO [2] Elders/Tradition [3] Neighbours	1-3

crit_sel	Selection Criteria	[1] Yield [2] Taste/Nutrition [3] Drought Resistance	1-3
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6.3. Barriers & Social Inclusiveness (Objective 2: Constraints)

What is the SINGLE biggest barrier preventing you from adopting more climate-resilient practices?

Variable Name	Constraint Category	Specific Barrier (Example)	Priority (Tick One)
cons_econ	Economic	Lack of cash for inputs/machinery hire	[]
cons_inst	Institutional	Lack of reliable extension or technical training	[]
cons_cult	Cultural	Spousal disapproval or social stigma for women	[]
cons_infra	Infrastructural	Poor road access or lack of water for irrigation	[]

6.4. Future Aspirations & Policy Needs (Thesis Recommendations)

If you could choose one form of support to improve your resilience, which would it be?

Variable Name	Support Type	Rank (1=Highest, 4=Lowest)
pref_mech	Gender-Responsive Mechanization (Affordable hire)	[]
pref_fin	Financial Inclusion (Women-only savings/VSLA)	[]
pref_info	Information Equity (Weather/market phone)	[]

	alerts)	
pref_land	Institutional Rights (Land titles in women's names)	[]

6.5. Resilience Outlook

Variable Name	Item	Response
res_conf	Future Confidence: How confident are you that your household will be food secure 5 years from now?	[1] Not at all [2] Slightly [3] Neutral [4] Confident [5] Very Confident

SECTION 7: MULTI-DIMENSIONAL FOOD SECURITY ASSESSMENT

7.1. Household Food Insecurity Access Scale (HFIAS)

Past 30 Days. Frequency: 1=Rarely (1-2 times), 2=Sometimes (3-10 times), 3=Often (>10 times).

In the past 30 days...	Occur (0/1)	Freq (1-3)	Variable Name
Worry household would not have enough food?	[]	[]	hf_worry
Unable to eat preferred foods?	[]	[]	hf_pref
Eat a limited variety of foods?	[]	[]	hf_vari
Eat foods you really did not want to eat?	[]	[]	hf_unwant
Eat a smaller meal than you felt you needed?	[]	[]	hf_small
Eat fewer meals in a day?	[]	[]	hf_fewer
No food of any kind in the household?	[]	[]	hf_none
Go to sleep at night hungry?	[]	[]	hf_sleep

Go a whole day/night without eating anything?	[]	[]	hf_daynight
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7.2. Household Dietary Diversity Score (HDDS)

24-Hour Recall. Inside the home only. Mark '1' if any member consumed.

Food Group	Examples	Consumed (0/1)
Cereals	Maize, sorghum, millet, rice, bread	[]
Tubers/Roots	Sweet potatoes, yams, cassava	[]
Vegetables	Leafy greens, rape, pumpkin, carrots	[]
Fruits	Mango, guava, wild fruits, citrus	[]
Meats	Beef, pork, poultry, goat, offals	[]
Eggs	Chicken or duck eggs	[]
Fish	Fresh/dried fish, kapenta	[]
Pulses/Nuts	Beans, cowpeas, groundnuts, roundnuts	[]
Milk Products	Fresh milk, sour milk (amasi), yogurt	[]
Oils/Fats	Cooking oil, butter, margarine	[]

7.3. Reduced Coping Strategies Index (rCSI)

Past 7 Days. Record number of days (0–7) strategy was used.

Strategy	Days (0-7)	Weight	Variable Name
Rely on less preferred/expensive food?	[/ 7]	1	rcsi_pref
Borrow food / help from friends/relatives?	[/ 7]	2	rcsi_borr
Limit portion size at mealtimes?	[/ 7]	1	rcsi_size

Restrict adult consumption for children?	[/ 7]	3	rcsi_kids
Reduce number of meals eaten in a day?	[/ 7]	1	rcsi_meal

Appendix 2: Key Informant Interview (KII) Guide

Project Title: Rural Women's Adaptive Agency: Sustaining Food Security and Agricultural Production Efficiency under Climate Stress in Murehwa District, Zimbabwe.

Interviewer Protocol

- **Respondent Profile:** Name, Designation/Organization, Ward/Village, Years of Experience.
- **Logistics:** Date and time of interview, interviewer details.
- **Note to Interviewer:** *Adapt these questions based on the respondent's specific role (e.g., Agritex officer, NGO project coordinator, local community leader, or policy maker).*

Section A: Agricultural Systems and Climate Vulnerability

1. **Production Dynamics:** What are the dominant agricultural enterprises in this ward, and how has the production landscape evolved over the past decade?
2. **Climate Sensitivity:** Which climatic shocks are most prevalent (e.g., intra-seasonal dry spells, heat stress, erratic rainfall), and how are they impacting crop yields and livestock health?
3. **Differentiated Impacts:** How do climate risks disproportionately affect specific demographics, particularly regarding the gendered experience of environmental stress?

Section B: Sustainable Agricultural Practices (SAPs)

4. **Adoption Landscape:** Which climate-smart practices are currently prioritized in this district? What is the current status of adoption rates?
5. **Drivers and Barriers:** What are the primary socioeconomic, cultural, or institutional barriers inhibiting the adoption of sustainable practices?
6. **Structural Constraints:** How do differentials in access to land, labor, information, and financial credit shape a household's ability to transition to sustainable farming?

Section C: Mechanization and Production Efficiency

7. **Technology Access:** Evaluate the current availability and ownership patterns of mechanization services (e.g., tractor hire, motorized planters, threshers).
8. **Gendered Access:** Are there systemic barriers that prevent women from accessing and utilizing agricultural technology?
9. **Labor-Saving Potential:** To what extent does mechanization effectively reduce the labor burden for women? How does it reconfigure the gendered division of agricultural labor?

Section D: Gender Agency and Socio-Economic Power

10. **Resource Governance:** How is the control of land and agricultural income typically structured within households?
11. **Decision-Making Power:** To what extent are women empowered in agricultural decision-making processes? How have these power dynamics evolved in recent years?
12. **The "Double Burden":** How do domestic responsibilities compete with women's agricultural production, and how do they navigate these competing time demands?

Section E: Institutional Support and Food Security

13. **Extension Efficacy:** How accessible and inclusive are agricultural extension services? Are these services currently designed to address the specific technical needs of women farmers?
14. **Food Security Pathways:** What are the primary drivers of food insecurity in Murehwa? Based on your observations, what is the correlation between sustainable practices/mechanization and improved household resilience?
15. **Policy/Intervention Gaps:** What targeted interventions or policy shifts are required to bolster the adaptive agency of women farmers in this district?

Closing

- **Final Synthesis:** Given your experience, what is the single most critical factor needed to enhance the synergy between climate resilience, mechanization, and women's food security in this district?

Appendix 3: Focus Group Discussion (FGD) Guide

Project Title: Rural Women's Adaptive Agency: Sustaining Food Security and Agricultural Production Efficiency under Climate Stress in Murehwa District, Zimbabwe.

1. Logistics and Participant Profiles

To ensure diverse perspectives and minimize power imbalances, participants should be stratified into the following groups:

- **Groups:** Women-only, Men-only, Youth-only (inclusive), and Mixed-gender groups.
- **Size:** 8–12 participants per session.
- **Time Commitment:** 90–120 minutes per session.

2. Discussion Guide

I. Community Climate and Livelihood Context

- **Icebreaker:** Participants introduce themselves and their primary farming activities.
- **Livelihood Landscape:** What are the dominant economic activities sustaining this community?
- **Climate Trajectory:** Reflecting on the last decade, how has the local climate changed, and what impacts are visible in crop and livestock production?
- **Socio-Economic Vulnerability:** Which households (e.g., female-headed, elderly, resource-poor) are most exposed to climate shocks, and why?

II. Adaptive Practices and Technological Agency

- **Adaptation Strategies:** What specific climate-smart practices are farmers implementing?
- **Diffusion Factors:** Discuss the barriers and enablers affecting the adoption of these practices. What benefits have been observed?
- **Mechanization Inventory:** What level of technology is currently available in the district (e.g., tractors, planters, threshers, animal draft power)?
- **Access Dynamics:** How is mechanization accessed? Evaluate the disparities in service access who benefits, who is marginalized, and what are the structural/gendered barriers (e.g., cost, distance, availability)?

III. Gendered Roles and Structural Barriers

- **Division of Labor:** How are roles distributed between men and women? Have these roles undergone recent shifts?
- **Decision-Making Authority:** How is agricultural decision-making power distributed at the household and community levels?
- **The Gender Gap:** What challenges do women face regarding equitable access to:
 - Land tenure
 - Financial credit and inputs
 - Agricultural extension services
- **Labor Burdens:** How do women manage the "double burden" of farm labor and domestic responsibilities (e.g., childcare, food preparation, community service) during peak production periods?

IV. Food Security and Resilience Pathways

- **Conceptualizing Security:** How does the community define "food security"?
- **Coping Strategies:** During periods of food scarcity, what survival strategies do households employ (e.g., diet modification, distress asset sales, casual labor, migration)?
- **Evaluation of Impact:** To what extent have sustainable farming practices or mechanization significantly improved household food availability and income?
- **Resilience Support:** What priority support mechanisms (policy, technical, or social) are required to bolster agricultural resilience, with a specific focus on the needs of women farmers?

V. Concluding Remarks

- **Open Floor:** Is there any critical information or local nuance regarding farming and resilience that we have not addressed?