Biochar in Smallholder Farming in Kenya: A Qualitative Study of Farmers’ Perceptions, Sustainability Considerations, and Adoption Challenges

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Abstract

Smallholder farmers in Kenya face interconnected environmental and socio-economic pressures such as erratic rainfall, prolonged droughts, seasonal floods, and soil degradation that undermine crop productivity, threatening their food security and livelihoods. In response, several field trials and clean energy initiatives in Kenya have introduced biochar for improving soil conditions, boosting yields, cleaner cooking fuel and mitigating climate change. Yet uptake among smallholders remains low. Existing research largely emphasises agronomic and climate outcomes, offering little understanding of how farmers view biochar in relation to their daily sustainability challenges. Without this perspective, dissemination may remain top-down and poorly aligned with local realities, limiting meaningful uptake. Drawing on qualitative methods, specifically focus group discussions and key informant interviews, this study investigates how smallholder farmers in Embu and Kwale counties perceive sustainability, situate biochar within these local dimensions, and identify barriers and enablers to its adoption.

Reflective thematic analysis of the study revealed that farmers' understanding of sustainability is grounded in lived realities expressed through continuity, resilience, and dignity amid precarious ecologies, fragile economies, and institutional neglect.

Biochar emerged as both a promising agricultural input and a symbolic source of hope. Farmers valued it for improving soil fertility, water retention, pest control, yields, reducing chemical fertiliser dependence, and enhancing agency. Engagement was shaped by visible results, hands-on experimentation, and peer learning. Experiences varied: farmers gained confidence through trials, while farmers new to biochar relied on community narratives, and youth viewed biochar entrepreneurially. Women acknowledged its health benefits as a cleaner cooking fuel; however, food security remained the overriding priority. While institutional actors often prioritise material needs, they frequently overlook farmers' emotional and symbolic dimensions like trust, hope, autonomy, and a sense of control, which shape cautious engagement with innovations and their adoption.

Adoption was uneven, influenced more by social, emotional, cultural, and institutional realities than technical performance. Limited access to knowledge, training, gender norms, and resource constraints shaped uptake, showing that willingness is not the barrier; systemic inequalities and institutional gaps are. Top-down initiatives, hesitation toward external actors, and past experiences with soil-degrading fertilisers fostered cautious innovation, while farmers' demand for ongoing training reflected a desire to build self-resilience and autonomy. Persistent gendered expectations linked biochar use to women's domestic roles, embedding adoption within broader social structures. Turning biochar's promise into practice requires sustained, farmer-centred training, gender-sensitive approaches, supportive institutional relationships, and equitable access to feedstock, markets, and guidance. Adoption is shaped not only by material capital and observable results but also by social influence, affective experiences, and power dynamics. Hope, frustration, and dignity play influential roles. Integrating technical, social, and institutional perspectives can help biochar move from fragile experimentation toward sustainable agricultural transformation, benefiting local livelihoods and contributing to climate change mitigation.

Keywords: Biochar Adoption, Climate Change Mitigation, Smallholder Farmers, Sustainable Development, Sustainability Perceptions.

Table of contents

List of figures: 6

Abbreviations: 7

1. INTRODUCTION 8

1.1. Background for the study 8
1.2. Biochar projects in Kenya 9
1.3. Statement of the problem and Scope 11
1.4. Research aim and Research questions 12

2. LITERATURE REVIEW 13

2.1. Understanding Sustainability and Sustainability Issues in Rural Kenya: Agricultural Systems, Energy and Climate Change Impacts 13
2.2. Biochar- properties and potential 13
2.3. Biochar Adoption and Research Gaps 16

2. THEORETICAL AND CONCEPTUAL FRAMEWORK 18

3.1. The Sustainable Livelihoods Framework 18
3.2. Diffusion of Innovations 19
3.3. Unified Theory of Acceptance And Use of Technology 19

4. METHODOLOGY 21

4.1. Study area 21
4.2. Research Design 23
4.3. Sampling Frame and Method 23
4.5. Data collection 25
4.6. Data Analysis 27
4.7. Ethical considerations 28

5. FINDINGS 29

5.1. Local Understandings of Sustainability 29
Theme A: Sustainability as Continuity and Resilience 29
Theme B: Sustainability as Lived Realities Shaped by Daily Challenges 31
5.2. Farmers' Perceptions and Experiences of Biochar 34
Theme A: Shared Promise, Uneven Knowledge, Local Experimentation 35
Theme B: Tangible Gains and Symbolic Hope 36
Theme C: Restricted Choice, Scarcity and Gender 38
5.3. Barriers to Biochar Adoption - Navigating Structural Constraints and Social Realities 41
Theme A: Uneven Access to Knowledge - A call for training and self-reliance 41

Theme B: Resource, Financial and Structural Constraint - The Scarcity Trap.......42
Theme C: Intersecting Social Dynamics - Constrained Decisions across Generations and Gender.......43

6. DISCUSSION 45

6.1. Sustainability as Lived Experience 45
6.2. Biochar in Practice: Perception of Smallholder Farmers 47
A: Shared Promise, Uneven Knowledge, Local Experimentation 47
B: Tangible Gains and Symbolic Hope.......48
C: Restricted Choice, Scarcity and Gender.......49
6.3. Barriers to Biochar Adoption – Navigating Structural Constraints and Social Realities 50
A: Knowledge Gaps and Institutional Failures: The Cycle of Partial Adoption 51
B: Resource and Financial Constraints: The Scarcity Trap.......52
C: Social and Generational Hurdles 53

7. CONCLUSION.......55

Policy Implications 55
Future Research.......56
Limitations.......56

References 58

Acknowledgements.......66

Popular science summary 67

Appendix 1 Questionnaire Focus Group Discussion.......68

Appendix 2: Questionnaire Key Informants Interview 69

List of figures:

Figure 1. Map of Embu County (a) and Kwale County (b) (Embu County Climate Change Action Plan, 2023; Devolving climate change governance in Kwale County, Kenya, 2021). 22

Figure 2. Focus Group Discussion framing. 25

Figure 3: The process of reflective thematic analysis (RTA), adopted from Braun and Clarke's (2006) six-phase framework 28

Abbreviations:

Abbreviation	Description
SLU	Swedish University of Agricultural Sciences
SDG	Sustainable Development Goal
FAO	Food and Agricultural Organisation
UN	United Nations
NGO	Non- Government Organisation

1. INTRODUCTION

1.1. Background for the study

Sustainability, a pressing concern, has become an indispensable goal at local, national, and global levels, exemplified by the UN Sustainable Development Goals (SDGs) as a universal framework for action (United Nations, 2015; Sachs, 2012). However, different stakeholders perceive and prioritise sustainability aspects differently (Hou, 2016), based on their interests, experiences, and local contexts. Broadly, the Brundtland Report (1987) defines sustainability as the long-term capacity of human societies to thrive within the limits of the planet (WCED, 1987). Since then, the concept has evolved into a transdisciplinary field that integrates science, policy, and practice (Clark & Dickson, 2003; Stock & Burton, 2011).

Over time, sustainability has often been conceptualised through the triple bottom line framework of economic, social, and environmental dimensions (Elkington, 1997). While influential, this approach has been debated and complemented by alternative perspectives, such as the planetary boundaries framework (Steffen et al., 2015), the social foundations approach (Leach et al., 2013), and the Doughnut Economics model (Raworth, 2017). These frameworks collectively reframe the economy not as a pillar of sustainability but as a tool to support environmental integrity and social well-being (Sundberg & Azzi, 2024). Leach et al. (2010) underscore that achieving sustainability requires both technological innovation and institutional change across multiple levels. They argue that dominant approaches to sustainability often fail by overlooking systemic complexity and competing narratives. They propose the pathways approach, which embraces uncertainty, diverse knowledge systems, and adaptive governance as a more effective way forward.

Agriculture lies at the heart of these sustainability challenges that play out, particularly in relation to smallholder farmers in developing countries who are disproportionately vulnerable to climate shocks, soil degradation, and economic marginalisation (Bryan et al., 2009). Meeting the food needs of a global population projected to reach 9 - 10 billion by 2050, and achieving SDG 2 (Zero Hunger) will require a 35-70% increase in production (Van Dijk et al., 2021; FAO, 2017), at a time when climate change and resource degradation are already undermining agricultural systems. Addressing these challenges requires strengthening the resilience of local smallholder farmers, which necessitates innovations that integrate environmental, social, economic, and systemic dimensions, thereby linking sustainability theory to practical solutions.

In Kenya, smallholders produce about 75% of national agricultural output and contribute nearly a quarter of gross domestic product (FAO, 2021; KNBS, 2022; World Bank, 2023). Despite their central role in the economy, they face declining crop yields, water scarcity, and heightened vulnerability to climate-related risks (Serdeczny et al., 2017; Bryan et al., 2013). Their livelihoods also rely heavily on biomass energy, which provides essential household fuel but simultaneously drives deforestation and environmental degradation (Kenya Climate Directory, 2020; MoE-CCAK, 2019; Njenga et al., 2016).

One proposed response to these intersecting challenges is biochar, a carbon-rich byproduct of biomass pyrolysis, which can be applied to soils to improve fertility and water retention, enhance crop productivity, and act as a carbon sink for climate change mitigation (Lehmann & Joseph, 2015; Kätterer, 2022; Shackley et al., 2012; Sundberg et al., 2020). When produced through clean cookstove technology, biochar can also provide cleaner household energy and reduce indoor air pollution (Gitau et al., 2019; Kätterer, 2022; Njenga et al., 2016; Sundberg et al., 2020).

Despite biochar's promise, adoption among smallholders remains limited. Some prior studies indicate that socio-economic barriers, lack of awareness, and insufficient integration of biochar with local livelihood systems could influence adoption decisions (Siddiqui, S. 2025; Müller et al., 2019). To deliver benefits aligned with the SDGs, its implementation must consider context-specific social, cultural, and institutional conditions (Siddiqui, S. 2025; Müller et al., 2019; Sundberg & Azzi, 2024) alongside scientific and technical knowledge.

This study contributes to that effort by exploring smallholder farmers' perceptions of sustainability and their views on biochar within the Kenyan context. By examining qualitatively how local definitions of sustainability align or conflict with scientific and policy framings, it seeks to assess not only the technical potential of biochar but also its social acceptability and contextual appropriateness as a sustainability solution perceived by the smallholder farmers.

1.2. Biochar projects in Kenya

As the thesis is situated within the BICEPS biochar project, here is a brief introduction to the Biochar projects in Kenya, the study area.

Research into biochar systems in Kenya conducted by the collaborative group of researchers and institutional partners began well before the BICEPS project, with foundational work dating back to 2006 (Sundberg et al., 2020). Initial long-term, researcher-managed biochar trials were established in Kenya applying high rates of biochar (up to 100 Mg ha^{1}) in maize - soybean rotations and maintained for over a decade (Kätterer et al., 2019). In 2016, a household-level intervention distributed biochar-producing gasifier cookstoves to 150 households across Kwale, Embu, and Siaya Counties. At the household level, these gasifier stoves serve a dual purpose: they provide heat for cooking while producing small amounts of biochar as a by-product. This intervention enabled studies on fuel efficiency, indoor air quality, and the quantities of biochar generated as a byproduct of cooking in a gasifier cookstove (Gitau et al., 2025). Wood was the main fuel used, with residues such as maize cobs and coconut shells as complementary fuels. Between 2016 and 2018, a participatory approach was employed to examine factors influencing household adoption of the gasifier cookstoves (Gitau et al., 2019)

Concurrently, on-farm trials evaluated the use of biochar produced from these cookstoves at realistic application rates (1, 5 and 10 Mg ha^{-1}), focusing on maize yield responses under smallholder conditions (Kätterer et al., 2019; Mahmoud et al., 2019). From 2016 to 2019, further studies assessed biochar quality, effects on soil fertility, and greenhouse gas emissions, generating multiple peer-reviewed publications (Njenga et al., 2016; Njenga et al., 2017; Gitau et al., 2019; Mahmoud et al., 2019; Kätterer et al., 2019). The farmers were also trained to use biochar scientifically for on-field application on field crops like maize and kale in participatory trials.

This extensive work laid the empirical and practical foundation for the launch of the BICEPS Project in 2021, which aimed to scale up biochar and climate-smart practices in Kenyan smallholder systems.

The BICEPS Project 2021-2025 (Biochar Integration in Small-Holder Cropping Systems; Economy, Food Product Value Chains, Climate Change Resilience and Soil Fertility) is a collaborative, transdisciplinary research initiative coordinated by the SLU, with partner institutions across Kenya, Norway and South Africa with a broad competence in system analysis, agronomy, soil science, and agricultural economy.

The project aims to assess the potential of integrating biochar into smallholder farming systems to enhance crop yields, improve soil fertility and water retention, support cleaner household energy through biochar-producing cookstoves, and contribute to climate change mitigation via carbon sequestration. By examining the impacts of biochar on crop productivity, climate resilience, food security, and farm profitability, the project seeks to address knowledge gaps regarding its use in Sub-Saharan African smallholder contexts. These multifaceted goals align with broader sustainable development priorities, particularly those outlined in Agenda 2030, including SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 13 (Climate Action). During this project, farmers were shown how to produce biochar at a somewhat larger scale in Kon-Tiki kilns (Schmidt and Taylor, 2014**)** using maize in Embu and coconut shells in Kwale as feedstock. This is a biochar production method where heat is not used as an energy source.

This thesis research contributes to the broader objectives of the BICEPS project, particularly under the Project's work package 4 (WP4), which aims to understand *"What other sustainability aspects are important to local stakeholders, and how can they be assessed?"*. WP4 addresses both technical and environmental performance with life cycle assessment, while also incorporating stakeholder perspectives as part of its research aim.

1.3. Statement of the problem and Scope

Biochar is widely recognised for its clean cooking energy, its potential to improve soil health, increase crop yields, and its contribution to climate mitigation. Yet its adoption by smallholder farmers in sub-Saharan Africa, including Kenya, remains limited. Much of the existing research has focused on agronomic trials, outcomes, and climate impact assessment, often overlooking the lived realities, priorities, and perceptions of the very communities it intends to benefit. Little is known about how farmers themselves understand sustainability, or how they evaluate biochar in light of their daily challenges. Without such understanding, efforts to promote biochar risk being top-down, misaligned with local needs, and ultimately risk adoption.

In Kenya, several clean energy initiatives using gasifier stoves have introduced biochar for cleaner cooking, while the biochar produced as a by-product from these stoves has been promoted for use in agricultural fields. At the same time, field trials through biochar projects have focused on its application as a soil amendment. Another potential use of the biochar is to substitute firewood and charcoal produced from traditional kilns, which could reduce pressure on forest resources and lower household exposure to smoke. However, biochar's potential to replace charcoal as a household fuel remains constrained by factors such as production scale, feedstock availability, and stove design, resulting in limited availability. If this limited biochar is instead diverted for use as fuel, it may reduce the quantity available for soil improvement, thereby limiting its contribution to soil fertility and crop yield enhancement. This situation presents a sustainability dilemma for smallholder farmers: to use biochar as a cleaner household fuel or apply it to the soil for long-term agricultural benefits. Understanding how smallholder farmers in Kenya navigate these competing uses provides insight into their constrained choices between household energy needs and agricultural productivity.

This research thus addresses this gap by exploring the everyday experiences of smallholder farmers in Embu County and Kwale County in Kenya, their understanding of sustainability, their perceptions of biochar, constrained choices and adoption challenges. While context-specific, the findings provide insights into locally embedded practices and opportunities for participatory inclusive interventions that support sustainable agriculture, climate resilience, technology innovation, and community well-being.

1.4. Research aim and Research questions

This thesis, aligned with the broader aim of the BICEPS project (WP4), develops a more focused inquiry centred on local stakeholder perspectives. Using qualitative methods, it explores how smallholder farmers from Embu county and Kwale county in Kenya perceive and define sustainability in their daily realities, how they view biochar within these local sustainability dimensions and barriers or enablers influencing their adoption. The research findings aim to inform both policy and practice by evaluating biochar's sustainability in terms of social acceptability and alignment with farmers' practices.

To guide the inquiry, the following research questions were framed:

RQ1: How do smallholder farmers define or describe sustainability, and how do they feel their current practices and experiences reflect (or do not) these ideals of sustainability?

RQ2a: How do smallholder farmers perceive biochar in relation to their sustainability priorities, and what benefits (if any) do they associate with it?

RQ2.b: How do farmers prioritise the use of biochar between agricultural purposes and household energy needs?

RQ3: What are the barriers and challenges to biochar adoption, if any?

2. LITERATURE REVIEW

2.1. Understanding Sustainability and Sustainability Issues in Rural Kenya: Agricultural Systems, Energy and Climate Change Impacts

In rural Kenya, smallholder farmers are central to the economy and face interconnected environmental and socio-economic pressures, including erratic rainfall, prolonged droughts, seasonal floods, soil degradation, and other climate change impacts within fragile social-ecological systems (Kenya Meteorological Department, 2024; CIDP, Embu and Kwale, 2023). These challenges have resulted in increased pest and disease incidences (Mafongoya et al., 2019), disrupted agroecological patterns, and negatively impacted soil structure (Gwenzi et al., 2015), further undermining crop productivity and food security (Serdeczny et al., 2017; Bryan et al., 2013). The majority of these smallholder farmers operate at subsistence levels, with limited access to financial services, agricultural inputs, and reliable markets, climate-resilient technologies, information, and infrastructure (World Bank, 2023; Masud et al., 2017), leaving them highly vulnerable.

To cope, farmers adopt strategies like crop diversification, drought-tolerant varieties, and altered planting dates, though adoption varies due to socioeconomic factors and land ownership (Bryan et al., 2013). Social structures and gender inequality further exacerbate vulnerabilities, as farmers often lack secure land tenure, access to credit, and participation in decision-making processes, limiting their adaptive capacity to climate risks (FAO, 2019; Njuki et al., 2014).

These intersecting challenges underscore the need for context-sensitive and inclusive approaches to sustainability, ones that actively address local power structures, cultural norms, and community survival strategies. Without such attention, well-intentioned interventions may risk deepening existing inequalities and undermining rural resilience (Chambers & Conway, 1992; Scoones, 2009; Manlosa, 2022; Doss, 2001).

2.2. Biochar- properties and potential

Biochar is a porous, carbon-rich product with a high surface area, produced through the pyrolysis or gasification of organic biomass (e.g., crop residues, maize cobs, coffee husks) under low-oxygen conditions. (Lehmann & Joseph, 2015). It is recognised for its agronomic benefits, including improving soil properties, enhancing fertility, and potentially serving as a clean cooking fuel (Lehmann & Joseph, 2015; Patel & Panwar, 2023; Njenga et al., 2017).

Biochar in Agriculture

Kenya's smallholder farmers face soil fertility decline, yield gaps, and mounting environmental pressures, which are likely to worsen as the population doubles from 47 million in 2019 to a projected 96 million by 2050 (FAO, 2019). Continuous cropping to meet the needs of a growing population, combined with the high cost of chemical fertilisers, has reduced options for resource-poor smallholder farmers who rely on their land for both food and income. Recent research highlights the urgent need for cost-effective, environmentally friendly solutions to address declining soil fertility and potential food insecurity.

Biochar has emerged as a promising option to address declining soil fertility and food insecurity, particularly in acidic, nutrient-depleted soils of tropical Sub-Saharan Africa (Jeffery et al., 2017; Gul et al., 2015; Gwenzi et al., 2015; Lehmann et al., 2011). Its agronomic benefits include improved soil aggregation, hydraulic conductivity, water retention, cation exchange capacity, and increased microbial populations, enhancing both soil fertility and crop resilience, particularly in degraded soils (Blanco-Canqui, 2017; Alkharabsheh et al., 2021). Studies have shown significant increases in plant growth, biomass, and yields for crops such as maize (Gonzaga et al., 2018; Major et al., 2010), with meta-analyses reporting average yield gains of 25% in tropical agroecosystems due to enhanced nutrient retention and resilience under climate stress (Jeffery et al., 2017). Biochar can also substitute synthetic fertilisers, reducing the chemical pressure in smallholder farming systems, supporting both productivity and sustainability (Mashamaite et al., 2024).

Beyond agronomic benefits, sustainable biochar production and soil application could mitigate up to 1.8 Pg CO_2-C annually while maintaining biodiversity and ecosystem stability (Woolf et al., 2010). These benefits are greatest in degraded or low-fertility soils, where nutrient retention, water-use efficiency, and soil resilience are enhanced. However, unsustainable production or poorly controlled emissions may negate these climate benefits, underscoring the need for responsible management practices (Woolf et al., 2010). To maximise its impact and meet growing demand, biochar can be produced at scale from abundant crop residues without creating additional environmental pressure (Roobroeck et al., 2019; Omulo, 2020). This will create a surplus to meet both agronomic needs and clean energy applications.

Despite this potential, adoption among smallholder farmers remains slow due to social, cultural, and institutional realities, including gender norms, labour allocation, and access to training and resources (Siddiqui, 2025; Njenga et al., 2016; Sundberg et al., 2020). Technical feasibility alone does not guarantee adoption; understanding local context, incentives, and barriers is essential for successful implementation.

Biochar and energy transitions

In Kenya, about 86% of households rely on solid fuels such as firewood and charcoal (Global Alliance for Clean Cookstoves, 2018). The country derives nearly 68% of its energy from biomass (firewood and charcoal), which accelerates deforestation and environmental degradation (Global Alliance for Clean Cookstoves, 2018). Inefficient stoves and indoor air pollution expose women and children to hazardous smoke, contributing to an estimated 23,000 deaths annually in Kenya, with women and children disproportionately affected (Kenya Medical Research Institute, 2023). In rural households, the burden of biomass collection and cooking falls largely on women and children, often as unpaid work, and they are exposed to health risks from indoor air pollution (Njenga et al., 2016; Global Alliance for Clean Cookstoves, 2018).

Beyond agricultural applications, biochar can be integrated into energy transitions. Studies in Embu and Kwale counties show that TLUD (Top-Lit UpDraft) gasifier cookstoves offer a dual benefit: they provide clean household energy and generate biochar as a by-product (Njenga et al., 2017). These stoves reduce indoor air pollution and fuel use by 28 – 47%, while cutting greenhouse gas emissions by up to 47% (Njenga et al., 2017; Gitau et al., 2019; Sundberg et al., 2020). In addition to gasifier stoves, smallholders can produce biochar using Kontiki flame-curtain kilns, which allow efficient, low-cost production of high-quality biochar from locally available residues (Schmidt & Taylor, 2014). Kontiki kilns are suggested as a suitable method for utilising locally available residues, such as maize cobs or coconut husks, making them an accessible option for both agronomic and energy applications in rural contexts.

However, despite the advantages, the successful adoption of appropriate cooking technologies requires a nuanced understanding of sociocultural, economic, physical, and technical dynamics (Ibe & Kollur, 2024). Barriers such as low economic status, high technology and maintenance costs, large family size, inadequate infrastructure, and unfavourable institutional frameworks continue to constrain widespread use (Ibe and Kollur, 2024; Njenga et al., 2016). Given that women are often the primary users and managers of household energy, addressing these barriers also requires targeted strategies to empower women across the energy supply chain, essential for advancing sustainable and equitable energy solutions (Njenga et al. 2016).

2.3. Biochar Adoption and Research Gaps

While biochar demonstrates clear agronomic and environmental potential, adoption in rural Kenyan communities has been reported as uneven. Previous studies in Kenya and India suggest that factors such as socio-cultural dynamics, gender roles, labour intensity, access to feedstocks, and perceptions of sustainability may strongly influence local adoption decisions (Müller et al., 2019; Gitau et al., 2019; Njenga et al., 2017).

Participatory approaches such as Participatory Rural Appraisal (PRA) and cognitive mapping (Eden & Ackermann, 2001) are essential for understanding localised experiences of sustainability and navigating conflicting priorities (Müller et al., 2019). In Kenya, with women often bearing the primary burden of production and cooking, gender dynamics, labour division, and perceptions of modern versus traditional stoves strongly influence the uptake of biochar cookstoves (Gitau et al., 2019; Njenga et al., 2016). These findings underscore the importance of moving beyond purely technical solutions and highlight the need to research and understand how biochar aligns with existing livelihood strategies, cultural practices, and local sustainability priorities.

Integrating stakeholder perspectives is essential for co-designing and implementing biochar interventions that reflect local understanding, which will facilitate adoption. For instance, projects like the Biochar for Sustainable Soils (B4SS) and C-Sink manager artisanal study tour in Kenya show that co-designed, gender-sensitive models can improve collaborative learning and local adaptation (UN, 2015; CBEN, 2024). Participatory frameworks like these provide valuable insights into how inclusive, stakeholder-driven design can facilitate the adoption and long-term sustainability. Scholars further highlight that gendered labour roles and local resource practices shape adoption decisions, emphasising that successful interventions require participatory, inclusive, and context-specific strategies (Mahmoud et al., 2021; Doss et al., 2001; Manlosa, 2022).

Despite biochar's well-documented agronomic and environmental benefits (Kätterer et al., 2022; Sundberg et al., 2020), significant gaps remain in understanding the social sustainability of biochar transitions in Kenya. Few studies examine how local stakeholders define sustainability in energy transitions, navigate trade-offs with household needs, or address gendered labour implications (Mahmoud et al., 2021; Njenga et al., 2017).

Rogers' Diffusion of Innovations Theory (2003) and Meijer et al. (2015) further highlight that adoption is influenced not only by technical performance and economic factors but also by socio-psychological dimensions, including knowledge, attitudes, and perceptions of new technologies. This study aims to understand these gaps by engaging smallholder farmers and stakeholders in Embu and Kwale counties.

2. THEORETICAL AND CONCEPTUAL FRAMEWORK

This study began with an exploratory, inductive orientation, privileging local voices and experiences rather than imposing analytical theories from the outset. However, certain theoretical frameworks were considered early on as potential interpretive tools and became more explicitly integrated during data analysis. This dual stance ensured that the analysis remained grounded in farmers' lived realities while also drawing on established conceptual structures to make sense of patterns in the data.

Biochar intersects with issues of livelihoods, innovation diffusion, and institutional support. To capture these dynamics adequately, this study employs three interrelated frameworks: the Sustainable Livelihoods Framework, the Diffusion of Innovations, and the Unified Theory of Acceptance and Use of Technology. Taken together, these frameworks enable a multi-scalar lens for analysing how smallholder farmers in Embu and Kwale interpret sustainability, assess biochar, and negotiate barriers to its uptake.

3.1. The Sustainable Livelihoods Framework

The Sustainable Livelihoods Framework (SLF), by Chambers and Conway (1992), is a tool for understanding how households, particularly in rural or vulnerable contexts, combine different forms of capital: natural, physical, financial, human, and social, to sustain their livelihoods. The framework emphasises the vulnerability context, including shocks, trends, and seasonal changes, while situating households within broader social and institutional systems that shape access to resources and opportunities. As per SLF, livelihood is considered sustainable if it can withstand shocks, maintain or enhance assets and capabilities, and safeguard environmental resources, making SLF a valuable approach for linking economic, social, and environmental dimensions of sustainability.

In this study, SLF provides a way of interpreting sustainability from the perspective of local farmers, for whom access to land and water, food security, and household stability are central. SLF helps explain how biochar might be evaluated not only as an agronomic input but as a livelihood strategy. However, SLF has also been widely critiqued: Scholars have argued that the classical SLF risks being static, overly technocratic, and inattentive to politics, power, and gender inequalities (Scoones, 2009). In response, more recent adaptations have extended the framework. Scholars like Manlosa (2022) incorporated notions of agency, knowledge, and institutional dynamics. Natarajan et al. (2022) emphasise how advancing a power-sensitive approach, like unequal access to technology, land rights, and market systems, shapes livelihood trajectories. This study takes such critiques seriously, employing SLF not as a prescriptive model but as a sensitising framework (Blumer, 1954), a heuristic for situating farmers' experiences of sustainability and resilience about land, labour, local and household dynamics, while recognising broader structural constraints.

3.2. Diffusion of Innovations

Rogers' (2003) Diffusion of Innovation (DOI) theory explains how, why, and at what rate new ideas and technologies spread through communities. It identifies five key characteristics that affect adoption: relative advantage (benefit), compatibility (fit), complexity (simplicity), trialability (testability), and observability (visible results). These characteristics shape users' evaluations of a new practice and their willingness to adopt or reject it. DOI, its construct and principle have been widely used in agricultural contexts. For example, Dougill et al. (2017) found that farmer-to-farmer extension and observability of results were central to conservation agriculture adoption in Malawi, while Foguesatto et al. (2020) demonstrated the importance of compatibility with local norms and peer learning networks, influencing sustainable practices.

This study applied DOI principles to explore how farmers in Embu and Kwale perceived biochar as an agricultural innovation. It helps explain patterns of acceptance, rejection, and hesitation by situating biochar within the broader dynamics of innovation diffusion in smallholder systems. However, DOI is primarily concerned with the attributes of the innovation and the social process of diffusion, rather than the deeper motivations or enabling conditions for adoption. This is where the Unified Theory of Acceptance and Use of Technology complements it.

3.3. Unified Theory of Acceptance And Use of Technology

Unified Theory of Acceptance and Use of Technology (UTAUT), developed by Venkatesh et al. (2016), was employed as a supplementary lens in this study to interpret barriers and enabling factors in biochar adoption. UTAUT emphasises four constructs: performance expectancy, effort expectancy, social influence, and facilitating conditions. Compared to DOI, which focuses on the diffusion process, UTAUT shifts attention toward individual perceptions and behavioural intentions. Performance expectancy refers to the degree to which a person believes that using a technology will enhance their performance. Effort expectancy reflects how easy or difficult the technology is perceived to be. Social influence considers the impact of peers, supervisors, or community members on the decision to adopt the technology. Facilitating conditions encompass the availability of resources, infrastructure, and organisational support that enable effective use. In this study, UTAUT is applied as a lens to examine how these factors shape farmers' adoption of biochar as a sustainable agricultural technology.

UTAUT has often been applied in digital and information technology contexts, but it is increasingly used in agriculture. For example, Nguyen et al. (2023) demonstrated how smallholder adoption of precision agriculture in Vietnam was shaped by perceived usefulness, social influence, and support systems. Applied here, UTAUT adds explanatory value, possibly by highlighting why some farmers view biochar as worth adopting, while others hesitate.

In short, whereas DOI helps map how biochar spreads through farmer networks, UTAUT sharpens the focus on why some farmer decides to adopt or reject it, influencing others, bringing forward the role of expectations, social norms, and enabling structures. Together, they provide a more holistic account of adoption dynamics.

4. METHODOLOGY

This chapter outlines the research methodology used to collect, analyse, and interpret data. It details the study area, research design, sampling frame and method, data collection, data analysis approach, and ethical considerations.

4.1. Study area

The study was conducted in two counties in Kenya - Embu (Central Kenya) and Kwale (Coastal Kenya), regions that represent distinct agro-ecological zones and farming systems where the BICEPS Project and other biochar-related projects were implemented (see 1.2). These counties were selected for their prolonged exposure to biochar interventions, particularly those involving technical training, field implementation, and farmer capacity building.

As part of these initiatives, farmers were introduced to gasifier stoves, which serve a dual purpose: providing cleaner cooking energy and producing biochar as a by-product. The projects trained farmers on both the production of biochar using gasifier cookstoves and its utilisation as a soil amendment to enhance soil fertility and crop productivity. While farmers traditionally rely on firewood and charcoal for household energy, many have adopted the gasifier stoves supplied by the projects, using them alongside their conventional cooking methods. In addition to gasifier stoves, farmers were trained to produce biochar using Kon-Tiki kilns, an open-pit method. However, this process presents practical challenges. The heat generated during biochar production in Kon-Tiki kilns is largely unused, limiting its potential as a source of cooking energy. Moreover, farmers often face feedstock and labour constraints, which affect the consistency and volume of biochar they can produce.

Although farmers in these counties have been technically engaged in biochar production and use, a participatory and qualitative exploration of their attitudes, perceptions, and lived experiences with biochar within their local contexts had not previously been undertaken. Earlier participatory efforts were made primarily to examine factors influencing the household adoption of gasifier cookstoves. The study area also provides an ideal context to explore how farmers navigate the competing uses of biochar as fuel and agricultural input within the constraints of their daily livelihoods and resource availability. The study area thus provides an ideal context to explore these gaps by engaging farmers directly. This study did not aim to assess cookstove adoption or diffusion in particular, which has been studied extensively (Lagerhammar et. al, 2024). Rather, I treated it only as contextual background, influencing how biochar was perceived for household cooking energy needs.

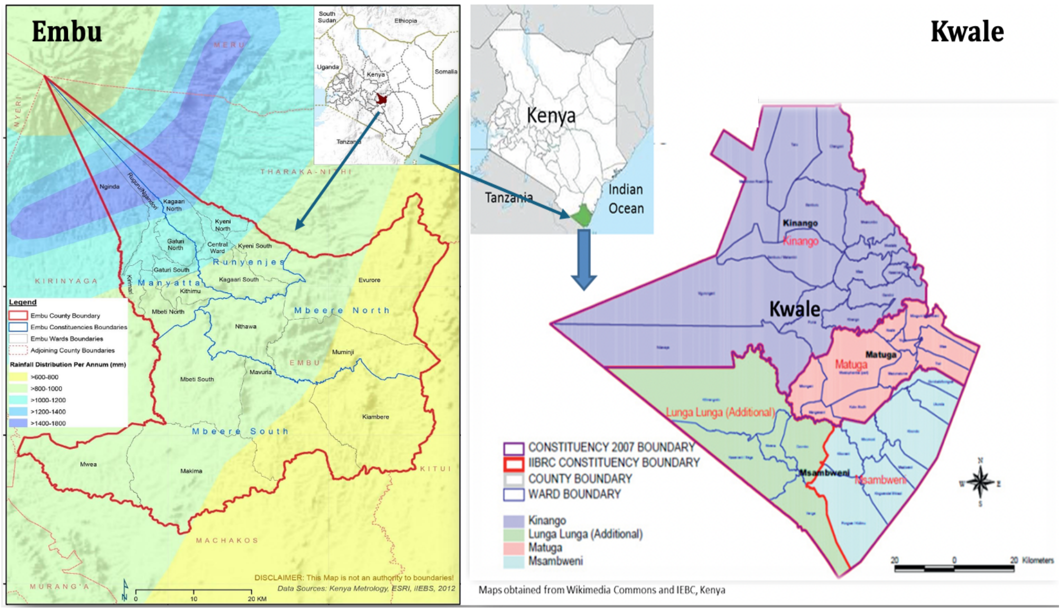

Figure 1. Map of Embu County (a) and Kwale County (b) (Embu County Climate Change Action Plan, 2023; Devolving climate change governance in Kwale County, Kenya, 2021).

Unless otherwise indicated, all county-specific data for Embu and Kwale are derived from the respective County Integrated Development Plans (CIDP) 2023-2027.

Embu County

Embu County is situated approximately 120 kilometres northeast of Nairobi, and the county covers an area of 2,818 km². Its topography rises from 515 meters at the Tana River Basin to 5,199 meters at Mount Kenya's summit. The climate is temperate, with annual rainfall between 600 mm and 1,495 mm and temperatures ranging from 12°C to 30°C. The main economic activity in Embu County is agriculture and livestock keeping. The county's diverse agroecology supports mixed farming systems with food crops including maize (60%), beans, cassava, and sweet potatoes, while cash crops such as Camellia sinensis, coffee (*Coffea arabica*), khat (*Catha edulis*), and macadamia nuts (*Macadamia spp*.) support household income.

Over 70% of households rely on firewood, mostly from their farms, for cooking, primarily using the traditional three-stone stove. Farm forestry is significant, with trees such as *Grevillea robusta* widely grown for shade in coffee and tea plantations and for providing domestic firewood and timber. The region faces environmental challenges like soil erosion, erratic rainfall, and flood risks. which are addressed through sustainable land-use strategies such as agroforestry, conservation agriculture, and soil and water conservation measures.

Kwale County

Kwale County lies along Kenya's southern coast, about 515 kilometres from Nairobi, and covers 8,270 km². Elevation ranges from sea level to 600 meters. The climate is hot and humid, with bimodal rainfall between 400 mm and 1,680 mm annually and average temperatures around 26°C. The population, estimated at 958,180 (2022), is predominantly rural, and settlement is shaped by proximity to water, arable land, and infrastructure. Kwale's ecology spans coastal strips, lowland plains, and the Shimba Hills.

The county's economy relies on agriculture, tourism, and fisheries, with smallholder farming being dominant. Key crops include coconuts, cashews, mangoes, cassava, maize, and cowpeas. Similar to Embu, most households rely on firewood and three-stone fires for cooking. The County faces growing environmental degradation, including soil erosion and deforestation, driven by unsustainable land use and heavy reliance on fuelwood. Climate variability, water scarcity, and frequent droughts have increased food insecurity among rainfed subsistence farmers. Kwale is tackling these challenges through sustainable land management, drought-resilient crops, and climate-smart agriculture.

4.2. Research Design

A qualitative research design was employed to explore farmers' understanding of sustainability, their experiences, preferences, and attitudes toward biochar and its use in their daily lives. This approach provided flexibility and enabled an in-depth understanding of human experiences, relationships, and social contexts (Hsieh & Shannon, 2005; Bohnsack et al., 2010). The study incorporated participatory principles and purposive sampling (Suri, 2011) to engage participants actively, ensuring representation of social, cultural, and demographic factors shaping smallholder farming practices.

4.3. Sampling Frame and Method

The sampling frame comprised smallholder farmers who had been engaged through the BICEPS project (2021–2025) and earlier biochar initiatives in Embu and Kwale counties, dating back to 2006 (see sections 1.2 and 4.1). These Biochar Project beneficiaries had participated in training and demonstrations on both cooking and agricultural applications of biochar. Between 2016 and 2019, farmers received gasifier cookstoves, which simultaneously produced biochar and provided household cooking energy. From 2016- 2019, they also learned how to produce biochar using maize cobs and coconut husks with kontiki/kilns, as well as how to apply biochar to field crops (maize and kale) since 2022.

Alongside these beneficiaries, a second group, newly interested farmers, was included. These farmers had not previously participated in formal biochar projects but had become interested through neighbour interactions and peer learning. By incorporating both experienced participants and new entrants, the study was able to capture retrospective insights and forward-looking aspirations regarding biochar use.

Participants categorised based on their biochar experience, i.e experienced farmers (biochar project beneficiaries) and new interested farmers (no prior exposure but expressed interest), were further divided into subgroups based on demographic characteristics (e.g., age and gender).

Once these categories were defined, random assignment was used to allocate participants to specific focus group discussions. For example, among all eligible female farmers, some were randomly selected into a women-only group, a male and female group, while others were assigned to heterogeneous or mixed-farmers groups. This approach balanced the purposive intent of capturing key subgroup perspectives with the benefits of randomisation, reducing bias and preventing overrepresentation.

Group Formation for Focus Group Discussions

Using this two-stage strategy, participants were organised into six Focus Groups per county (12 in total), with 8–10 participants per group, resulting in 109 participants overall. Group formation followed two logics:
Homogeneous Groups within experienced farmers (to encourage openness within peer groups):

1. Women Farmers Group
2. Youth Group (ages 18–30)
3. Elder Farmers Group (ages 55+)
4. Male and Female Farmers Group (no demographic restriction)

Heterogeneous Groups (to capture diverse perspectives):

5. Mixed Farmers Group (Experienced)
6. Newly Interested Farmers Group

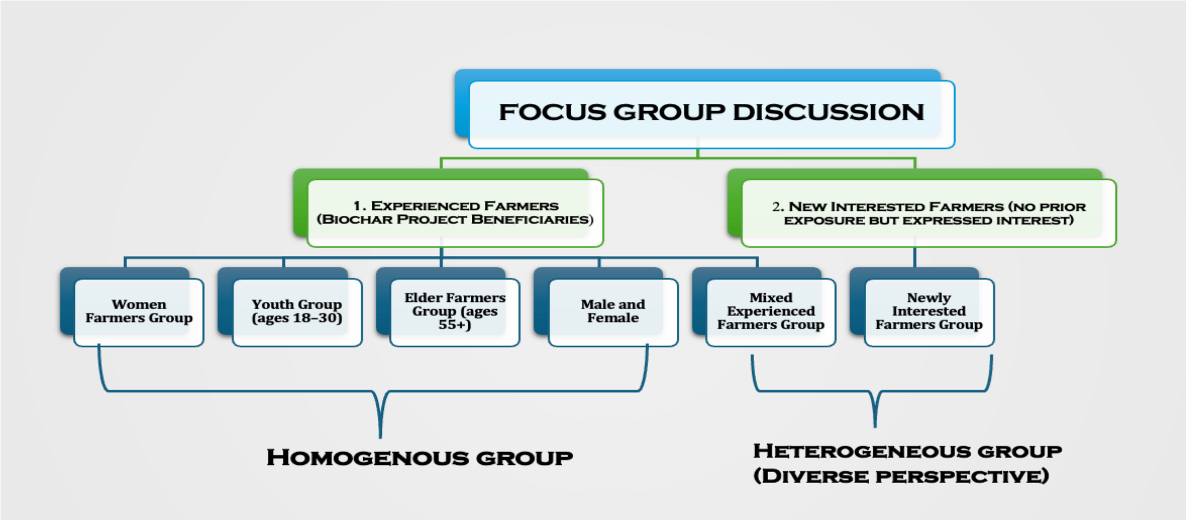

Figure 2. Focus Group Discussion framing.

Each participant was assigned to only one focus group, ensuring independence of contributions. This multi-layered sampling strategy, purposive selection followed by random allocation, enabled the study to capture both depth and diversity of perspectives across farmer categories and social demographics.

4.5. Data collection

I conducted fieldwork in Kenya during April 2024, spending one month in the study areas of Embu and Kwale counties. My data collection combined Focus Group Discussions and Key Informant Interviews using semi-structured, open-ended questions, which I complemented with informal field visits, observational notes, and unstructured interactions with farmers. This allowed adaptive follow-up during face-to-face interactions, enabling participants to express themselves freely and revealing context-rich information on biochar utility, sustainability concerns, and adoption barriers.

Focus Group Discussions

Focus Group Discussions (FDGs) were conducted primarily in local languages (Swahili in both Kwale and Embu), and the translator sometimes used local dialects to facilitate better understanding, to ensure participants expressed themselves comfortably and naturally. I worked alongside trained local translators fluent in both English and the respective local language to facilitate communication. Additionally, many farmers seem to have a basic understanding of English.

During the discussions, the translator interpreted questions and participants' responses, allowing me to follow and facilitate the discussion in real time. Rather than using audio recorders, I employed a participatory visual documentation approach (mind maps). Key ideas, phrases, and responses were captured directly on field charts and mind maps, created collaboratively during each session. These visual tools allowed for on-the-spot clarification and validation of participant contributions. After each session, I have transcribed the content into detailed textual transcripts, using the original Swahili and local terms where applicable, alongside their contextual translations and explanations. This process aimed to capture participants' meanings as closely as possible, including culturally embedded terms such as *uendelevu* (translation of sustainability in Swahili). The reflective statements (translated into English on site) were recorded as direct quotes in the field notes for possible use in future writing. The FGDs were guided by a flexible discussion guide (Appendix I), and participants were encouraged to reflect freely. This approach allowed me to observe certain patterns and identify themes organically in real time. Individuals who were not residing in the study area, had no direct or expressed interest in biochar, or were minors (under 18 years) were excluded from participating in the FGDs.

Key Informant Interviews

In addition to FGDs, ten semi-structured Key Informant Interviews (KIIs) were conducted with stakeholders, including NGO practitioners, agricultural scientific officers, workers' co-operative, researchers and local leaders. The interviews were done in English as all the stakeholders were conversant in the language. These participants were selected purposively based on their direct involvement in agricultural, community support, or relevant experience in sustainability/biochar-related interventions.

The KIIs were designed to provide contextual and institutional perspectives to enrich the findings of the discussion of the focus groups. The Interviews often serve a supplementary role, providing deeper insights into an issue as interviews are considered a social production of knowledge (Kvale & Brinkman, 2009). An interview guide (Appendix 2) was created to structure the interviews and ensure that relevant topics were discussed, allowing flexibility for the interviewer to probe and explore topics beyond a strict script (Kvale & Brinkman, 2010).

Six interviews followed a full semi-structured guide covering all key themes (sustainability, coordination among stakeholders, implementation challenges, institutional support and opportunities for scaling use in smallholder farming systems, biochar use, barriers to adoption, etc). Interviews lasted approximately 50-60 minutes. Before each session, respondents were informed about the study's purpose and how the collected data would be used. The remaining four were partial interviews, where informants offered targeted insights on select issues based on their roles or availability. The responses from interviews were documented directly onto structured questionnaires during the sessions, complemented by field notes.

4.6. Data Analysis

This study employed Reflexive Thematic Analysis (RTA), developed by Braun and Clarke (2006, 2009), situated within a contextualist epistemology. Reflexive Thematic Analysis recognises participants' lived experiences while situating them within wider social and environmental contexts, and it foregrounds the researcher's interpretive role in meaning-making rather than measurement. The analysis drew on a combination of field notes, transcripts, and participatory mind maps recorded during all Focus Group Discussions and Key Informant Interviews.

Following Braun and Clarke's six-phase RTA (Figure 3), I first engaged in familiarisation with the data repeatedly by reading and annotating transcripts and notes. Initial codes were then developed manually through line-by-line reading, staying close to participants' words before grouping codes into broader categories. Multiple rounds of thematic review helped me refine consistency and minimise potential bias. Participant quotes were integrated to keep interpretations grounded in their accounts, while noting that some cultural nuances may have been softened in translation. This approach helped participants' voices guide the construction of meaning around the research topics, rather than my assumptions or expectations.

While the coding process was predominantly inductive, I recognise that my interpretation was also shaped by sensitising concepts from the study's conceptual framework (e.g., sustainability, livelihoods, technology adoption). Thus, the analysis followed an iterative approach, where data-driven codes were subsequently interpreted in light of theoretical perspectives. Themes such as sustainability challenges, local framings of sustainability, and biochar's perceived roles reflect this interplay between participants' accounts and conceptual lenses. Importantly, theoretical frameworks such as the SLF, DOI and UTAUT were not used to guide coding; instead, codes were grouped in relation to the research questions, and the frameworks were drawn upon only in the discussion stage to help interpret and contextualise the findings.

To strengthen methodological rigour, triangulation was applied across multiple sources: FGDs, KIIs, field observations, mind maps, and survey data (previously generated during the BICEPS Project), allowing cross-checking and richer interpretation. Reflexively, I acknowledge that my position as a non-local student researcher shaped both the research process and participants' responses. While I approached the study with an academic interest in biochar as a sustainability innovation, I did not share the lived experiences or languages of the farming communities, and I remained critically aware of how this outsider status informed the analysis.

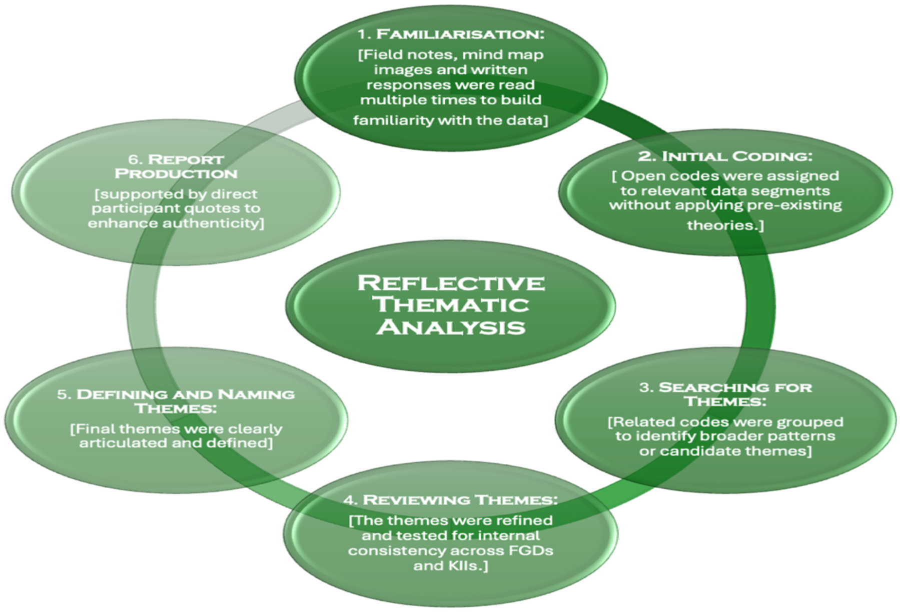

Figure 3: The process of reflective thematic analysis (RTA), adopted from Braun and Clarke's (2006) six-phase framework

4.7. Ethical considerations

The study adhered to ethical research standards, including obtaining informed consent from all participants before data collection. To address potential power dynamics, particularly the perception that I might be linked to the BICEPS Project or have influence over future support, I emphasised that participation was voluntary, that I was independent of development aid, and that there were no right or wrong answers. Trained local translators supported clear communication, and clarifications were sought whenever meanings were uncertain.

Participants were informed of the study's purpose, voluntary nature, confidentiality, and their right to withdraw at any time without penalty. The respondents were also confirmed by the interviewer that all the information they provided would be kept and used anonymously, i.e. people reviewing the data in the research will not know exactly who took part in and gave particular responses. Ethical approval was sought and signed by the supervisor and me, ensuring compliance with SLU's institutional ethical guidelines for student thesis fieldwork and student research. The research team ensured cultural sensitivity and respect throughout interactions with participants.

5. FINDINGS

This chapter presents the empirical findings from FGDs and KIIs conducted in Embu and Kwale counties. The findings are guided by RTA, where I identified an interlinked theme that captures both the explicit experiences and perspectives of participants (semantic) and the deeper meanings (latent) interpretations related to sustainability and biochar adoption based on their lived experiences. It is further triangulated with insights from extension officers, researchers, NGO members, local leaders, and representatives obtained through KIIs.

The findings are organised around the three research questions outlined in Chapter 1, with key themes and subthemes supported by illustrative quotes from FGDs and KIIs.

- Local understandings of sustainability.
- Farmers' perceptions and experiences of biochar. Farmers' choice between biochar for agriculture and/or household energy fuel?
- Barriers and challenges to biochar adoption.

5.1. Local Understandings of Sustainability

To uncover these, participants were first asked to reflect on what sustainability means to them using the Swahili term "*uendelevu*". The discussion was then deepened by exploring daily challenges, aspirations, and farming experiences that reflect their ideas of sustainability.

Theme A: Sustainability as Continuity and Resilience

Participants described sustainability in grounded and personal terms, describing it as a lived experience of "stability", "continuity", and a "long-lasting process". Their understanding was equally shaped by its absence, manifested in a lack of land, water, knowledge, and institutional support rather than distant ecological ideals. Sustainability was understood as a condition of life that could be trusted, shaped by memories of past resilience, current struggles, and future hopes.

Definitions varied by generation and gender: Elderly farmers recalled past resilience, fertile soils, farming that *"worked without fertiliser*," predictable rains, and expressed a sense of loss. Women reflected a need for support from their partners and food security, often tied to the stability of the household. Youth, by contrast, saw sustainability as aspirational, linked to opportunity, knowledge, and innovation. They challenged the assumption that current practices were sustainable, highlighted persistent soil degradation, crop failure, and economic insecurity as barriers, and called for self-sustaining systems beyond subsistence. One youth group in Kwale remarked, "*Farming today is not sustainable with all the challenges. You plant and lose. That's not safe for the future,"* while another in Embu stated, *"Farming alone is not sustainable. We need to do the Agribusiness"*.

Participants in Embu emphasised 'long-term soil health' and voiced rejection of reliance on chemical fertilisers, reflecting both practical concerns and aspirations for greater agency over their farming futures. Beneath these definitions lie an aspirational desire for autonomy and resilience in the face of vulnerability to environmental degradation, economic instability, and knowledge and institutional constraints. For these farmers, sustainability is not merely ecological but tied to social empowerment, self-sufficiency, and securing the future. This emphasis was particularly evident in their focus on access to knowledge, extension support, and practical tools to manage land and livelihoods more effectively. As one mixed farmers group in Embu expressed, *"If they came to train us, maybe we could farm better, but they don't come",* highlighting the integral role of support systems in enabling sustainable farming practices.

KIIs revealed that farmers often view sustainability through a survival lens, focusing on fertile soil, water, technical guidance, and low-cost inputs. Some also noted younger farmers' aspirational linking of sustainability with agribusiness or diversification. While most Key Informants demonstrated a broad awareness of sustainability, their interpretations were often ambivalent and shaped by institutional roles. Institutional actors mostly framed sustainability in technical and results-driven terms such as input provision, dissemination of improved practices, and measurable adoption outcomes. Local leaders emphasised structural resilience, water access, tree planting, and recovery from shocks. Interestingly, NGO practitioners often offered more grounded and adaptive understandings rooted in lived community realities.

Despite this, a common thread across several KIIs was the recognition of disconnects between actors and farmers, particularly around participation and trust. For instance, a researcher remarked, *"Without funding, we can't connect with farmers,"* while another reflected how NGOs are *"seen as people with money,"* pointing to a latent sense of mistrust and dependency that has been cultivated by past top-down interventions.

These narratives signal not only a structural failure in co-designing sustainability solutions but also a deeper feeling among farmers of being recipients rather than agents. As one respondent from an NGO described, *"Farmers harvest their* *produce early, even before official data collection, because it's finally healthy"*. This remark, while factual, also latently revealed feelings of scarcity, insecurity, and urgency. Institutional actors recognised farmers' material needs but often overlooked the emotional and symbolic dimensions of control, dignity, and well-being that were seen in focus groups. This gap highlights the deeper challenge of implementing sustainability as a collaboratively shaped experience, rather than treating it solely as a technical system.

Theme B: Sustainability as Lived Realities Shaped by Daily Challenges

Having outlined how farmers define sustainability in terms of survival, resilience, and dignity (see Theme A.), it is also clear that their current practices and lived experiences often fall short of these ideals. In this sense, sustainability is not only an aspiration but a daily struggle to maintain continuity under conditions of environmental, economic, and institutional constraint. This tension between what sustainability means and what it looks like in practice forms the basis of Theme 5.1.B: Sustainability as lived realities shaped by daily challenges. Their accounts illustrate farming as a site where multiple challenges converge, shaping a deeply pragmatic and survival-oriented understanding of sustainability.

Subtheme: Precarious Ecologies: Living with Environmental Shocks

Farmers define sustainability as continuity and resilience, but environmental shocks, manifested in erratic rainfall patterns, water scarcity, droughts, floods, soil erosion and infertility, pest problems and wildlife damage directly undermine their capacity to farm reliably. These factors were frequently cited as reasons for low yields, failed crops (e.g., "*maize not growing despite inputs*"), increased pests and diseases and disrupted food systems. As one women's group in Kwale explained, *"It rains too much or too little; we can't store water, so it creates a lot of farming challenges.* Declining soil fertility, a persistent challenge of unresponsive soil often linked to overuse of chemical inputs, was a recurring frustration. In Embu, a mixed farmers group described, *"In the maize crop, we have provided all the necessary inputs, but the crop still fails to grow above knee height. We don't know why",* underscoring the challenges in a precarious system.

Environmental shocks also interrupted food systems and disrupted market access. For instance, one women's group in Kwale reported, *"When trees fall, and we can't go to market, due to logistical challenges (fallen trees, floods, and* *disrupted transport), there is an increase in fuel price, and even bringing food becomes hard"*. KII respondents corroborated these experiences, citing climate change, deforestation, declining soil fertility, erratic rains, and pest/disease pressures as major threats. One KII respondent noted that "*erratic weather makes biochar feedstock unreliable*," illustrating how climate variability can hinder adaptation strategies.

These environmental issues are experienced not as isolated events but as part of a systemic ecological decline, eroding farmers' control over livelihoods and the loss of traditional ecological balance, threatening their sustainability. This sense of loss and disempowerment is reflected in statements such as '*soil used to be fertile*' and '*farming is too hard now*,' which highlight frustrations tied to environmental changes beyond farmers' control and compounded by insufficient institutional support.

Subtheme: Fragile Livelihoods: The Weight of Economic Constraints Interwoven with Environmental and Social Realities

Independence and dignity are farmers' sustainability aspirations, but economic hardship underpinned nearly every group's description of daily life challenges, making them dependent and insecure. Inability to buy inputs (expensive fertilisers, seeds), limited access to land, labour, and livestock inputs, making even basic farming increasingly unaffordable.

Many groups linked these financial difficulties directly to their inability to sustain farming or diversify livelihoods. As a new farmers group from Kwale explained, *"We want to farm better, but no money for tools, no money for fertiliser. Even the water we have to pay for*." Another mixed farmers group, Kwale, emphasised *"Money solves everything, if we have money, we'd be okay"*. Youth, in contrast, spoke of being locked out of opportunity, startup capital, and job alternatives, and tended to downplay household concerns like cooking energy. They instead emphasised moving from subsistence farming to agribusiness. Elderly men highlighted physical limitations and financial hardship as compounding their inability to continue productive farming, and a possible alternative to income generation. Giving examples like Macadamia nuts and tea plantation farmers highlighted the compounding logistics challenges, like market-related issues, poor transport infrastructure, high fuel costs, and volatile crop prices.

These economic hardship emerges as a core limiting factor that perpetuates a cycle of vulnerability. Money is not just a resource but a gatekeeper that restricts access to knowledge, technology, and opportunities. Farmers repeatedly cited "*lack* *of money," "lack of opportunity,"* and *"lack of skills*" as barriers to improved farming inputs, sustaining agriculture or investing in alternative income-generating activities, reinforcing vulnerability and dependency. Monetary insecurity also underpins social tensions, such as the women's expressed lack of support from spouses; it links farming struggles to broader concerns like decision-making and food insecurity.

KII reflections reinforced that economic fragility is not just a contextual difficulty but a structural barrier to sustainability, restricting access to knowledge, technology, and opportunity, and perpetuating dependency. One KII participant who has been working with women explained that women are often forced to choose to use biochar between cooking and farming, not due to preference but because of limited supply and financial trade-offs.

Another KII working with smallholders noted, *"Shifting from traditional to agri-ecological systems is hard; they tend to revert". There's no labour, no money, and they expect input subsidy,* acknowledging the difficulty of transitioning farmers to sustainable systems without first addressing their basic needs. This reflects that economic precarity functions as a gatekeeper determining who can access sustainable practices and locking others in cycles of vulnerability.

Subtheme: Limited Support, Knowledge Gaps and Institutional Neglect

Farmers consistently emphasised the importance of knowledge and autonomy in achieving a sustainable livelihood, yet limited extension services, inadequate follow-up, and weak institutional support constrained their ability to realise these ideals. Participants repeatedly expressed frustration over the lack of agricultural extension, training, and access to credible knowledge, as they said, *"the right way to productive farming"*. Many expressed that they lacked understanding of how to manage pests, soil acidity, and environmental shocks. They emphasised managing poor soil conditions and farming better, with impounding challenges requiring them to have agricultural training and services, which were lacking.

As one mixed farmer group in Embu explained, "*We hear about good practices, but no one teaches us. We use trial and error"*. Similarly, a new farmers' group in Embu expressed, "*If they came to train us, maybe we could farm better. But they don't come."* Elderly participants in Kwale echoed these concerns: *"We want to farm better, but there is no one to teach us."*

Across all the groups, farmers showed eagerness to learn, while some participants lamented the lack of access to extension services. A recurring frustration was that technologies are introduced without sufficient follow-up support or instruction. Even when new techniques like biochar or better agriculture practices were discussed, few participants knew how to apply them correctly. Many said they had been told about innovations but had never received continuous training. The absence of institutional support limited farmers' ability to adapt.

KII highlighted systemic gaps, pointing to limited capacity for sustained farmer engagement, disconnects between research and farmer realities, knowledge gaps, institutional shortfalls and funding constraints that hinder outreach. One KII respondent observed, "*We have heard from the farmers that biochar is good, and we want to try it in our research plot to disseminate it, as the adoption is still very slow"* Another noted, "*We have the option to provide capacity building, but we don't have huge funding, and it's hard to reach farmers from deep within the village"*.

These knowledge gaps and limited institutional support underscore structural barriers rather than evidence of farmers' resistance. It reflects cautious attitudes toward new technologies, with hesitancy emerging as an effect of insufficient guidance and support. As one NGO participant (KII) observed, *"Farmers expect support; if none is given, they are hesitant to adopt the technology."* Despite these constraints, farmers' curiosity and enthusiasm for better practices demonstrate their aspirations for empowerment, modernisation, and improved livelihoods.

In sum, farmers articulate clear ideals of sustainability but experience them as continually undermined by conditions largely outside their control. These findings directly address RQ1 by showing both how smallholders define sustainability and how current realities diverge from their aspirations. This sets the stage for examining whether biochar, as a promoted innovation, aligns with these priorities or not.

5.2. Farmers' Perceptions and Experiences of Biochar

This section explores how farmers perceived biochar within their daily struggles and broader sustainability aspirations. Findings revealed how biochar was experienced as both an agricultural amendment and deeper symbolic meanings, highlighting a source of hope for continuity, agency, and self-reliance.

Theme A: Shared Promise, Uneven Knowledge, Local Experimentation

Across all groups, biochar was widely described as a promising tool that aligned with some of their pressing farming challenges. These perceptions, however, were shaped by the levels of their experience, exposure, and access to information and curiosity within different groups.

Experienced farmers grounded their confidence in direct trials and visible improvements, reporting healthier crops, better soil conditions, and cost savings from reduced fertiliser use. Newly interested farmers, with little formal training, expressed enthusiasm based on peer experiences, visible crop performance, and community narratives rather than technical guidance. A participant from this group described, *"I saw on the farm where the firewood was burned, the crops grew taller on the soil with remains of charcoal in it. I was curious."* These observations among peers created a strong narrative of biochar as a solution for them.

Youth groups often took a more entrepreneurial view, seeing biochar as an option for a potential business and income generation. Women's groups and a few men valued its health benefits and faster cooking time when used as cooking fuel. Nevertheless, across all groups, the priority was its agricultural use for household food security then as a clean cooking fuel.

Despite this optimism, farmers' understanding of biochar's precise application remained uneven. Some farmers broadcast biochar directly, others mixed it with manure, and several assumed it was a complete fertiliser substitute. In many cases, these knowledge gaps were addressed through on-farm experimentation rather than formal training. As one farmer in Kwale explained: *"My crops are growing very good, I have manure stocked in my field, but I don't use it anymore, biochar is enough."* Similarly, another farmer described her approach: *"I have spread it (broadcast) on the sites, and it is very easy to apply"*.

KII respondents echoed farmer experiences, noting visible yield gains, reduced nematode pressure, and lower input costs. One KII respondent stressed that *"even with no rain, we got the biggest cassava with biochar because it retained water and increased nutrient use efficiency."* They also agreed that adoption was driven more by observed results than scientific understanding. As one KII respondent noted: *"I've heard farmers say it improves soil fertility, but adoption is slow. I want to try on our demo plot, as farmers believe in seeing the result for themselves"*.

Beyond the expected agricultural and household energy uses, farmers actively experimented with biochar, extending its functions in innovative ways that reflected both necessity and ingenuity. Some repurposed biochar as a form of mosquito repellent, burning it as briquettes inside homes or placing it around fruit trees to protect them from pests. One woman described creating a small incubator system using biochar's heat-retaining properties, claiming it successfully warmed her chicken eggs for four days and significantly reduced fuel costs. An NGO respondent, along with a farmer, mentioned experimenting with biochar as a sewage filter. These examples underscore how farmers do not simply adopt technologies as designed, but adapt them to their contexts, drawing on local priorities and creative problem-solving. Such practices highlight agency in constrained environments, where experimentation becomes a pathway for reducing household risks and expanding the perceived value of biochar.

This combination of confidence and uncertainty highlights both the creativity and vulnerability of local experimentation. The differences between experienced and new farmers reveal how trust is built through peer observation and how curiosity fuels experimentation. While farmers frequently discussed biochar in positive terms, *"good," "safe," "lasting", "easy to apply",* and *"cheaper than chemical inputs",* their enthusiasm is interwoven with knowledge gaps and repeated calls for training.

Theme B: Tangible Gains and Symbolic Hope

Farmers across counties consistently linked biochar to some of their central sustainability concerns: fertile soil, balanced pH, water retention, reduced input costs, and increased yields, pest control (specifically nematodes). It was contrasted with chemical fertilisers, which they perceived as costly and harmful to long-term soil health and explicitly linked biochar use to reduced fertiliser dependency, cost savings. As a male and female group in Embu noted, *"Biochar is safe; it does not pollute the soil like fertiliser, which is not sustainable".* Although challenges were similar across both sites, their intensity differed; water scarcity was more acute in Kwale, while soil degradation dominated in Embu.

Several groups observed improved productivity on previously "*unresponsive soils,*" reinforcing its perceived value. As a farmer from the Male and female group in Embu explained, *"I have applied biochar on the field where Maize did not grow even after all the required inputs, but after biochar application, it grows"*. Farmers further emphasised its benefits for soil health: *"Biochar makes the soil fertile", "retains water in the soil", "gives healthy crops", and "more yield* (Mixed farmers group, Kwale). Many noted that biochar reduces pest pressure. "*The ashes from biochar reduce the worms (nematodes) in the soil" (*Women's group, Embu).

Embu farmers described biochar as a tool for soil restoration and were eager to experiment with more crops. Kwale farmers linked biochar adoption more closely to monetary support and soil moisture challenges. Nonetheless, in both counties, biochar was framed as a symbol of hope and continuity, suggesting that while motivations diverged, aspirations converged.

For farmers, biochar's value extended beyond technical outcomes; it represented a potential break in cycles of failure and insecurity. This perception motivated the willingness to purchase biochar to meet their need for the entire farm, though concerns about future affordability were common. Farmers expressed hope that biochar would remain accessible and supported with training, while fearing that commercialisation could price out smallholders, as had occurred previously with fertilisers or hybrid seeds. Some expected that NGOs or projects introducing biochar would provide ongoing support, reflecting a mixture of aspiration and insecurity. Biochar symbolised a chance for long-term stability, but only if surrounding systems remained reliable and inclusive.

Key informants corroborated biochar's technical promise but highlighted constraints in supply and access. One KII respondent noted, *"We lack mass production. Biochar is promising, but not available in large amounts,"* while others warned that continuous access could be undermined by marketisation, high pricing, or elite capture, echoing past experiences where early beneficiaries were later priced out.

Latently, biochar became a symbol of stability, continuity and possibility. Farmers highlighted its "*lasting*" quality in the soil as a reassurance in fragile systems. For many, biochar was not only a soil amendment but as a means of breaking the cycle of high input costs, poor soil, and insecure harvests. Experienced farmers even discussed scaling up biochar production, not just as users but as potential sellers. One youth group in Embu stated*, "If we can make biochar and sell it, it can be a new income,"* reflecting aspirations for financial independence and moving beyond subsistence farming into agribusiness pathways.

Women, particularly, and a few men valued biochar for its health benefits when used as fuel, noting that it produced less smoke and cooked faster when better stoves were available. In practice, farmers referred to the gasifier cookstove here, which allows them to use agricultural residues (such as maize cobs, coconut husks, or firewood) as feedstock. The stove first provides heat energy for cooking, while simultaneously producing biochar as a byproduct. That residue can then be applied to the soil as a soil amendment, or in some cases, reused for cooking fuel.

However, limited biochar and poorly designed stoves restricted their household use. As one women's group in Embu explained, *"It produces less smoke, it's healthy and cooks faster,"* while a group in Kwale noted, "*We could use it for cooking, but the stove design is small and not good,"* referring to the gasifier stoves they were currently using. This inclination to better dual-use technology (biochar for cooking fuel, and biochar production for soil amendment) potential reflects aspirations for integrated systems that support both household well-being and farming stability

Finally, both KIIs and FGDs' findings highlighted how biochar adoption is embedded within farmers' broader social realities. While often framed by external actors as a technical solution, its meaning to farmers is layered with insecurities and historical experiences of top-down aid. Several informants (KII) noted that" *farmers mostly harvest early, even before project visits for data collection*, *"as these crop looks healthy,* reflecting farmers' crisis-preparedness mindset rather than long-term planning.

Another KII respondent explained that *"farmers expect funding, if they know you are from NGOs or projects",* a legacy of past top-down, project-based aid that has conditioned expectations of handouts and dependency towards external initiatives. However, these behaviours should not be read as reluctance or resistance to new practices; rather, they are adaptive strategies, shaped by fears of losing support and a broader loss of confidence in the continuity of assistance from development actors.

While these themes were broadly shared, county contexts shaped their emphasis. In Embu, sustainability was framed primarily through soil fertility concerns, with farmers motivated by curiosity and experimentation. In Kwale, water scarcity dominated discussions, and sustainability was framed more as survival under institutional neglect. Yet across both counties, farmers consistently expressed a desire for training and agency in shaping their futures.

Theme C: Restricted Choice, Scarcity and Gender

Farmers primarily produce biochar using gasifier cookstoves, kilns, or the Kon-Tiki method. However, the volume generated through these techniques is generally modest and often insufficient for large-scale soil application. Farmers trained to use

Kon-Tiki systems also face trade-offs: the heat produced during biochar production is not captured for other uses, and output levels can vary depending on feedstock availability and labour constraints. This situation creates a sustainability dilemma for smallholder farmers: whether to use the limited biochar as a cleaner household fuel or to apply it to the soil for long-term agricultural benefits. To better understand how farmers make this choice under conditions of scarcity, they were asked about their preferred use of biochar: as an agricultural input, as household cooking fuel, or for both purposes. Their responses showed that decisions were influenced not only by resource limitations but also by gender roles, household priorities, and aspirations for more integrated and efficient farming systems.

When households had biochar in hand, they faced a direct choice: apply it to soil or use it as a clean cooking fuel. Across all FGDs, a clear consensus emerged, agriculture came first. Fertile soils and reliable harvests were described as the foundation of both food security and income. As farmers in Kwale put it plainly: *"If I have to choose, I will use it for farming. We can't farm if we don't have good soil"* (Male and female group). Similarly, a mixed group in Embu stressed, *"Better to use it for crops; we can continue using firewood for fuel. Farming is important."* This prioritisation was strategic, not merely a response to fuelwood scarcity; most households had adequate firewood. Biochar was limited, so maximising agricultural benefits (like improving soil fertility, water retention, pest control, and yield) was considered the most strategic allocation. Any surplus might be used for cooking, but soil fertility and crop yields dominated decisions.

Scarcity was further reinforced by upstream limitations in biomass availability. Although gasifier cookstoves provided multiple benefits: they produced biochar while cooking, supplied heat for household needs, reduced smoke, saved time, and improved health. However, their small size, combined with the labour-intensive process of preparing and feeding biomass, was unsuitable for all types of cooking, and the limited output meant that households prioritised applying biochar to soil, where it had the greatest perceived impact on food security. Even when women wanted to use biochar for household energy, these technological limitations shaped allocation patterns, with agriculture remaining the primary use and cooking a secondary yet still valued application.

Decision-making over biochar allocation was also gendered. Male household heads typically had authority over resource allocation, with farming positioned as the priority. While women, though highly aware of cooking benefits such as cleaner energy, often had to defer to farming needs. Their experiences with gasifier stoves shaped this view on biochar's potential use as a fuel: *"If we had better stoves, we would use biochar (replacing firewood) for cooking; it produces less smoke, and* *cooks faster"* (Embu Women's Group). Limited stove efficiency and the small quantities of biochar generated further curtailed women's ability to pursue cooking benefits. Thus, women's preferences for cleaner energy were acknowledged but frequently subordinated to agricultural needs.

Interestingly, some men also mentioned cooking benefits, though often indirectly and framed through women's labour or household harmony. A man in Kwale remarked, *"She can cook anything I ask for, like tea, beans, anything, very fast, and she is very happy with it."* Such statements reveal how men valued using gasifier cookstoves not for their own direct use but in relation to women's domestic responsibilities and their service to the household. Key informants echoed these dynamics, sometimes unintentionally reinforcing traditional gender expectations. One NGO actor described cookstoves' design to reduce smoke, improved marital relations because *"the woman doesn't smell bad anymore after cooking."* While intended as praise, this framing reduces women's experiences to their domestic roles and relational value, rather than recognising women's autonomy, health, or agency. Such narratives illustrate how technologies, even when designed with clear practical benefits, if introduced without deliberate attention to social structures, can inadvertently reproduce existing inequalities. In this case, the perceived benefits of the cookstove extend beyond efficiency or fuel savings to reflect broader gendered expectations, highlighting the importance of considering social context when introducing technological innovations.

A feminist reading of these findings shows that women's prioritisation of farming is not merely pragmatic but shaped by structural inequalities in land access, decision-making, and technology design. Women were positioned as primary labourers for both farming and cooking, yet their ability to decide how biochar was used was constrained by limited supply, male authority over agricultural priorities, and the design of stoves and kilns that did not fit women's daily realities.

Despite these constraints, women expressed hope for integrated, circular solutions where biochar could simultaneously support agricultural productivity and household energy. Improved stove designs, more reliable biochar supply, and supportive institutions were potential enablers of systems in which the same resource could strengthen both food security and household well-being. Prioritising soils over stoves reflects a broader survival-oriented mindset: crops are existential, while cooking improvements, though valued, remain secondary. Biochar embodies both practical utility and aspirational potential, symbolising food security, energy, and household stability.

These findings illustrate that restricted choices are not merely about resource scarcity but are deeply intertwined with gendered labour divisions, decision-making power, and technology design. A feminist reading highlights that integrated, circular systems could allow biochar to reinforce both agricultural and domestic sustainability, rather than forcing restricted choice that entrenches gendered responsibilities.

Together, these findings respond to RQ2 by showing that biochar is perceived both as a useful agricultural input and also as a source of hope and agency, symbolising the possibility of improved food security, self-reliance, and stability in their daily sustainability challenges. These perspectives illuminate the central role biochar plays in farmers' sustainability priorities, linking to the overall research aim.

5.3. Barriers to Biochar Adoption - Navigating Structural Constraints and Social Realities

As described in the findings above, farmers in Embu and Kwale view biochar as a promising tool for addressing key sustainability needs. However, despite this enthusiasm, adoption is constrained by three interconnected challenges: (A) Uneven access to knowledge, (B) resource, financial and structural constraints, and (C) constrained decisions across generations and gender. These barriers are not isolated; they are shaped by historical experiences of exclusion, short-lived in development interventions, and fears that promising innovations will ultimately slip beyond their reach.

Theme A: Uneven Access to Knowledge - A call for training and self-reliance

Knowledge about biochar production and application varied widely across groups. While some experienced farmers, particularly those involved in project trials, understood recommended practices (e.g., Kiln use, mixing with manure, applying in furrows) but the uncertainties persisted even among this group. Questions ranged from dosage and crop suitability to possible long-term soil effects. As a farmer from the elders group, Embu questioned, *"Is there any disadvantage to the continuous application of Biochar on soil like chemical fertiliser? How much is the right amount?"*. While younger farmers, Embu raised environmental concerns about the production process in Kontiki:*"Doesn't making biochar by burning create pollution, and does the soil around that become bad?"*. Such questions reflect caution and a desire to understand the long-term implications of biochar before committing to its widespread use. Farmers' concerns stem from past experiences with chemical fertilisers that, while initially beneficial, eventually degraded soils and created cycles of dependency. Their probing reveals a determination not to repeat those mistakes.

These reflections highlight that farmers are not passive recipients of new practices. Rather, they are experimenting, questioning, and critically evaluating technologies like biochar within their own ecological and livelihood contexts. Their engagement demonstrates an active pursuit of sustainability on their own terms, balancing innovation with lessons from history. At the same time, their concerns about long-term soil health, environmental impacts, and appropriate application rates illustrate a key adoption barrier: without clear, context-specific evidence and trusted guidance, uncertainty can outweigh perceived benefits. This reinforces the need for participatory approaches and knowledge co-production that address farmers' questions directly, building confidence while aligning biochar adoption with local priorities.

Newly interested farmers often relied on peer learning and visible results, leading to enthusiasm (*"Where do we get biochar from?" "Can you use it in different ways?"*) but also preconceptions such as viewing biochar as a complete replacement for manure, fertiliser, or even pesticides. Across groups, farmers stressed that new technologies (other than biochar as well) are often introduced without sufficient follow-up, leaving them dependent on trial-and-error. As one farmer participant, Embu. put it: *"If they came to train us, maybe we could farm better. But they don't come."* Key informants confirmed that without consistent engagement and technical support, *"even trained farmers revert to old practices"*.

This pattern reinforces a broader perception that sustainability projects can become temporary and unreliable, something to benefit from while they last, but not to rely on for the long term. Beneath the technical gaps lies a deeper aspiration: farmers want to make informed decisions that protect their soils and livelihoods in the long term, not just receive instructions. So they can adopt biochar with confidence and without dependency on external actors.

Theme B: Resource, Financial and Structural Constraint - The Scarcity Trap

Even when biochar was valued and perceived as effective, resources and financial limitations restricted their ability to adopt, produce or scale it. These constraints surfaced across many groups, revealing both logistical barriers and deeper insecurities about long-term access and sustainability. Feedstock scarcity driven by deforestation, low rainfall, and declining yields reduces the availability of residues like maize cobs or firewood.

While farmers recognise biochar's long-term cost-saving potential, many lack the upfront means to produce or purchase enough for larger plots. The fear that commercialisation will put biochar out of reach was repeatedly voiced: *"If they start selling it, the price will go high, and we can't afford it"*–Participant, Kwale.

KIIs echoed these concerns, noting that market-driven supply often benefits better-connected farmers first, leaving remote or poorer households excluded. One participant described a commercial model in which farmers sell residues for biochar production but still *"have to buy the finished product at a possible low cost."* While presented as a win–win, this keeps farmers as buyers rather than co-owners, reflecting an imbalance in benefit distribution. The same interviewee admitted that reaching remote areas is *"too hard without support from local government and extension bodies,"* reinforcing focus groups' concerns that access is patchy and tied to project proximity.

Without targeted support, biochar risks remaining within reach only of better-connected farmers, deepening existing inequalities. Farmers' willingness to buy, share, or scale biochar shows commitment but also highlights that adoption is contingent on systemic support, not just individual effort.

Theme C: Intersecting Social Dynamics - Constrained Decisions across Generations and Gender

As discussed earlier, limited biochar supply and small, labour-intensive cookstove designs force households, especially women, to prioritise soil application over cooking fuel. These constraints illustrate how technical solutions, when misaligned with daily realities and labour demands, create adoption barriers and limit the full benefits of biochar. Farming remained the primary livelihood priority, yet women emphasised biochar's potential to improve household health and reduce cooking labour, benefits they could only realise with better-suited technology. This mismatch forces women into restricted choices that could be avoided through an integrated, gender-responsive design.

As one KII respondent observed, "*Why should women have to choose between cooking and agriculture? Why can she not have access to both?"* underscoring structural constraints rather than simple preferences. Another noted, *"Women can do better if provided with better opportunities,"* highlighting embedded gender inequities. Without addressing these embedded constraints alongside feedstock scarcity and competing household uses, adoption will remain uneven and potentially reinforce existing inequalities.

Youth participants described additional hurdles, such as generational resistance: *"It is hard to convince the elders unless they see proof on their fields"* (Youth group, Embu) and the spread of misinformation, land issues, and reluctance to try new methods until visible results are seen. This underscores the importance of trust-building, demonstrations, and consistent support rather than relying on one-off technical dissemination.

Beneath these constraints lies a cautious optimism: farmers see biochar as an investment in their soils and future harvests, but worry that without secure feedstock access, fair pricing, and ongoing training, its promise may remain limited or slip away or benefit only a few. Scaling biochar effectively also requires "*integrating it into carbon markets, strengthening supply chains, and providing continuous extension services"*, as one KII noted. But it is hindered by "*time and labour scarcity, trust issues, and technology knowledge gaps."* KII stressed the need for reliable services, stronger value chain linkages, and sustained extension support to move biochar beyond pilot phases, positioning it as a realistic long-term solution for biochar needs rather than a short-lived intervention.

These findings addressing RQ3 illustrate that adoption constraints are less about willingness and more about systemic inequalities, institutional gaps, and technology misalignment. Understanding these intersecting structural, emotional, social, gender, and generational dynamics situates biochar adoption within the broader realities of smallholder sustainability priorities.

6. DISCUSSION

This chapter links the empirical findings presented in Chapter 5 to the relevant literature, theories, and concepts, drawing out key insights about sustainability and biochar adoption in Embu and Kwale counties. The discussion situates farmers' lived experiences within the classical SLF (Chambers & Conway, 1992), contemporary critiques, and emerging expansions such as Natarajan et al.'s (2021) SLF for the 21st century. The discussion further integrates concepts such as affective power and constrained agency (Jakimow, 2022; Manlosa, 2022) and other scholars. Similar studies conducted for smallholder farming systems are used to contextualise findings. The chapter addresses the three research questions sequentially, highlighting thematic connections and systemic constraints.

6.1. Sustainability as Lived Experience

Farmers' narratives highlighted *uendelevu* (sustainability) as a lived reality, negotiated daily through farming, household survival, and community relations. Sustainability was understood as a fragile balance between ecological stability, economic viability, and social dignity anchored in historical memory, daily struggles, and aspirations for autonomy over the future. This relational understanding extends the SLF (Chambers & Conway, 1992). While the SLF captures natural, human, financial, social, and physical capital, farmers' accounts showed that sustainability hinged less on assets alone than on the power to act within structural limits, as Manlosa's (2022) concept of constrained agency. The emotive understanding of sustainability, like dignity, pride, and emotional security, as seen in my findings, is largely absent in the apolitical SLF. This resonates with Jakimow's (2022) call to account for affective power in development: emotions such as pride in self-reliance ("no longer depending on fertiliser") or shame in dependency mediate choices and expose blind spots in purely material framings.

Smallholder farmers' perceptions of sustainability are deeply shaped by local environmental realities. Farmers reported experiencing erratic rainfall, declining soil fertility, water scarcity, pest and disease pressures, and other environmental shocks that directly constrain agricultural sustainability. Similar patterns are documented in Zimbabwe, where smallholder farmers' perceptions of climate and sustainability were highly contextual and shaped by local environmental realities (Mtambanengwe et al., 2012). In contrast, Baccar et al. (2020) found that farmers in Morocco's Saïs plain understood sustainability mainly through an economic lens, with environmental concerns considered only when resource scarcity made them unavoidable. In Kenya, farmers also prioritised material survival within fragile ecologies and economies, but their narratives extended further, revealing underlying emotional concerns such as dignity, trust, and hope. This underscores how sustainability is not a fixed idea but a contextual one, shaped differently by the pressures and lived experiences of each setting.

Farmers' definitions of *uendelevu* reflect not only what they lacked (land, water, inputs, support) but also what they needed to thrive: reliable knowledge, tools, and autonomy in decision-making. This aligns with Pretty et al. (2011), who argue that ecological improvements alone are insufficient without affordable inputs and market access. Repeated claims that *"money solves everything"* express not just material need but the aspiration for agency, echoing Manlosa's (2022) concept of operationalising agency in sustainable development. These challenges further illustrate how ecological variability interacts with resource limitations, influencing both production outcomes and adaptive capacities.

Farmers' perceptions of sustainability were differentiated by generation and gender. In line with Huijsmans et al. (2020), older farmers' accounts reflected adaptive aspirations, a focus on restoring soils, safeguarding food today, and keeping farms viable under uncertainty, while younger farmers voiced more transformative aspirations centred on agribusiness, markets, and innovation. These orientations were also shaped by historical memory and positionality within livelihood systems. As Natarajan et al. (2022) highlight, livelihoods are best understood as situated within historic, temporal and social contexts, rather than being defined only in terms of assets. Women's experiences are shaped by both agricultural and domestic labour responsibilities, often with limited decision-making power *("we want support from our spouse"*), reflecting longstanding evidence that households are not unitary decision-makers (Doss, 2001). These dynamics influence which sustainability strategies are feasible and whose aspirations are prioritised.

Farmers' conceptions of *uendelevu* were deeply influenced by institutional support or the lack thereof. Farmers' sustainability horizons were actively constrained and reshaped by institutional gaps, embedding their understanding of what is possible or realistic. Institutional failings and sporadic support, as Musafiri et al. (2022) argue, undermine adaptation by eroding trust and agency rather than enabling transformative change, a barrier to climate adaptation. Statements such as *"train but do not return*" highlight how one-off interventions fail to support meaningful learning or long-term adoption. Broader structural and historical inequalities also shape what is considered feasible, as underscored by Natarajan et al. (2022), emphasising the importance of multi-scalar, context-sensitive approaches. The institutional neglect sharpened farmers' conviction that sustainability requires co-created knowledge systems and enduring partnerships rather than externally imposed models (Pretty et al., 2011). Without addressing these systemic imbalances, technical knowledge transfer alone is unlikely to secure farmers' visions of sustainability.

In sum, farmers' understanding of sustainability in Embu and Kwale emerges from the complex interplay of everyday challenges. Their concept of *uendelevu* reflects both pragmatic coping strategies and longer-term aspirations, highlighting that sustainability is not a uniform ideal but a socially and contextually embedded practice.

6.2. Biochar in Practice: Perception of Smallholder Farmers

This subsection discusses how farmers came to view biochar as both promising and uncertain, highlighting dynamics of knowledge, diffusion, and local experimentation.

A: Shared Promise, Uneven Knowledge, Local Experimentation

Farmers' perceptions of biochar were shaped by both excitement and uncertainty. Across sites, it was widely recognised as something that works, yet understanding of how and why varied. Some pointed to visible changes in soil conditions and yields, while others relied on neighbour observations *("I saw crops grow taller where charcoal was used").* This reliance on social proof illustrates Rogers' (2003) principle of observability: technologies diffuse more readily when their effects can be seen.

Economic framings revealed generational differences. For many, biochar's value lies in reducing fertiliser costs, strengthening their financial capital within the SLF (Chambers & Conway, 1992). Younger participants, however, described biochar as an entrepreneurial opportunity (*"can sell biochar"),* echoing Huijsmans et al.'s (2020) insights that youth often link sustainability innovations to aspirational futures. In UTAUT terms (Venkatesh et al., 2016), both groups expressed performance expectancy, but in distinct forms: cost-saving for older farmers, business potential for youth.

Yet, knowledge gaps and misconceptions (e.g., that biochar alone could replace fertiliser) limited adoption, also echoing Jeffery et al.'s (2017) caution about over-optimism and agronomic realities. These reveal weak facilitating conditions (UTAUT) and highlight Scoones' (2009) critique of short, projectised extension services.

Farmers also responded through their own experiments, testing feedstocks and other uses. This aligns with Manlosa's (2022) notion of operationalising agency: even within constraints, farmers adapt technologies to fit local routines. Rather than passive recipients, farmers acted as experimenters, translating biochar into locally meaningful practices, echoing Pretty et al.'s (2011) argument that sustainable intensification requires co-created knowledge. Similar peer-driven adaptation was observed in Zimbabwe (Mtambanengwe et al., 2012); the adoption of conservation agriculture hinged much on peer-to-peer experimentation than on training. It also suggests that when technology aligns with daily routines, farmers are ready to innovate and adapt, echoing Rogers' (2003) concept of reinvention, where adopters find new, locally meaningful ways to use an innovation (eg, farmers using biochar as an incubator for chickens).

In sum, farmers' experimentation revealed both the promise and fragility of biochar: while it inspired innovation, uneven knowledge and weak institutional support meant that its value often depended on social learning. This provides the foundation for examining how farmers came to see biochar not only as a tool for agriculture, but also as a symbol of broader hope.

B: Tangible Gains and Symbolic Hope

Building on these dynamics of knowledge and experimentation, this subsection turns to what farmers valued in biochar, both in its tangible agronomic benefits and its symbolic meaning as hope and autonomy hinged on theories.

Farmers consistently linked biochar to their most pressing livelihood priorities, emphasising its tangible agricultural gains. Narratives foregrounded immediate technical benefits such as improved soil moisture retention (Basso et al., 2013), enhanced soil fertility and pH buffering, and increased crop yields (Lehmann et al., 2015; Biederman & Harpole, 2013; Roobroeck et al., 2019; Kätterer et al., 2022). These accounts resonate with a wide body of agronomic research confirming biochar's capacity to improve soil structure, nutrient-use efficiency, and crop resilience under stress. Farmers also highlighted pest control benefits, particularly in reducing nematode pressure, an observation that aligns with the findings of Ikwunagu (2019) and Poveda et al. (2021). Beyond agricultural outcomes, biochar's potential for clean energy fuel reinforces insights from Njenga et al. (2020), Gitau et al. (2019) and Mahmoud et al. (2021), who noted its dual role in both farming that improves soil fertility and household energy systems.

Biochar's capacity to "revive tired soils" and "reduce fertiliser costs" spoke directly to farmers' sustainability needs. These outcomes strengthen both natural and financial capitals in the SLF (Chambers & Conway, 1992) and align with Venkatesh et al.'s (2016) UTAUT's performance expectancy, the degree to which farmers believe biochar will improve their agricultural productivity and livelihood outcomes.

At the same time, Biochar also embodied hope and autonomy. Farmers described it as *"staying in the soil*" or freeing them from fertiliser dependence, representing self-reliance, dignity, and the possibility of stable yields. This resonates with Jakimow's (2022) idea of affective power, where technologies embody hope, fear and pride and Huijsmans et al.'s (2022) notion of aspirational futures. Yet, these aspirations were fragile: concerns over commercialisation and inequitable access highlighted that the potential benefits of biochar could be constrained by broader structural inequalities and historic experience, limiting who could actually benefit from interventions more generally (Natarajan et al., 2022).

Together, these findings reveal biochar as both an input and a symbol: it provides tangible agronomic improvements while representing hope, self-determination, and cautious optimism. Frameworks help unpack these dual meanings: SLF and UTAUT explain practical benefits (enhancing capital and performance expectations), while affective power and constrained agency illuminate the symbolic resonance and aspirational significance of biochar.

C: Restricted Choice, Scarcity and Gender

Biochar's dual potential as soil amendment and fuel was widely recognised, but scarcity forced prioritisation. Farming almost always took precedence, showing how livelihood capitals (SLF) and survival logics dominate decision-making.

For women, clean cooking and reduced smoke were meaningful benefits, but stove design flaws, feedstock scarcity, and extra labour constrained adoption. These reflect UTAUT's facilitating conditions: without enabling infrastructure, adoption falters (Nguyen et al., 2023), even valued technologies like biochar. Williams et al. (2018) highlighted that gendered vulnerabilities are frequently overlooked in adaptation and technology design. Women's "choices" were not neutral but also shaped by structural constraints: expectations around care, labour, and food provision. Men's comments *("my wife is happier"; "she cooks faster*"; "*improving marriages because women smell better")* highlight how benefits were framed relationally, echoing critiques that women's agricultural and care work is often rendered invisible (Doss et al., 2018). Natarajan et al.'s (2022) call for a relational

SLF highlights that without addressing historical and structural inequities, gender-neutral innovations may risk reproducing inequalities rather than reducing them.

Gendered experiences of sustainability and biochar adoption also revealed dimensions that go beyond material access to resources. In particular, women's accounts pointed to the often invisible forms of work they carry out in sustaining households and livelihoods. This resonates with the concept of Hardt & Negri*'s* affective labour, which refers to the work of producing and managing emotions, care, and relationships, forms of labour that are often unpaid, invisible, and disproportionately carried by women (Hardt 1999; Weeks, 2007; Singh, 2013). Together, these critiques reveal how "gender-neutral" approaches risk reinforcing inequities. Singh (2013) extends feminist debates on affective labour by showing how caring and emotional work, often unpaid and gendered, is central to social and economic life yet remains undervalued. This lens helps interpret how, in development contexts, women's unpaid emotional and care work can become further entrenched rather than transformed. In this study, women valued biochar for its clean cooking and health benefits, but their decision-making power remained constrained. At the same time, they expressed aspirations for integrated systems, showing practical resourcefulness in adapting biochar to meet both agricultural and household needs despite structural limits, reflecting Manlosa's (2022) concept of operationalising agency under constraint.

Thus, SLF and UTAUT reveal how scarcity and enabling conditions influence use, while feminist critiques and affective labour highlight how those dynamics are gendered. The result is not "choice" but constrained agency and practical resourcefulness actively negotiating structural limitations to derive both agricultural and household benefits.

6.3. Barriers to Biochar Adoption – Navigating Structural Constraints and Social Realities

Farmers' interest in biochar was positive, but adoption was uneven due to gaps in knowledge and institutional support, limited resources, and gendered or generational norms. Examining these barriers through the SLF and the UTAUT highlights how structural constraints limit agency and influence farmers' decision-making. These challenges illustrate how even promising technologies are hindered by embedded structural inequities.

A: Knowledge Gaps and Institutional Failures: The Cycle of Partial Adoption

Farmers' engagement with biochar was often inconsistent, reflecting uneven dissemination, fragmented support, and limited follow-up. From an SLF perspective, these dynamics reveal deficits in human capital (skills and knowledge) and institutional capital (extension support, reliable access to information). As DOI literature and participatory technology design critique dominant linear adoption models, which often assume uniform scalability, overlooking local knowledge, priorities, and context-specific constraints (Rogers, 2003; Pretty, 2011).

While some farmers, particularly those involved in trials, demonstrated proficiency in biochar production and application, many others lacked technical knowledge, such as optimal application rates or suitable feedstocks. This led to non-recommended practices (e.g., complete substitution of fertilisers) reflecting the gap between anticipated and actual outcomes, as observed by Jeffery et al. (2017). Farmers without access to knowledge relied on social proof, observing neighbours' practices, a process Rogers (2003) identifies as a driving force in adoption through observability.

This partial adoption is reinforced by weak facilitating conditions, a central concept in UTAUT, which erodes farmers' confidence in performance and effort expectancy (Venkatesh et al., 2016). Similar studies in developing countries show that integrated farming systems only improve livelihoods when institutional support aligns with local experimentation; otherwise, innovations are unevenly adopted (Goswami et al., 2016).

The recurring complaint of lack of training reflects Scoones' (2009) critique of project-based interventions that neglect long-term capacity building. This erodes trust and reinforces perceptions of external actors as unreliable. Climate-smart interventions that assume linear scaling often overlook farmer priorities, producing shallow adoption (Musafiri et al., 2022).

Some farmers assume biochar can completely replace conventional fertilisers, but its effects are highly soil-dependent and may be harmful in the long term. For instance, in well-structured soils, it may improve yields but can cause nutrient imbalances, decrease water retention over time (Brtnicky et al., 2021). These limitations further underscore the importance of knowledge sharing and farmer empowerment to ensure biochar is adopted correctly, applied effectively, safely, and in combination with other soil amendments like compost or nitrogen fertilisers (Haider et al., 2024; Rajkovich et al., 2012).

Farmers' calls for regular training reflect a desire not just for technical skills but for recognition as knowledge producers. Co-created knowledge systems, integrating scientific guidance with local experimentation, align with Pretty et al.'s (2011) argument that sustainable intensification requires active farmer participation. Manlosa (2022) further emphasises that empowering smallholders requires participatory adaptation, continuous engagement, and recognition of farmers as active knowledge producers rather than passive recipients only. These dynamics also reveal affective dimensions of hope, pride, and frustration as discussed by Jakimow (2022) and generational aspirations highlighted by Huijsmans et al. (2020).

Across Africa, vulnerability assessments and extension services often under-engage local perspectives, producing findings with limited practical relevance (Williams et al., 2018). Extension frequently lacks biochar-specific know-how and contextualised materials (Colclasure et al., 2024), and adoption falters without long-term engagement and peer-to-peer learning (Manlosa, 2022). In Kenya specifically, Kyalo et al. (2025) show that awareness, education, credit access, and land tenure arrangements shape biochar adoption intensity, explaining why train-and-exit models underperform.

Bringing this back to adoption theory, these realities depress observability and trialability, key drivers in diffusion (Rogers, 2003) and undermine performance/effort expectancy and facilitating conditions central to UTAUT (Venkatesh et al., 2016). The barrier is therefore not farmer receptivity but institutional architecture that fails to sustain learning, lower risk, and recognise farmers as knowledge producers.

B: Resource and Financial Constraints: The Scarcity Trap

Even when knowledge exists, material constraints limit adoption. Farmers frequently cited difficulty securing sufficient feedstock amid deforestation, declining yields, and competing household needs. It is important to recognise that these constraints are not solely socio-economic; they also reflect biophysical limits. The quantity of locally available biomass sets an upper bound on biochar production, meaning that farmers' aspirations for abundant biochar can only be partially met through improved technology, social organisation, governance, or management. These biophysical constraints interact with livelihood factors, as biochar adoption is also intimately tied to farmers' access to land, residues, labour, and time, highlighting the interconnected roles of natural and financial capital in shaping adoption (SLF). This aligns with Pretty et al. (2011), who emphasise the need for integrated resource solutions for sustainable intensification.

Fears of commercialisation and elite capture echo broader histories of exclusion, showing how structural inequities shape adoption. Farmers' cautious optimism coexisted with fear, reflecting past experiences where externally introduced solutions became inaccessible and uniform scaling models often overlook contextual barriers such as socio-economic, cultural, and agroecological diversity (Natarajan et al., 2022; Musafiri et al., 2022). These emotional responses echo Jakimow's (2022) affective dimensions of hope and fear of dependence and exclusion.

Baccar et al. (2020) similarly highlight that in resource-constrained environments where water, soil fertility, and other inputs are limited, farmers' perceptions of sustainability often diverge from externally defined frameworks. In such contexts, farmers focus on immediate economic survival and practical management of their own resources, rather than broader environmental or long-term sustainability goals. This divergence shapes adoption behaviour, producing uneven uptake of innovations as farmers selectively engage with technologies that align with their immediate priorities and capacities.

Comparative literature converges on similar institutional fault lines. In Kenya, households adapt incrementally but struggle to invest in higher-cost changes without institutional and financial scaffolding (Bryan et al., 2013). As Manlosa (2022) argues, livelihood sustainability hinges not just on resource access but on agency-centred systems that allow smallholders to adapt technologies without undermining survival priorities.

C: Social and Generational Hurdles

Barriers were not solely material. Gender norms and social expectations shaped who could benefit from biochar. Women's domestic responsibilities (as discussed in 6.2.C) often constrained their ability to adopt and integrate new technologies, even when they stood to gain from reduced smoke, faster cooking, and improved health (Doss et al., 2018; Williams et al., 2018). From an SLF lens, these constraints intersect social and human capital, shaping access to knowledge, labour, and decision-making power. While SLF does not explicitly foreground gender, integrating feminist critiques highlights how these capitals are mediated by gendered norms and roles. UTAUT complements this perspective by showing how weak facilitating conditions, such as limited training, infrastructure, or supportive institutions, particularly constrain women's adoption and effective use of biochar.

Generational hierarchies also affected adoption. Younger farmers reported difficulty convincing elders of biochar's value, reflecting Rogers' (2003) emphasis on social influence and the need for peer validation in innovation uptake. Elders prioritised soil stability and survival (adaptive aspirations), whereas youth viewed biochar as a pathway to entrepreneurial opportunities (transformative aspirations) (Huijsmans et al., 2020). Without mechanisms to bridge these orientations, intergenerational differences risk stalling adoption.

Overall, biochar adoption is not merely a technical choice but is constrained by interlinked knowledge, resource, and socially embedded processes shaped by norms, trust, and community structures. Barriers extend beyond technical feasibility to questions of who controls the technology, who benefits, and who bears the costs (Jakimow, 2022). SLF and UTAUT elucidate how structural constraints, limited facilitating conditions, and performance expectations shape adoption, while feminist and affective frameworks illuminate how these constraints are experienced emotionally and relationally. Adoption thus reflects constrained agency, with farmers actively negotiating opportunities and limitations, demonstrating incremental adaptation and ingenuity despite social and structural challenges.

7. CONCLUSION

Biochar offers clear potential for sustainable agriculture and climate change mitigation among smallholder farmers in Kenya, with reported benefits including improved soil fertility, higher yields, reduced fertiliser costs, cleaner household energy, and lower pest pressure. Adoption, however, is influenced not only by technical performance but also by social, cultural, emotional and institutional realities, including gender norms, resource constraints, and access to training and support.

Effective biochar adoption requires an integrated approach to bridge the gap between farmers, local stakeholders, research, and policy support; ensuring that biochar technologies are accessible, affordable, and adapted to local conditions. Farmers' engagement and entrepreneurial interest in biochar can transform them from passive recipients to active co-producers, but success ultimately hinges on whether the technology aligns with farmers' lived realities, not just scientific promise.

By integrating technical, emotional, social, and institutional perspectives, biochar can move from fragile experimentation toward sustainable agricultural transformation, contributing to both local livelihoods and broader climate change mitigation goals.

Policy Implications

- Support participatory, farmer-led programs that integrate biochar into broader livelihood strategies, ensuring that adoption aligns with farmers' existing agricultural and household priorities.

- Provide sustained, gender-responsive extension services including training, workshops, and on-field demonstrations to strengthen farmers' knowledge and maintain capacity even when technical support is limited. This ensures that acquired knowledge is effectively translated into practice.

- Promote equitable access to feedstock, markets, and technology through community-based resource management, participatory allocation mechanisms, and farmer engagement in planning and oversight. This helps ensure transparency, fair benefit distribution, and safeguards against elite capture. In both public and private ventures, farmers organised through cooperatives, self-help groups, or commodity interest groups should have equal participation and decision-making rights in large-scale commercial biochar production, ensuring that beneficiary communities remain fully included in resource management and that local priorities are respected.

- Facilitate farmers' entrepreneurial engagement in biochar production through small-scale cooperatives, self-help groups, or community-based production models supported with seed funding. This approach enables farmers to participate as co-producers while meeting local demand.

- Technologies should be designed using context-sensitive and participatory approaches that consider farmers' lived realities and gender norms. Such approaches should aim to reduce women's labour burden and generate tangible benefits without reinforcing existing inequalities, thereby ensuring that biochar and cookstove innovations align with household and agricultural needs while empowering women.

Future Research

- Assess long-term socio-economic and environmental impacts of biochar adoption.
- Future studies could include a broader cross-section of farmers, including non-beneficiaries and those hesitant to adopt Biochar, to provide a more balanced understanding of perceptions, barriers, and challenges.
- Examine gendered dimensions of labour, decision-making, and resource access.
- Explore co-created knowledge systems that merge scientific expertise with farmers' experimentation.
- Identify effective adoption and dissemination strategies tailored to diverse contexts.
- Evaluate integrated models of farmer-led biochar production, training, and market access for sustainability and resilience.
- Understanding the potential of biochar in crop protection.

Limitations

This study was subject to several limitations. One limitation was the language barrier, as participants spoke unfamiliar local dialects, although some farmers spoke English at a basic level. To address this, translators were employed during FGDs to assist communication and to reflect participants' views as closely as possible. Nonetheless, some nuances or subtle meanings may not have been fully conveyed in translation. In addition, the study focused on biochar project beneficiaries and farmers interested in adopting the technology. While participants provided valuable insights into adoption barriers, their generally positive disposition toward biochar may have led to a positive selection bias, potentially overrepresenting perceived benefits. As a result, the findings may not fully capture the perspectives of non-participating or sceptical farmers. Furthermore, the findings are context-specific to smallholder farmers in Embu and Kwale counties. Caution should therefore be exercised when generalising these results to other regions. Nevertheless, they offer valuable insights that can inform similar initiatives elsewhere, provided local socio-ecological and cultural contexts are taken into account.

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Popular science summary

Smallholder farmers in Kenya face multiple challenges, including declining soil fertility, unpredictable rainfall, and dependence on biomass fuels. These challenges threaten both their livelihoods and food security. Biochar, a carbon-rich material produced from agricultural residues, has been promoted as a climate-smart solution to improve soil fertility, water retention, and crop yields. However, its adoption among smallholder farmers has been limited.

This study explored how farmers in Embu and Kwale counties understand sustainability, perceive biochar, and navigate barriers to adoption. Using interviews and focus group discussions, the research highlighted that farmers value biochar not only for its practical benefits in farming but also as a tool that enhances their sense of control, resilience, and hope in fragile agricultural systems. Farmers experimented with biochar in various ways, such as using it to improve soil fertility, repel pests, or even as an incubator for poultry, showing creativity and agency in adapting the technology to their needs.

The study also found that adoption is shaped by structural, social and emotional factors. Peer learning, community narratives, and visible results encouraged use, while past intervention failures, lack of access to knowledge, fears of exclusion, and rising costs limited the engagement. Gender roles also influenced how biochar was used, particularly linking women to domestic applications like cleaner cooking.

Overall, the findings emphasise that promoting biochar requires more than technical feasibility; it needs sustained, farmer-centred support, participatory approaches, and the empowerment of farmers through knowledge, while also considering social, cultural, and emotional dimensions. By understanding farmers' perspectives, this research contributes to strategies that can make biochar a meaningful and sustainable solution for smallholder agriculture in Kenya.

Appendix 1 Questionnaire Focus Group Discussion

1. *What does Sustainability/* "*uendelevu"* (equivalent to sustainability in Swahili) mean to you?
2. *What are the sustainability challenges you face in your daily life?*
3. *Does biochar address any of these challenges you mentioned above?" How does it help? Any other challenges you want to add?*
4. *Does biochar address these challenges you mentioned above? Where do you think biochar helps address these needs? How?*
5. *Where do you think biochar fits best for your needs, agriculture and energy source (if it does)? Which one, or both? Why agriculture/energy and why not ?"*
6. *What are the benefits of Biochar in Agriculture that you have observed?. (This question was added in the field as biocar use in agriculture became central to the discussion.)*
7. *Would you like to continue using a Biochar? Why and why not? What are the challenges in adopting biochar (if any)?*
8. *What kind of support (financial, technical, policy, incentives) would help in adopting biochar?*
9. *Follow-up: "Would you be willing to use biochar if this support were provided?*
10. Do you have any feedback or suggestions? Did we miss anything that you wanted to share?

Appendix 2: Questionnaire Key Informants Interview

1. *From your perspective, what are the key sustainability issues that are faced in your community today?*
2. *What sustainability aspects do local stakeholders prioritise, and what else beyond farming?*
3. *What challenges do you encounter in promoting or implementing sustainability initiatives? Example?*
4. *How do you engage with other stakeholders (e.g., government, community groups) on sustainability issues?*
5. *What policies or strategies have been most effective in advancing sustainability in your sector?*
6. *How do economic, social, and cultural factors influence sustainability decision-making in your role?*
7. *What opportunities exist for improving sustainability outcomes at the local level?*
8. *Are you aware of Biochar, and what's your experience with Biochar?*
9. *Can Biochar address any sustainability issues that you have mentioned?*
10. *Where does biochar fit within broader local sustainability concerns?*
11. *What kind of support would help in increasing biochar adoption?*
12. *What recommendations do you have to address sustainability practices?*
13. *Is there anything else you'd like to add?*

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