

# **IMPACT OF MOBILE MONEY ON CLIMATE SMART AGRICULTURAL PRACTICES AND GHG EMISSION REDUCTION IN KENYA'S AGRICULTURAL SECTOR**

**A Thesis**

**Submitted to the Master's Study Program of MFin in Sustainable Finance in partial fulfillment of  
the requirements for the degree of**

**Master of Finance (M.Fin.)**



By:

Ruwaida Mohamed Majid

03222320004

UNIVERSITAS ISLAM INTERNASIONAL INDONESIA

DEPOK

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## ACKNOWLEDGEMENT

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## **ABSTRACT**

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This study investigates how mobile money facilitates the adoption of climate-smart agricultural (CSA) practices and reduces greenhouse gas (GHG) emissions through waste-to-energy transitions in Kenya's agricultural sector. Despite agriculture being a major contributor to Kenya's GDP, farmers face severe financing constraints, receiving only 3.5% of total bank lending in 2023, which limits their ability to invest in sustainable technologies. This financial exclusion presents a significant barrier to climate mitigation and adaptation, particularly among smallholder farmers vulnerable to weather volatility and rising GHG emissions. Using monthly time-series data from 2008 to 2024, this study applies the Autoregressive Distributed Lag (ARDL) model to analyze the impact of mobile money and financial inclusion on CSA adoption and GHG emissions. A scenario and sensitivity analysis were also conducted to evaluate farmers' potential earnings from carbon credit sales through briquette compaction and organic fertilizer production. The results indicate that a 1% increase in mobile money use reduces GHG emissions by 0.384%, while a similar rise in financial inclusion leads to a 0.217% decline. Moreover, the scenario and sensitivity analysis reveal a compounding pattern: carbon revenue increases with both carbon price and adoption scale. At just 5% adoption and \$20/tCO<sub>2e</sub>, briquette compaction can yield \$31.36 (KES 4,547) per farmer per month, enough to lift some above Kenya's rural poverty line of KES 3,252/month. Even at base-case levels (\$10, 1% adoption), farmers can earn KES 1,134/month, which can cover school fees or repay input loans. The study concludes that mobile money is a scalable tool to close the agricultural finance gap, enhance CSA adoption, and operationalize Kenya's climate ambitions.

*Keywords: Climate Smart Agriculture, Carbon Finance, GHG Emissions, Mobil*

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## LIST OF ABBREVIATIONS

GHG	:	<i>Greenhouse Gases Emissions</i>
CO <sub>2</sub>	:	<i>Carbon Dioxide</i>
CH <sub>4</sub>	:	<i>Methane</i>
N <sub>2</sub> O	:	<i>Nitrous oxide</i>
PPM	:	<i>Parts per million</i>
PPB	:	<i>Parts per billion</i>
IPCC	:	<i>The Intergovernmental Panel on Climate Change</i>
DIT	:	<i>Diffusion of Innovation Theory</i>
MMUI	:	<i>Mobile Money Usage Index</i>

# CHAPTER 1 INTRODUCTION

## 1.1 Research Background

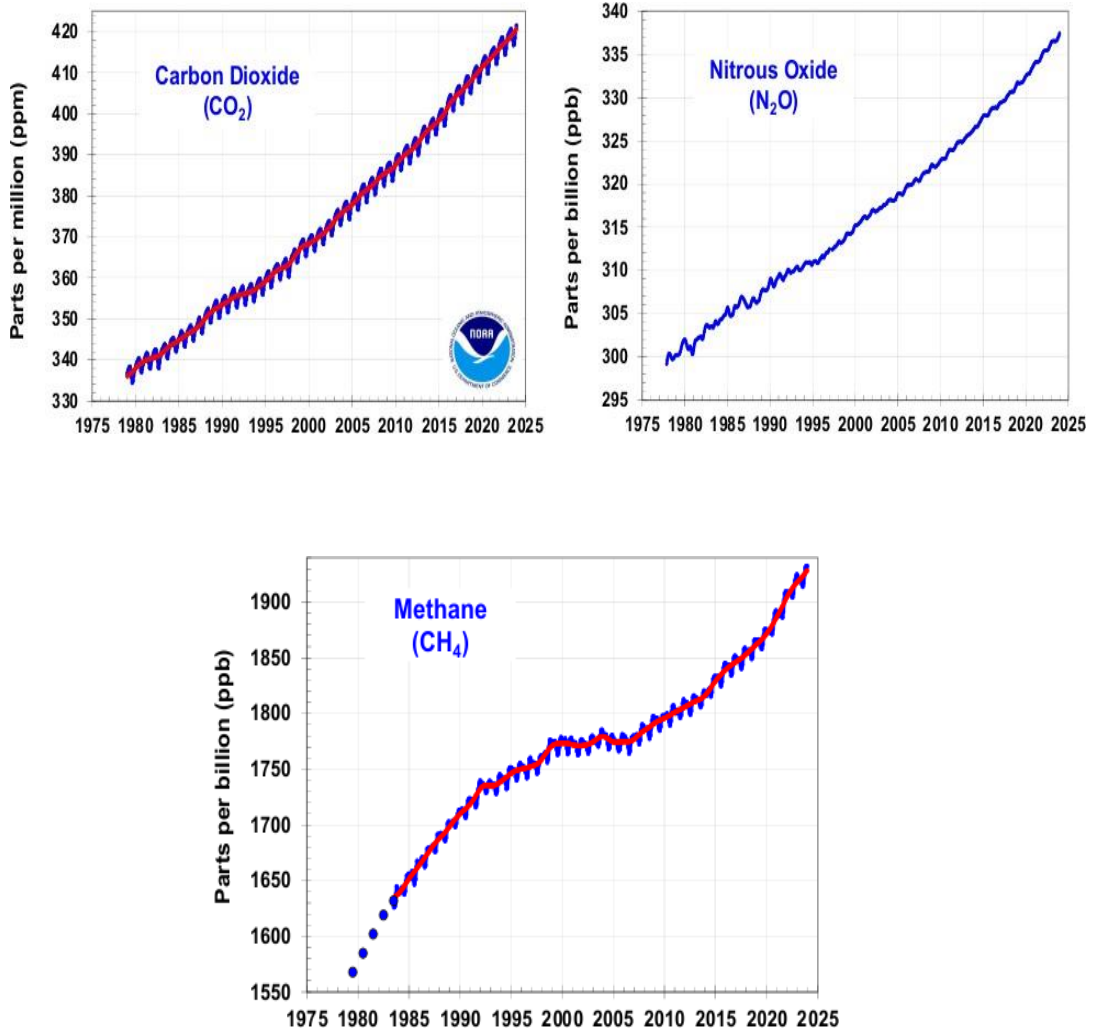
Climate change is among the most significant challenges of our time, profoundly affecting ecosystems, economies, and livelihoods worldwide. Over the past century, greenhouse gas concentrations, which were stable for millennia, have surged to unprecedented levels (Anand, 2023). Gases that trap heat in the atmosphere are called greenhouse gases. The three most common and significant contributors to global warming are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). Since the industrial revolution, the substantial rise in atmospheric greenhouse gases primarily stems from human activities, significantly contributing to the rise of global temperature (IPCC, 2021). Figure

1.1. depicts this sharp ascent, demonstrating significant spikes in GHG concentrations. For instance, CO<sub>2</sub> levels have surged from 330 parts per million (ppm) in 1975 to an estimated 420 ppm in 2025, marking a 27.3% increase over

50 years. This rise has been relatively steady, accelerating with notable acceleration after 2000 due to intensified fossil fuel consumption and deforestation. Between 2020 and 2025, CO<sub>2</sub> levels rose from 415 ppm to 420 ppm, a smaller but still concerning 1.2% increase over five years.

Similarly, methane (CH<sub>4</sub>) concentrations have grown from around 1,550 parts per billion (ppb) in 1975 to 1,900 ppb in 2025, reflecting a 22.6% increase over five decades. The rise has been driven primarily by agricultural practices, natural gas extraction, and waste decomposition. From 2020 to 2025, methane levels increased from 1,875 ppb to 1,900 ppb, a more moderate 1.3% growth. Nitrous oxide (N<sub>2</sub>O), although present in smaller quantities, has also increased consistently, moving from 295 ppb in 1975 to 335 ppb in 2025, representing a total rise of 13.6%. This increase is largely attributed to nitrogen-based fertilizers and industrial activities. From 2020 to 2025, N<sub>2</sub>O concentrations grew from 330 ppb to 335 ppb, a 1.5% increase.

Figure 1.1 Annual Greenhouse Gas Emissions Around the World



Source: The National Oceanic and Atmospheric Administration Global Monitoring Laboratory (2024).

These patterns highlight a significant rise in greenhouse gas levels, with carbon dioxide (CO<sub>2</sub>) emerging as the most influential contributor to climate change. Although the annual percentage increases may appear modest, their long-term effects are substantial; each rise in CO<sub>2</sub> concentration intensifies the planet's heat retention, thereby driving global temperature increases. The Intergovernmental Panel on Climate Change (IPCC, 2021) cautions that even if CO<sub>2</sub> concentrations were to hold steady at current levels, global temperatures could still rise by around 3°C over time due to the lag in the climate response.

The Annual Greenhouse Gas Index (AGGI), which measures the total warming impact of human-induced greenhouse gases, took nearly 240 years to reach a value of 1 from 0 demonstrating the slow but steady build-up of emissions. However, in recent decades, the pace of increase has accelerated sharply, primarily due to intensified human activity. This rapid escalation underscores the lasting impact of present-day emissions and highlights the critical importance of implementing strong and immediate mitigation measures.

The escalation of greenhouse gas emissions caused by greenhouse gas concentration has posed a significant threat to the global biosphere, intensifying the global focus on curtailing it as the severity of resulting climate change. The increasing frequency of natural disasters, rising temperatures, and erratic weather patterns highlights the pressing urgency. In response, the United Nations Framework Convention on Climate Change instituted the Paris Agreement, aiming to limit global warming to a maximum of 2 °C above pre-industrial levels, with efforts to maintain it within 1.5 °C. The implementation of the 2015 Paris Agreement calls for strengthening global responses to climate change and transition to a low or net-zero greenhouse gas emissions by 2050.

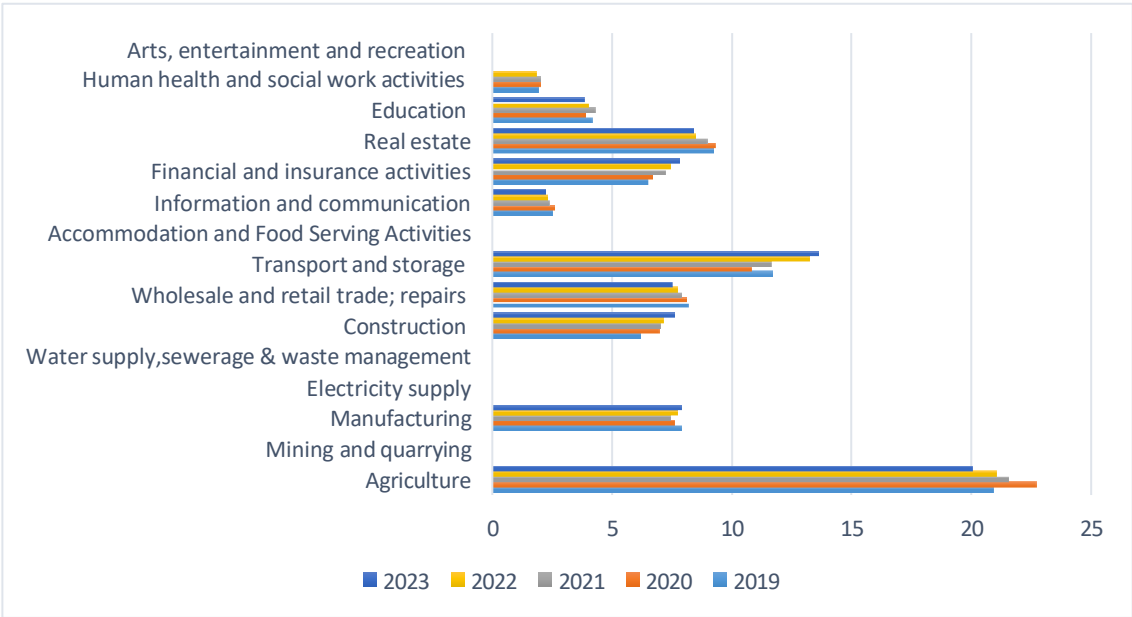
Among the factors contributing to climate change, agricultural production plays a prominent role. According to Intergovernmental Panel on Climate Change (IPCC), agriculture, forestry and other land use account for 22% of global greenhouse emissions making them major drivers of global warming. Consequently, climate change has far-reaching impacts on the agricultural sector through increasing temperatures, changing precipitation patterns, and greater frequency of some extreme events. In Kenya, agricultural sector is responsible for 41% of the country's total GHG emissions (Ndetu et al., 2024), exemplifies the intricate relationship between agriculture and climate change.

Kenya's geographical diversity, spanning from highlands to arid regions, further complicates this relationship. With 80 percent of the country classified as semi-arid and arid, and 23 out of the 47 administrative units lying in these areas (Nyanjom, 2014), the impact of climate change is profound.

The resulting unpredictable and adverse weather conditions significantly impact the economy and financial sector. Notably, the agricultural sector, contributing one-fifth of the economy's output, is directly vulnerable to physical climate risks.

Agriculture remains Kenya’s largest economic sector, contributing significantly to GDP, as shown in Figure 1.1.2 below. During the COVID-19 pandemic in 2020, agriculture’s GDP contribution increased due to government initiatives to bolster local food production, preventing shortages, and ensuring vulnerable populations had access to essential nutrition amidst movement restrictions and lockdowns. However, its share declined from 22.7% in 2020 to 20% in 2023, driven by prolonged droughts, floods, and erratic weather exacerbated by climate change. These challenges have disrupted farming cycles, reduced yields, and heightened greenhouse gas emissions, underscoring the need for climate-smart solutions.

Figure 1.2 Kenya’s Sectors’ Contribution to GDP (%)



Source: Kenya National Bureau Statistics,2024

Kenya’s reliance on rain-fed agriculture, employing over 70% of the rural population, renders it particularly susceptible to climate change (USAID, 2024). With 80% of Kenya’s land classified as arid or semi-arid, recurrent droughts and floods jeopardize food security and livelihoods (Climate links, 2024). Moreover, Kenya’s population, estimated at 56,432,944 in 2024, a 1.98% increase from the previous year further intensifies the pressure to meet growing food demands. This situation has driven widespread deforestation to expand farmlands, worsening environmental degradation.

To enhance agricultural productivity, the government, in partnership with multinational organizations, has implemented initiatives focused on irrigation, fertilizers, and high-yield crop varieties. However, these intensified farming practices have led to increased emissions of nitrous oxide and methane, contributing further to climate change.

Agricultural waste has traditionally been treated as an environmental burden but this thesis reimagines it as a monetizable asset. When converted into briquettes, or organic fertilizer, agricultural waste becomes both an input for green utilities and a catalyst for climate-smart farming. However, many smallholder farmers lack the financial means to invest in these conversion technologies. Mobile money widely used for personal transfers but underutilized for productive purposes offers a promising pathway to bridge this financing gap. This study explores the potential of mobile money to fund, enable, and monetize agricultural waste-to-utility transitions as part of agricultural GHG reduction and CSA strategies in Kenya.

To address these challenges, Kenya has committed to reducing greenhouse gas emissions by 32% by 2030 (UNDP, 2023). Initiatives like the Kenya Climate-Smart Agriculture Project (KCSAP), funded by the World Bank, play a pivotal role in achieving this target by enhancing resilience in agriculture and reducing emissions. However, the success of such initiatives requires innovative financial tools that can effectively integrate with climate-smart agricultural practices. Traditional financial systems often fall short in rural areas due to limited infrastructure, high transaction costs, and barriers to accessing credit. This gap necessitates solutions like mobile money, which provide scalable, efficient, and inclusive financial services tailored to the needs of farmers.

This study highlights agricultural waste not just as a by-product of farming, but as a climate-smart opportunity waiting to be unlocked through financial innovation. When converted into briquettes or organic fertilizer, agricultural waste becomes both an input for green utilities and a catalyst for climate-smart farming. These two conversion pathways briquetting and composting are emphasized in this thesis because they are not only technically viable and cost-effective for smallholder farmers, but have also been empirically observed in Kenyan CSA pilot programs and field-level initiatives.

Specifically, interventions supported by the Climate Resilient Agricultural Transformation (CRAFT) project and the Alliance for a Green Revolution in Africa (AGRA) have documented farmer adoption of waste-to-briquette and composting techniques.

These approaches are favored for their low entry barriers, compatibility with small-scale production, and measurable emission-reduction potential. While other waste-to-energy options such as anaerobic digestion for biogas or pyrolysis for bio-oil are acknowledged in the literature, their high capital costs and limited field adoption make them less accessible for the Kenyan smallholder farmers. The decision to focus on briquettes and organic fertilizer thus reflects not just technical relevance, but alignment with ground-tested practices and observed behavioral uptake in the Kenyan agricultural context.

Kenya's mobile money ecosystem, led by M-Pesa, provides the infrastructure necessary to support this transformation. Launched in 2007 by Safaricom, M-Pesa started as a platform for transferring money between urban and rural areas. Over time, it has evolved into a comprehensive financial solution, offering services such as payments for goods and services, savings, loans, and insurance. Embedded products like Fuliza, an overdraft facility, allow users to complete transactions even with insufficient funds, while M-Shwari facilitates savings and microloans via mobile devices, addressing critical cash flow challenges faced by farmers (GSMA, 2021).

The dominance of Kenya's mobile money sector is evident, with over 604,000 active agents serving more than 51 million customers across seven African countries. In 2024, mobile money transactions in Kenya reached KSh 6.5 trillion (\$43.4 billion), marking an 18% increase from the previous year. Daily transactions averaged KSh 21 billion, underscoring its role as a cornerstone of the nation's economic and social infrastructure (Telecom Review Africa, 2024).

The expansion of Kenya's telecommunication infrastructure has been instrumental in reinforcing M-Pesa's role as the country's primary financial enabler. Over the past decade, improvements in network coverage, mobile data accessibility, and digital financial services have transformed rural connectivity, ensuring that even the most remote farming communities can engage in mobile-based transactions.

The widespread adoption of 3G and 4G networks has significantly reduced barriers to mobile money usage, while ongoing 5G trials promise enhanced transaction speeds and network reliability, further integrating farmers into digital economies (Parliament of Kenya, 2025). Beyond traditional mobile networks, innovative connectivity solutions are emerging to support M-Pesa's scalability. The deployment of low-cost satellite internet, spearheaded by companies like Starlink, is extending coverage to previously underserved areas, enabling seamless mobile financial transactions without reliance on urban infrastructure (Broadcast Media Africa (2024). Additionally, the expansion of WiMAX networks and localized community broadband initiatives is improving digital access, allowing farmers to interact with agricultural marketplaces like Twig Foods without requiring smartphone-based apps or Wi-Fi.

Presently, Kenya's government and private sector partnerships are accelerating the transition to a fully digital financial ecosystem. Public initiatives such as the Universal Service Fund are directing investments into telecommunications infrastructure for marginalized communities, ensuring that mobile money adoption is inclusive and sustainable. Meanwhile, private sector players, including Safaricom, continue to develop offline mobile transaction capabilities, allowing rural farmers to engage in financial activities regardless of internet availability (Odhiambo,2024).

This growth is driven by Kenya's high mobile penetration rate (92%) and innovative financial products, particularly M-Pesa, which operates seamlessly on basic mobile devices. Unlike mobile banking, which requires smartphones and stable internet connectivity, M-Pesa ensures inclusivity for low-income and rural populations, providing an accessible financial solution. M-Pesa also surpasses branchless banking in convenience, allowing transactions to be conducted instantly from anywhere, without the need for physical agents or kiosks. This accessibility makes M-Pesa particularly advantageous for farmers, who benefit from its efficiency and practicality in managing seasonal cash flows and accessing essential services, supporting their financial and agricultural needs.

These innovations are particularly transformative for farmers enabling financial inclusion and resilience. As global environmental challenges intensify, there is an increasing focus on balancing economic growth with ecological sustainability. This transition is particularly vital for Kenya's agricultural sector, a significant contributor to greenhouse gas emissions and one of the most climate- vulnerable industries. One promising avenue for mobile money's further impact lies in its integration with climate-smart agriculture, offering farmers access to mobile credit and enabling investments in advanced irrigation systems and high-efficiency fertilizers, thereby improving resilience against climate variability. Mobile money platforms also facilitate financial protection mechanisms, such as weather-indexed insurance, which safeguards farmers against financial risks posed by extreme weather events (Jena and Thakur, 2023).

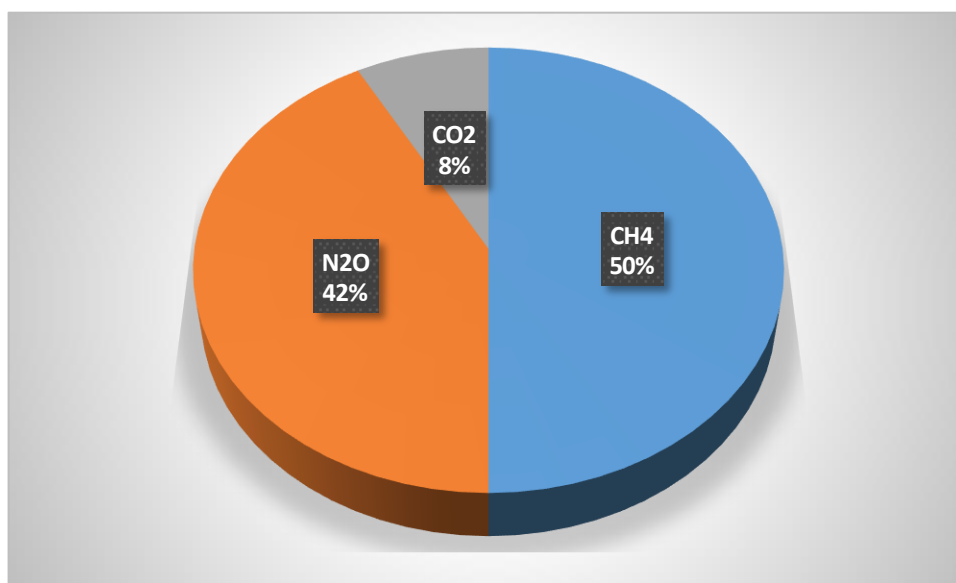
The widespread adoption of mobile money, driven by platforms like M- Pesa, underscores its potential to drive sustainable development. Its ability to bridge the gap between financial inclusion and ecological sustainability positions mobile money as a critical enabler of Kenya's climate-smart agriculture initiatives and its broader emission reduction goals.

## **1.2 Research Problem**

In Kenya, where agriculture plays a crucial role in economic growth, climate change exacerbates the challenges faced by agricultural production and rural development (Maggio & Sitko, 2019). Agriculture is a major contributor to the country's GHG emissions contributing 41% of the country's GHG emissions (Ministry of Environment and Climate Change, 2023). According to data from the Ministry of Environment and Climate Change, methane (CH<sub>4</sub>) accounts for 50% of emissions, nitrous oxide (N<sub>2</sub>O) for 42%, and carbon dioxide (CO<sub>2</sub>) for 8%, as shown in Figure 1.3. below.

Farmers in Kenya face key climate-related issues, including recurrent droughts, occasional floods, and erratic rainfall patterns, all of which threaten food security and livelihoods (Ochieng et al., 2016). To address these challenges, various mitigation and adaptation measures, such as climate-smart agriculture, have been introduced to boost farm productivity and improve food security. However, due to their limited capacity to adapt, farmers continue to struggle with the impacts of climate change (Asfaw et al., 2016).

Figure 1.3 Agricultural GHG Emissions by Gas



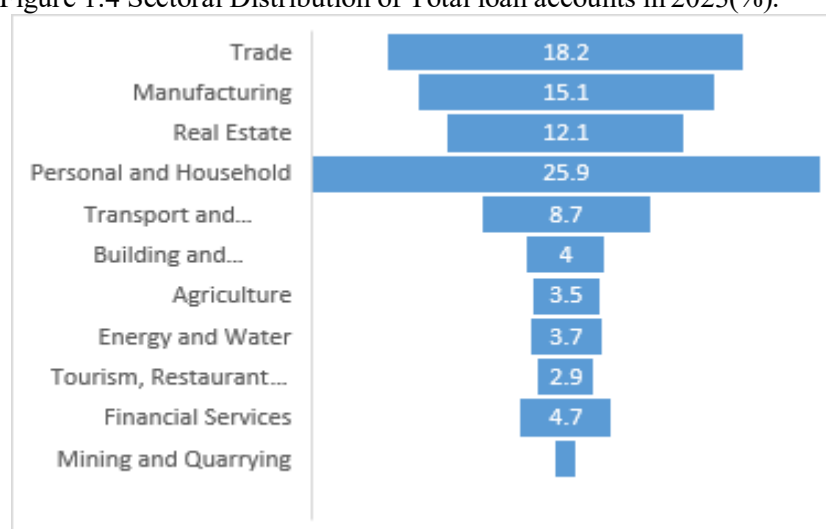
Source: Ministry of Environment, Climate Change and Forestry (2023)

Farmers in Kenya face key climate-related issues, including recurrent droughts, occasional floods, and erratic rainfall patterns, all of which threaten food security and livelihoods (Ochieng et al., 2016). To address these challenges, various mitigation and adaptation measures, such as climate-smart agriculture, have been introduced to boost farm productivity and improve food security. However, due to their limited capacity to adapt, farmers continue to struggle with the impacts of climate change (Asfaw et al., 2016).

Agriculture sector is underfunded, receiving only 3.5% of commercial banks' lending portfolios in 2023, while sectors such as personal and household, trade, manufacturing and real estate received higher proportions, as illustrated in Figure 1.4 below. This financial disparity highlights a pressing need for innovative solutions to bridge the funding gap and enhance sustainability.

Most Kenyan farmers operate at the intersection of subsistence and semi-commercial farming, depending heavily on rain-fed agriculture, which constitutes about 95% of all farming activities (The International Crops Research Institute for the Semi-Arid Tropics, 2023). This dependence on rain-fed farming makes them highly vulnerable to climate variability and extreme weather events such as droughts, floods, and rising temperatures.

Figure 1.4 Sectoral Distribution of Total loan accounts in 2023(%)



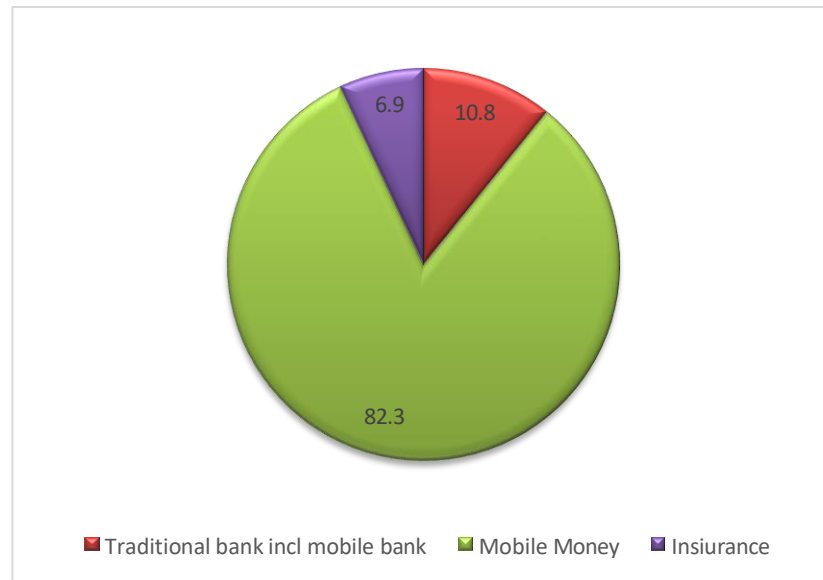
Source: Central Bank of Kenya, 2023

Th conditions exacerbate crop and livestock losses, food insecurity, and financial fragility, further entrenching inefficiencies in the sector. Not only wasting vital resources but also contribute to increased GHG emissions. In response to these challenges, mobile money has emerged as a transformative financial tool in Kenya, offering an alternative to traditional banking. The FinAccess Household Survey (2024) highlighted a significant rise in mobile money usage among farmers, with 82.3% using mobile money compared to 10.8% using traditional banking and only 6.9% accessing insurance services, as shown in Figure 1.5 below.

However, as per the survey done by financial Sector Deepening Kenya (2024), most farmers do not utilize mobile money for agricultural purposes. The financial disconnect is further evident in how mobile money, despite reaching 82.3% of farmers, is primarily used for non-agricultural purposes. This underutilization represents a missed opportunity to leverage mobile money for financing climate smart agricultural practices, and potentially reduce greenhouse gas emissions in the agricultural sector.

This study argues that mobile money can finance the adoption of low- emission technologies like waste conversion systems. If properly integrated, mobile money could serve as the engine that transforms Kenya’s agricultural waste from a climate liability into a climate asset.

Figure 1.5 Farmers Financial Access by Products in 2024 (%)



Source: Fin Access Household Survey in Kenya, 2024

As Kenya transitions towards sustainable and climate-resilient pathway, integrating mobile money into agricultural financing offers immense potential. Mobile money can enable farmers to access credit for climate-resilient inputs, secure insurance against extreme weather events, and adopt practices that reduce GHG emissions. This study investigates the potential of mobile money to transform Kenya's agricultural sector by addressing its financial and environmental challenges, thereby supporting the nation's journey towards a sustainable and climate resilient future.

### 1.3 Novelty and Significance of the Study

This study addresses a significant gap in the academic literature by exploring the intersection of mobile money and sustainable agricultural practices, and its potential to reduce greenhouse gas (GHG) emissions in Kenya's agricultural sector. While mobile money has been widely recognized for its role in enhancing financial inclusion (Mwikamba et al., 2024), improving agricultural productivity (Zhang et al., 2022; Ky et al., 2021), and supporting rural livelihoods, few studies have examined how it can function as a financial enabler of climate-smart agricultural practices that would reduce agricultural GHG emissions.

Concurrently, a growing body of research has emphasized agriculture's role in GHG emissions and the adoption of climate-smart agriculture (CSA) as a mitigation strategy (Omotoso & Omotayo, 2024; Petersen et al., 2023; Abernethy & Jackson, 2022; Israel et al., 2020). In Kenya, initiatives such as the Climate Resilient Agribusiness for Tomorrow (CRAFT) program and AGRA's projects have demonstrated the practical uptake of climate-smart agriculture (CSA) techniques. These include the adoption of drought-tolerant maize varieties, composting of organic waste to restore soil fertility, and on-farm briquette production using crop residues such as maize stalks and sugarcane bagasse. During the 2024 drought season, farmers engaged in these CSA interventions reported improved yield stability, reduced input costs, and greater resilience compared to non-adopters highlighting the tangible benefits of these practices under climate stress. However, despite their proven effectiveness, the broader adoption of these innovations remains constrained by limited access to affordable finance and upfront capital. Many smallholder farmers lack the liquidity to invest in briquetting equipment, composting infrastructure, or certified drought-resilient seeds. This underscores the need for scalable, inclusive financial mechanisms such as mobile money platforms that can bridge the affordability gap and accelerate the diffusion of low-emission, climate-resilient technologies across Kenya's agricultural landscape.

Therefore, this study introduces a novel perspective by empirically testing the role of mobile money as a behavioral and transactional conduit for adopting such practices. Rather than treating mobile money as a static financial tool, this study positions it as the digital infrastructure through which farmers can finance waste-to-energy transitions, participate in low-emission value chains, and eventually access carbon market revenue streams. By linking mobile money usage with measurable reductions in GHG emissions through agricultural waste valorization, this research extends the conversation from financial access to environmental monetization.

Furthermore, this study is significant in the context of three urgent and interconnected global priorities: climate change mitigation, GHG emission reduction, and the strategic deployment of financial technology.

In Kenya and across many developing economies, smallholder farmers are increasingly exposed to the adverse effects of climate change, including prolonged droughts, rising temperatures, and erratic rainfall. These climatic shocks threaten agricultural productivity and rural livelihoods. According to the Intergovernmental Panel on Climate Change (IPCC), Kenya could face a 20–50% decline in agricultural output by 2050 in the absence of urgent adaptation and mitigation strategies. Moreover, developing economies are projected to absorb approximately 85% of global GDP losses associated with climate impacts, with agriculture and energy-intensive sectors most at risk.

The significance of this study lies in empirical insights into how mobile money can enable decentralized sustainability action at the grassroots level. By reframing mobile money as a conduit for environmental value creation rather than solely a medium of exchange, the study provides a systems-oriented lens through which digital financial infrastructure can be mobilized to advance Kenya’s climate resilience goals. In doing so, it illustrates how mobile money can empower smallholder farmers to participate meaningfully in low-emission, revenue-generating agricultural value chains. The study also responds directly to calls by international institutions such as the UNFCCC, FAO, and UNEP for integrated approaches that blend financial technology and environmental accountability reinforcing the need for intersectional solutions that work at scale in the Global South.

#### **1.4 Research Questions**

The study will address the following questions:

1. What are the short-run and long-run effects of using mobile money in climate-smart agriculture on GHG emission reduction by converting agricultural waste into utilities and energy?
2. What are the potential earnings that farmers can generate in reducing agricultural GHG emission through the adoption of climate smart agricultural practices from voluntary carbon credit market?

## **1.5 Research Objectives**

1. To analyze the short-run and long-run effects of using mobile money in climate-smart agriculture on GHG emission reduction through the conversion of agricultural waste into utilities and energy.
2. To forecast the potential of GHG emission reduction in generating carbon credit monetization opportunities for farmers.

## **1.6 Contribution of the study**

This study contributes to the growing body of literature on the intersection of digital finance, climate mitigation, and sustainable agriculture by demonstrating how mobile money empowers farmers to adopt climate-smart practices that convert agricultural waste into energy and other productive utilities. The findings confirm that mobile money serves not only as a financial access tool, but also as a critical enabler for on-farm investments that reduce greenhouse gas (GHG) emissions particularly from agricultural waste.

By demonstrating how mobile money enables the adoption of low- emission agricultural practices in Kenya, this study positions the country as a global frontrunner in leveraging financial technology for climate mitigation in the agriculture sector. Kenya's leadership anchored by the success of M-Pesa serves as an example for other developing nations facing similar challenges, such as high agricultural emissions, and widespread mobile phone ownership stand to benefit from adapting this Kenyan model to their own contexts.

This study also contributes to the broader conversation on sustainable circular economies by highlighting how mobile money can activate value chains around agricultural waste. Through briquette compaction and organic fertilizer application tracked and transacted digitally farmers can unlock carbon-based revenues and close the loop between production, waste, and climate mitigation.

It also provides insights to the Ministry of Agriculture, telecom operators, and Agri-finance actors with a framework to design mobile money carbon farming schemes, where emission reductions from waste conversion can be measured, certified, and eventually monetized through access to voluntary carbon markets. This is critical for operationalizing Kenya's NDCs, not just through policies, but through tools already in the hands of millions of farmers.

### **1.7 Outline of the Thesis Organization**

The present thesis is organized in the following manner to effectively complete the predetermined goals and come up with solutions to the research problem: The literature will be presented in chapter two, the methodology and data used in this research will be explained in chapter three, the findings will be presented and discussed in chapter four, and lastly, in chapter five conclusions and recommendations of the study will be presented.

## **CHAPTER 2 LITERATURE REVIEW**

This section establishes the theoretical framework for this study draws on several key concepts and theories that can help explain the relationship between mobile money usage, climate smart agricultural practices, and greenhouse gases emissions reduction in Kenya's agricultural sector. Following this, the next step involves evaluating previous research to identify gaps and insights, and formulating hypotheses based on this evaluation. Finally, a conceptual framework will be developed to guide the empirical analysis, clearly illustrating the relationships between mobile money adoption, climate finance accessibility, and greenhouse gases emissions reduction in Kenya's agricultural sector.

### **2.1 Conceptual Background**

#### **2.1.1 Climate-Smart Agricultural Practices in Kenya**

In recent years, there has been growing focus on incorporating scientific and technological innovations into agriculture, given their capacity to increase productivity and improve farmers' earnings. This is especially important in developing countries, where agriculture is a key driver of poverty alleviation, food security, and the livelihoods of small-scale farmers (World Bank, 2019). Interest in climate-smart agriculture (CSA) is steadily growing among scholars and innovators in the agricultural sector, largely because its success is closely tied to the surrounding social and environmental conditions.

CSA is built upon key global development objectives, aiming to increase food production in a sustainable way, enhance the ability of farming systems to adapt to climate change, and minimize emissions of greenhouse gases (Egeru et al., 2022). Climate-smart agriculture (CSA) is an integral part of Kenya's response to climate change strategy, offering a comprehensive approach that addresses productivity, adaptation, and emissions reduction.

Numerous initiatives have been implemented in Kenya to encourage the adoption of climate-smart behaviors. Smallholder farmers adjusted their practices and developed localized coping strategies aimed at increasing resilience and maintaining productivity. One widely adopted approach is the use of drought-tolerant crop varieties, such as improved maize strains developed through initiatives like the Water Efficient Maize for Africa (WEMA) project. These improved maize varieties are genetically selected or bred to withstand prolonged periods of low rainfall by using water more efficiently, maintaining growth and yield with less moisture than traditional varieties. This makes them particularly valuable in regions increasingly affected by erratic rainfall and prolonged dry spells (Mugo, 2020).

According to Tamagnone, Comino and Rosso (2020), rainwater harvesting has become a critical water management strategy under CSA. Rainwater harvesting involves collecting and storing rain runoff typically from rooftops or surface catchments for agricultural use during dry periods. Though not new, its systematic integration into farming systems is increasingly recognized as a climate-smart practice, especially in areas with seasonal rainfall. Farmers are also turning to small-scale irrigation systems like drip irrigation, which delivers water directly to the plant roots in precise amounts, and water pans, which are shallow reservoirs used to store runoff for supplemental irrigation (Ray and Majumder, 2024). These innovations help manage water scarcity, reduce evaporation losses, and optimize water use efficiency—all key principles of CSA.

Another widely adopted CSA practice is agroforestry, the integration of trees with crops or livestock. This approach improves soil fertility through nitrogen fixation, enhances biodiversity, stabilizes microclimates, and provides farmers with alternative income sources such as timber, fruits, or medicinal plants (De Giusti, Kristjanson and Rufino, 2019). At the same time, access to climate information services and early warning systems is helping farmers make more informed decisions. These services are often delivered through extension officers, farmer cooperatives, community-based organizations, and local radio broadcasts, providing timely weather forecasts, and agronomic advice (Findlater et al., 2021).

The CSA efforts are not only policy-driven but also tested and proven at the grassroots level. In counties like Kitui, Makueni, and Meru, where projects such as the Climate Resilient Agricultural Transformation (CRAFT) initiative and the Alliance for a Green Revolution in Africa (AGRA) have been implemented, smallholder farmers have reported tangible benefits. Through these interventions, farmers have been trained in climate-resilient techniques including the use of drought-tolerant seeds, composting of organic farm waste, water management innovations like water pans and drip irrigation, and agroforestry (Cereal Growers Association and Alliance for a Green Revolution in Africa, 2022).

According to news broadcast by NTV Kenya, many farmers indicated noticeable improvements in yield stability and household income, even during erratic or shortened rainy seasons. Some farmers interviewed on air shared that before adopting CSA practices, they often lost entire harvests when rains failed. However, with drought-tolerant maize varieties and the compost they now make from agricultural waste, they can harvest reliably, even during shorter rainy periods. Others mentioned that water pans have helped them sustain vegetable farming throughout prolonged dry spells. These firsthand testimonials emphasize how CSA can transform rural livelihoods from climate vulnerability to resilience when effectively supported.

However, despite its clear benefits, the adoption of CSA remains low among small scale farmer. This has been confirmed by various studies across the country (Muriithi, et.al, 2023; Phiri et.al, 2022; Ngigi and Muange,2022). Factors such as inadequate access to finance, limited exposure to CSA knowledge, and a lack of infrastructure and support services hinder widespread uptake. Many smallholder farmers, who form the backbone of Kenya's food system, are unable to afford the inputs required for CSA and lack the necessary information to apply these techniques effectively. As a result, even when there is awareness of climate change and willingness to adapt, the practical barriers remain too high for many farmers (Chepng'etich, et.al, 2024; Nyang'au, 2021).

Farmers positive experiences illustrate a shift in mindset of viewing climate change as an insurmountable crisis toward seeing it as a challenge that can be strategically managed with the right tools, knowledge, and infrastructure. The localized evidence of success strengthens the case for integrating CSA through scalable solutions such as mobile money services that can play in unlocking CSA's full potential by bridging financial and informational gaps.

### **2.1.2 Evolution of Fintech in Kenya**

The adoption of climate-smart agriculture (CSA) in Kenya has coincided with the country's rapid advancement in financial technology (fintech). Fintech refers to the use of innovative technology to improve and automate the delivery and use of financial services (Giglio, 2021). One major area of fintech in Kenya is digital finance (Musamali, et.al,2023). While the terms fintech and digital finance are often used interchangeably, they are not the same.

Digital finance refers specifically to financial services delivered through digital platforms, such as mobile money, online banking, or branchless banking. In contrast, fintech is a broader concept that includes all technological innovations aimed at enhancing or transforming financial systems. This encompasses digital finance as well as advanced services such as blockchain technologies, algorithmic lending, digital investments, and AI-based credit scoring (Gomber, Koch and Siering, 2017). Thus, digital finance can be viewed as a subset of fintech, with a primary focus on access and delivery, whereas fintech includes back-end innovations, platform development, and entirely new financial models.

Kenya has emerged as one of the leading fintech hubs in Africa, largely due to the introduction and rapid expansion of M-Pesa, a mobile money platform developed by Safaricom in partnership with Vodafone (Ndungu,2021). Launched in 2007, M-Pesa revolutionized access to financial services by enabling users to send and receive money via mobile phones without needing a formal bank account. Today, M-Pesa is widely used across both urban and rural areas in Kenya and is deeply embedded in everyday life (Van Hove and Dubus, 2019).

Among smallholder farmers, mobile money platforms like M-Pesa are primarily used to meet personal and household needs such as paying school fees, covering medical expenses, buying food and household goods, or supporting extended families. These services have significantly improved the financial resilience of rural communities by offering a secure, accessible, and convenient way to manage money without relying on physical banking infrastructure (Parlasca, Johnen and Qaim, 2022).

It's essential to differentiate between mobile money and branchless banking, as they are often mistaken due to their shared use of agent networks in remote areas. Mobile money refers to financial services conducted entirely via mobile phones using electronic wallets, eliminating the need for a traditional bank account. Users can save, send, and receive funds on their phones, frequently facilitated by mobile agents who handle cash-in and cash-out transactions. Critically, services like M-Pesa are usually provided by telecom operators, not banks and can be used by individuals outside the formal banking system (Shaikh, et.al,2022).

In contrast, branchless banking involves delivering conventional bank services without relying on physical branches. This model still uses agents, mobile units, ATMs, or digital platforms but is directly tied to a formal bank account and managed by licensed financial institutions. Users must register with a bank to access these services, and any savings or loans are held within their bank account, even if accessed through off-site channels. While both approaches promote financial inclusion by expanding reach to underserved communities, mobile money is generally more accessible to unbanked individuals especially in rural or low-income regions where mobile phone ownership is common but traditional bank access remains limited (Mutarindwa, et.al,2024). This accessibility explains why mobile money, particularly in Kenya, has seen widespread adoption and become an indispensable financial resource for millions not served by formal banking.

Despite the strong uptake of mobile money, fintech in Kenya remains at a relatively nascent stage. Mobile money is currently the most developed and utilized form of digital finance, while other fintech innovations have yet to be fully explored or scaled. According to Bright Shalom (2023), this limited expansion is due to an underdeveloped regulatory framework, capacity gaps within oversight institutions, tax policy uncertainties, and insufficient public and private sector investment in fintech infrastructure. As a result, mobile money has become the dominant pillar of Kenya's digital finance system, overshadowing other promising fintech solutions.

The rise of M-Pesa highlights the Kenyan government's commitment to promoting inclusive finance, but it also reveals a disproportionate focus on mobile money at the expense of the broader fintech ecosystem (Musamali, , Jugurnath and Maalu , 2023). Mobile money has been instrumental in advancing financial inclusion, particularly through M-Pesa's widespread reach, other fintech innovations that could enhance agricultural resilience and productivity remain underexploited. As climate-smart agriculture (CSA) continues to gain adoption, fintech has the potential to fill critical financial and informational voids among smallholder farmers. However, unlocking this potential requires a deliberate shift to extend fintech services beyond consumer-level applications into productive sectors like agriculture.

### **2.1.3 Mpesa Ecosystem**

Mpesa is an abbreviation of mobile money in Swahili whereas M means Mobile and Pesa means money. It has evolved into Kenya's preeminent mobile money platform, reaching more than 96% of households and amassing over 49 million wallet holders in 2024 (Safaricom,2024). The platform has empowered a substantial proportion of the population particularly those previously excluded from formal banking systems to engage in everyday financial activities such as remitting funds, purchasing airtime, paying utility bills, and saving money. Its success is closely tied to the inefficiencies of the pre-existing financial infrastructure, which depended heavily on formal institutions like the Kenya Postal Corporation and excluded many rural and low-income users.

M-Pesa ecosystem is largely agent-driven, comprising more than 600,000 agents across Kenya. It includes sub-agents such as airtime vendors, small retailers, supermarkets, and postal outlets who interface directly with customers to facilitate cash-in and cash-out transactions, provide registration services, and deliver user education. Principal agents supervise multiple sub-agents, manage float and ensure operational continuity. These agents serve not only as transaction intermediaries but also as critical conduits for promoting digital financial literacy in underserved and remote regions.

Kenya's M-Pesa network is primarily driven by a vast agent system, with over 380,000 active agents nationwide as of late 2024 (Safaricom,2024). This network includes numerous sub-agents such as airtime sellers, local shopkeepers, supermarkets, and postal counters who serve as the key contact point for customers, handling cash-in cash-out services, account registration, and user training (Wachira and Njuguna ,2023).

Principal agents, also known as master or head agents, oversee clusters of sub-agents, manage cash float, and ensure continuous operation. These agents are more than transaction intermediaries, they are pivotal in promoting digital financial literacy, especially in underserved and hard-to-reach areas. Figure 2.1 below illustrates the financial intermediation facilitated by agents in M-pesa system, independent of formal banking institutions.

Mpesa model is designed to enhance financial inclusion by ensuring efficient monetary transactions between customers and businesses through agent networks. At the core of the ecosystem is the telecommunication company known as Safaricom, which holds and regulates digital funds, ensuring liquidity and transaction security. Agents serve as essential intermediaries, facilitating both cash-in and cash-out services for individuals and businesses. Agents interact with customers, enabling deposits, withdrawals, thereby ensuring seamless access to mobile financial services. As well as engage with businesses, enabling them to receive payments, settle transactions, and manage operational finances providing a secure and accessible means of conducting financial transactions, such as savings, bill payments, and remittances, without reliance on conventional banking infrastructure (Safaricom,2023).

Meanwhile, businesses benefit from this agent-driven model by streamlining financial operations, reducing cash-handling risks, and improving payment efficiency. By removing reliance on commercial banks, this model enhances accessibility, enabling the widespread adoption of mobile financial services in regions with limited banking penetration (Wachira and Njuguna 2023). The role of agents as financial facilitators underscores the decentralized nature of the ecosystem, supporting both personal and business transactions in a manner that promotes economic participation and financial resilience.

M-Pesa's technical design allows customers to transact using basic mobile phones via SIM toolkit applications, eliminating the need for internet connectivity. This low-tech accessibility is particularly salient in bridging the financial divide for Kenya's unbanked and underbanked populations (Van Hove and Dubus, 2019). The platform supports a broad spectrum of transaction types, including peer-to-peer (P2P) transfers and customer-to-business (C2B) payments.

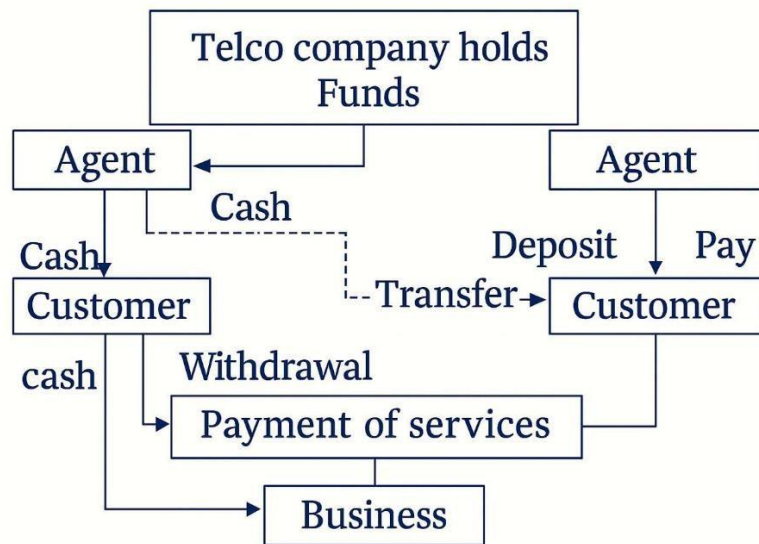
Features such as Pay Bill and Buy Goods and Services allow users to make payments for school fees, utility bills, and essential services like electricity, clean water, and liquefied petroleum gas. These pay-as-you-go models are especially transformative for low-income households, enabling more affordable and efficient access to basic services.

With more than 950,000 registered merchants and 5 million businesses integrated into the platform, M-Pesa functions as a digital marketplace enabler (Mpesa Africa, 2024). Services like M-Shwari (mobile microcredit) and Fuliza (overdraft facility) inside M-Pesa have further embedded credit access into daily financial behavior, thereby reducing dependency on traditional banks and enhancing user autonomy. The platform's contribution to formal financial inclusion is substantial. In markets where M-Pesa operates, financial inclusion rates have increased by up to 84% (McKinsey, 2022). These improvements are especially meaningful in rural areas, where the platform enables secure savings, emergency transfers, and digital market participation.

Beyond Kenya, M-Pesa has extended its footprint to several African countries including Tanzania, Ghana, Mozambique, Lesotho, Egypt, Ethiopia, and the Democratic Republic of Congo as well as Romania. Through strategic partnerships with global payment platforms like TerraPay, AliPay, and WeChat Pay, M-Pesa now facilitates international remittances from the United States, China, Germany, India, Bangladesh, and Pakistan (Chitavi et al., 2021).

M-Pesa’s sustained success is underpinned by four interdependent factors: an expansive agent network, enabling regulation, high levels of consumer trust, and intuitive mobile technology. In contexts where formal financial institutions are sparse and telecommunications unreliable, this model has proven both scalable and resilient. Its threefold legacy enhancing national payment systems, promoting mobile-based microfinance, and fostering digital entrepreneurship continues to inspire adaptation across Africa, Asia, and America, with peer economies drawing lessons from Kenya’s experience through knowledge-sharing platforms such as the Alliance for Financial Inclusion (Vodafone,2025).

Figure 2.1 M-Pesa Ecosystem



Source: Author’s Compilation

## **2.2 Theoretical Framework**

### **2.2.1 Financial Inclusion Theory**

Financial Inclusion Theory provides a critical lens through which to understand the transformative role of mobile money in enhancing economic participation among underserved populations, particularly in rural and agricultural communities. According to (Demirgüç-Kunt et al, 2021), Financial inclusion encompasses not just access to formal banking services, but also the ability to use these services effectively to improve livelihoods and resilience.

This theory is especially relevant in emerging economies where many smallholder farmers remain excluded from traditional banking systems due to geographic, economic, and social barriers. The rise of mobile money platforms has addressed these barriers by enabling individuals to save, borrow, insure, and transfer money using basic mobile phones without needing a bank account or physical access to financial institutions (GSMA, 2023; World Bank, 2021).

Mobile money plays a pivotal role in closing the financial access gap for farmers and catalyzing investment in climate-smart agriculture. These digital financial services allow farmers to accumulate savings over time, access credit for inputs, receive remittances from relatives or diaspora members, and pay for services such as irrigation or insurance, all via mobile phones (Mungai, et.al, 2021).

This enhanced access to liquidity reduces farmers' dependence on informal and often exploitative lenders and empowers them to make forward-looking investments in sustainable farming practices. Such practices include the adoption of drought-resistant crops, conservation agriculture, and integrated soil fertility management, which are crucial for reducing greenhouse gas emissions and increasing climate resilience (EIB, 2022; FAO, 2021). Mobile money services enable users to store and transfer money, facilitating access to financial products like loans and savings accounts (Voptia & Stukalina, 2024). Studies indicate a significant correlation between mobile money usage and improved financial inclusion metrics across various Sub-Saharan African countries (Gyamerah & Tetteh, 2024).

The behavioral impact of mobile money is equally significant. Peter (2024) examined how access to formal saving accounts impacts resilience of Kenyan households in wake of external shocks using OLS. He found a greater sense of financial security, enabling farmers to manage risks more effectively and reduce vulnerability to climate-related shocks. This reduction in risk aversion encourages them to shift from low-input, subsistence-oriented farming to more productive and sustainable agricultural models. Furthermore, the accessibility and convenience of mobile transactions increase the frequency of financial engagement and promote a habit of saving and reinvestment among rural populations (Suri & Jack, 2018; GSMA, 2023).

These behavioral changes are reinforced by social networks and peer influences, where early adopters of mobile money often encourage others in their community to adopt the technology, creating a ripple effect that accelerates financial inclusion and CSA adoption.

Recent empirical evidence supports this theoretical link. For instance, Bekele (2024) found that in Ethiopia's Sidama region, mobile money significantly contributed to farm households' resilience to climate shocks by increasing income diversification and asset accumulation. Similar findings across Sub-Saharan Africa demonstrate that mobile money is more than a transaction tool. It is a catalyst for inclusive, climate-resilient development. Infrastructure such as reliable mobile networks, digital literacy programs, and partnerships with agri-tech companies further enhance the utility of mobile money in rural farming ecosystems.

This study adopts the Financial Inclusion Theory to examine how access to mobile financial tools influences the decision-making processes of farmers with respect to CSA. Specifically, it explores how mobile money not only increases access to finance but also shapes behavior through improved liquidity, reduced uncertainty, and stronger financial planning.

By embedding financial access within farmers' daily decision-making structures, mobile money becomes instrumental in advancing sustainable agriculture and climate resilience in developing contexts. The intersection of digital finance and agricultural innovation presents an opportunity to transform how development goals are pursued in rural economies, making financial inclusion a central pillar of climate adaptation and food security strategies.

### 2.2.2 Sustainable Development Theory

Sustainable Development Theory emerged from the 1987 Brundtland Report named as our common future, which was spearheaded by the World Commission on Environment and Development. The theory emphasizes the integration of environmental, economic, and social dimensions of development, advocating for practices that meet the needs of the present without compromising the ability of future generations to meet their own needs (Visser,2017).

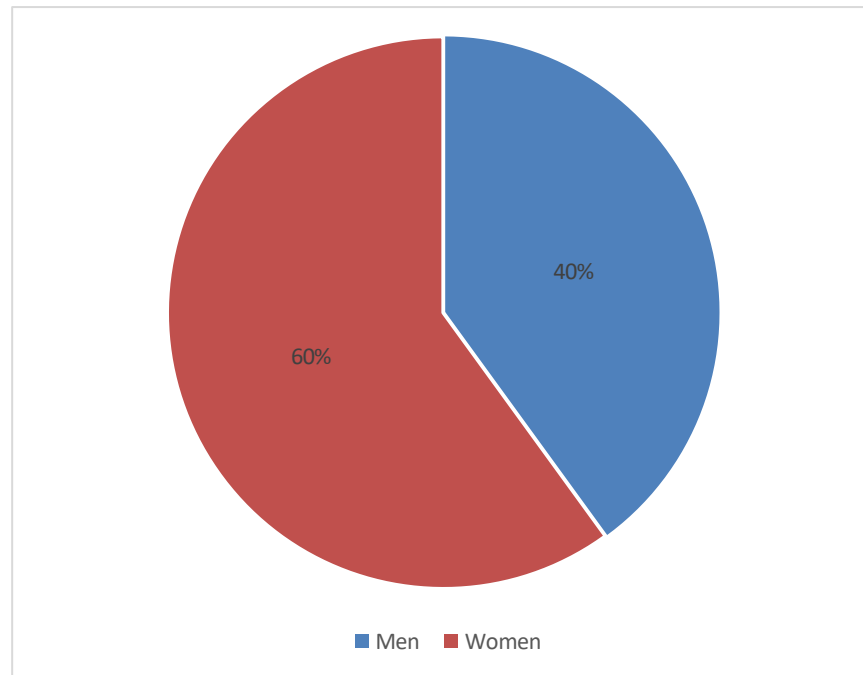
This theoretical framework underpins contemporary global efforts to reduce poverty, address climate change, and foster inclusive economic growth. According to Sachs (2015), sustainable development requires improving the quality of human life while remaining within the Earth's ecological limits. This involves not only protecting natural resources but also advancing social equity and economic opportunity particularly for marginalized populations.

A fundamental component of sustainable development and sustainable finance is social inclusion. Mobile money services like M-Pesa have greatly increased financial inclusion for historically underserved populations, particularly women and young people, in Kenya's rural economy. To increase household resilience to financial and climate-related shocks, these platforms give the unbanked access to insurance, microloans, savings, and remittance services.

According to GSMA (2023), gender-focused mobile finance initiatives have raised the number of women engaged in agriculture, increasing household economic stability and productivity. This supports Kenya's larger shift to a green and inclusive economy and directly advances Sustainable Development Goal 10 which is to reduced inequality. In Kenya, women make up over 60% of smallholder farmers, compared to 40% of males, as seen in figure 2.2. below. This stems from gendered labor patterns, as males seek off-farm income in metropolitan areas while women tend to stay in rural areas doing farming.

Rural women frequently encounter systemic obstacles such limited access to formal financing, lack of land rights, and exclusion from extension programs, despite playing a crucial role in food production. By providing easily accessible, collateral-free financial services often via cooperatives, or women's savings groups mobile money platforms aid in bridging these gaps. By enabling digital payments for climate-smart inputs, peer-to-peer loans, and pooled savings, these systems increase women's agency in agricultural decision-making.

Figure 2.2 Gender Distribution of Smallholder Farmers in Kenya



Source: KNBS, 2024

From the perspective of sustainable development, mobile money serves as a tool for social protection and resilience in addition to facilitating financial transactions. For instance, cash transfers, weather-indexed crop insurance, and subsidy payments are being provided to rural residents using mobile-based platforms. Smallholder farmers may use these methods to invest in long-term agricultural improvements, manage risk, and smooth consumption amid climatic shocks.

Additionally, the study's emphasis on climate-smart agriculture (CSA) and lowering greenhouse gas emissions is consistent with the theory's environmental component. According to Safdar et al. (2024), CSA techniques including low-emission tillage, composting, effective irrigation, and agroforestry are essential for increasing food security and reducing agricultural emissions. Agriculture is a significant source of greenhouse gas emissions worldwide, according to the Intergovernmental Panel on Climate Change (IPCC), which also emphasizes sustainable land use as a vital mitigation strategy. In this regard, mobile money facilitates farmers' access to the funds required to implement such methods, especially in areas with a deficiency in traditional banking infrastructure.

This study extends their application by exploring how mobile money beyond being a tool for inclusion can serve as a behavioral and transactional enabler of low-emission farming. Specifically, it investigates how mobile money facilitates the adoption of waste valorization practices, such as briquette production and composting, thereby aligning financial inclusion with environmental transformation.

### **2.2.3 Diffusion Innovation Theory**

The Diffusion of Innovation Theory (DIT) developed by Rogers (1995), provides an extensive framework for comprehending the temporal adoption of new technologies and ideas inside a certain social system. This theory is applicable to this study, which looks at the impact of mobile money in promoting the adoption of climate-smart agricultural (CSA) practices and lowering greenhouse gas (GHG) emissions from agriculture in Kenya. DIT contributes to the understanding of how innovations such as mobile-based financial tools are viewed, accepted, and progressively implemented by agricultural communities.

DIT's emphasis on key innovation attributes such as relative advantage, compatibility, complexity, trialability, and observability sheds light on how mobile money services can influence behavioral change and accelerate the adoption of sustainable agricultural technologies. These innovative qualities show out in a variety of ways in the context of mobile money, which have a direct impact on farmers' adoption of CSA methods.

The capacity of mobile money to provide quicker, safer, and easier financial transactions such as weather-index insurance and credit for sustainable inputs is its relative advantage. By investing in techniques like solar irrigation, agroforestry, or drought-tolerant crops, these services help farmers lessen their susceptibility to climatic shocks and cut down on greenhouse gas emissions. The way that mobile money fits in with farmers' current informal savings organizations and cell phone usage shows compatibility and lowers adoption barriers. Complexity is crucial because services like M-Pesa are available even in remote locations without WIFI since they are made for low-literate consumers using straightforward USSD codes.

Trialability fosters confidence by enabling farmers to try services on a modest scale, such as sending low-value transactions or obtaining financing. Diffusion is further accelerated by observability, since surrounding farmers are encouraged to use CSA and mobile money strategies by positive results observed in peer networks, such as prompt payouts or increased yields. Recent empirical research supports these dynamics. Kingiri and Fu (2019) emphasized how M-Pesa's fit with informal economies and community trust networks fueled its spread throughout Kenya. Although 80% of Kenyan farmers use mobile money, less than 15% use it for agriculture, according to a national survey-based study published in *Global Food Security* (2022). This suggests that although the platform is widely used, its targeted use for CSA is still limited, especially because of the low observability and complexity of certain products.

Using panel data from 50 African nations, Avom et al. (2023) verified that the usage of mobile money enhances financial inclusion, particularly when backed by user-friendly platforms. According to Rogers' model, trialability and peer influence are powerful indicators of usage, according to a 2024 meta-analysis of fintech uptake in Africa. Mutinda et al. (2021) demonstrated the importance of social systems and collective learning in CSA adoption by demonstrating how peer learning in agricultural cooperatives plays a crucial role in the dissemination of mobile financing.

In contrast to previous theory of technology adoption, such as the Technology Acceptance Model (TAM), DIT provides a more comprehensive and socially based explanation for the acceptance of advances in mobile money. TAM ignores the impact of social networks, communication channels, and time-based adoption patterns, despite its primary focus on individual-level perceptions of utility and usability. These elements are particularly important in rural and community-driven environments, such as Kenya's agricultural sector. The examination of innovation diffusion as a communal process influenced by both individual perceptions and community-level dynamics is made possible by DIT, in contrast. This makes it especially appropriate for the current study, which investigates the impact of mobile money-enabled CSA practices to lessen the effects of climate change.

#### **2.2.4 Successful Integration of Mobile Money in Agriculture in other Emerging Economies**

The integration of mobile money in agriculture has transformed farming economies worldwide, with Kenya's M-Pesa leading the way in financial inclusion and has set a precedent for mobile money adoption in other emerging economies. This model has inspired similar developments worldwide. In Tanzania, the Kilimo Trust initiative integrates mobile-based agricultural financing, allowing farmers to receive real-time payments for climate-smart inputs and services (Kilimo Trust, 2021). In Ghana, the MoMo for Agriculture Initiative, led by MTN Ghana, has improved farm productivity and incomes by providing farmers with mobile-based access to credit and digital financial services (MTN Ghana, 2023).

In Côte d'Ivoire, the e-Agriculture Project connects farmers directly to mobile-based marketplaces, enabling better market access and price transparency (FAO, 2022). Similarly, Uganda's AgriPay platform, developed in partnership with Airtel, offers mobile-based savings, loans, and insurance products tailored to smallholder farmers (GSMA, 2021).

Beyond Africa, mobile money is increasingly advancing climate-smart agriculture across Southeast Asia and South Asia. In Indonesia, the Digital AgriFinance Initiative is helping smallholder farmers access mobile-based microloans to finance climate-smart technologies such as solar-powered irrigation and organic fertilizers (ADB, 2023). In Malaysia, AgriTech Mobile Payments platforms enable farmers to purchase climate-resilient inputs and access precision farming services through mobile transactions (FAO, 2022).

China's Three Rivers Sustainable Grazing Program integrates mobile-linked financial tools to incentivize low-carbon grazing practices and reduce agricultural emissions (IFAD, 2022). India's Climate-Smart Villages Initiative applies mobile-based financial models and extension services to promote climate-resilient farming across diverse agro-ecological zones (CGIAR, 2023). Meanwhile, in Pakistan and Bangladesh, mobile money platforms such as bKash and Easypaisa offer microfinance products and crop insurance solutions to help farmers manage climate risks and improve adaptive capacity (GSMA, 2021).

A particularly compelling example of integrated digital agriculture is found in Uka Farm in rural Albania, which utilizes Vodafone's Smart Agriculture technology to optimize key aspects of farm management. This system enables real-time monitoring of soil moisture, light intensity, and crop health, helping farmers make precise, data-driven decisions on planting, irrigation, pest management, and harvest timing all without requiring physical presence in the field (Jobe, 2024). Uka Farm also automates planting, treatment, and harvesting processes, reducing costs, optimizing resource use, and promoting more sustainable agricultural practices.

These global cases highlight the rapidly growing role of mobile money and digital finance in transforming agricultural sustainability. Kenya's experience with M-PESA-driven financial inclusion remains one of the most influential models, inspiring efforts worldwide to integrate mobile transactions, digital credit, and climate-smart agriculture. Such innovations are increasingly critical in reducing GHG emissions, fostering greater resilience among farmers, and contributing to global climate mitigation goals.

## **2.3 Empirical Literature**

### **2.3.1 Mobile Money and Climate-Smart Agriculture Practices Nexus**

The integration of mobile money in agriculture has transformed farming economies worldwide, with Kenya's M-Pesa leading the way in financial inclusion and has set a precedent for mobile money adoption in other emerging economies. This model has inspired similar developments worldwide. In Tanzania, the Kilimo Trust initiative integrates mobile-based agricultural financing, allowing farmers to receive real-time payments for climate-smart inputs and services (Kilimo Trust, 2021). In Ghana, the MoMo for Agriculture Initiative, led by MTN Ghana, has improved farm productivity and incomes by providing farmers with mobile-based access to credit and digital financial services (MTN Ghana, 2023).

The potential role of mobile money in supporting the adoption of climate-smart agricultural (CSA) practices has drawn growing interest in development and agricultural economics, particularly as policymakers seek scalable solutions to the challenges of financial exclusion and climate adaptation. Empirical findings to date reveal a complex and evolving relationship, one that varies across contexts and over time.

Mobile money and climate-smart agricultural practices are two transformative innovations with significant implications for Kenya's agricultural sector. As climate change intensifies, agriculture faces unprecedented challenges, from extreme weather events to declining productivity and disrupted food systems. Vulnerable regions like Sub-Saharan Africa, South Asia, and Central America are already seeing rising risks of malnutrition and food insecurity, with these threats expected to worsen as global temperatures climb beyond 1.5°C. In response, climate-smart agriculture has emerged as a vital solution, integrating sustainable practices to boost productivity, reduce greenhouse gas emissions, and build resilience against climate shocks (Safdar, et al., 2024). By adopting strategies like climate-resilient crops, efficient water use, and low-emission farming methods, climate smart agriculture empowers communities to adapt and thrive in the face of climate change (Misal, et al., 2022).

Mobile money plays a critical role in accelerating climate-smart agriculture adoption by increasing financial inclusion for farmers, many of whom lack access to traditional banking in Kenya. With mobile money, farmers can secure loans, purchase climate-resilient seeds, and invest in climate farming technologies. Additionally, mobile platforms facilitate access to weather forecasts, market information, and peer networks, enabling informed decisions and better resource management. By connecting farmers to financial and informational resources, mobile money complements climate-smart agriculture practices, creating a pathway for agriculture to adapt and contribute to climate solutions (Jones, et al., 2023).

Several studies have been conducted to determine whether the adopted climate-smart technologies are effective in boosting resilience and reducing the effects of climate change while simultaneously improving agricultural output and incomes. Teklu, Simane, and Bezabih (2023) employed an endogenous switching regression model to investigate the impact of climate-smart agriculture innovations on building climate resilience capacity among smallholder farmers in Ethiopia. They found that climate-smart agriculture innovations significantly increased the climate resilience capacity of smallholder households overall. They recommended scaling up climate-smart agriculture innovations by deploying early warning systems and social networks to support climate resilience and build the climate resilience capacity of smallholder farmers.

One of the latest experimental studies on this nexus is by Batista and Vicente (2020), who evaluated the introduction of remunerated mobile savings accounts among smallholder farmers in Mozambique. Their field experiment showed that such mobile products significantly raised savings and boosted investment in modern inputs, particularly fertilizers. However, the effect on more sophisticated or long-term CSA technologies such as conservation tillage or agroforestry was not directly observed, pointing to a tendency for mobile money to initially support basic productivity improvements, rather than transformative shifts in farm practices.

Similarly, Yang et al. (2024) examined the impact of farmers' participation in the digital economy on adopting ecological agricultural technologies to promote sustainable agriculture. They employed treatment effect and mediating effect models, using data from 2,825 grain farmers from the 2020 China Rural Revitalization Survey. Farmers' participation in the digital economy was characterized by digital production, digital sales, and digital finance. The results revealed that digital economy participation significantly promotes ecological agricultural technology adoption.

Specifically, digital finance enhance adoption by increasing demand for agricultural machinery services, improving information availability, and raising food safety awareness, while digital production boosts adoption through increased demand for agricultural machinery services. The findings further showed that the promotion effect is stronger among farmers with higher digital literacy and larger cultivated land areas. These insights underscore the potential of digital technology in advancing sustainable agriculture, offering valuable guidance for China and other nations aiming to meet sustainable development goals.

Using digital technology to empower agriculture brings new opportunities to promote sustainable agricultural development. Zhao et al. (2022) investigated the impact of digital finance on the adoption of sustainable agricultural practices among smallholder farmers in China. Using panel data spanning 31 provinces from 2011 to 2020, they explored how digital finance influences farmers' decisions to adopt sustainable agricultural practices.

Their findings revealed that digital finance significantly increased the number of sustainable agricultural practices adopted by small farmers, highlighting its role in fostering sustainable agriculture. Based on these insights, the researchers recommended that the government invest in rural network infrastructure and implement training programs to ensure that smallholder farmers can access digital financial services affordably and securely.

Similarly, A study by Yu et al. (2020) explored the impact of digital finance on the adoption of green control techniques by family farms in China, focusing on 441 farms in Henan provinces. Using a mediating effect model, they examined how digital finance influences the adoption of these techniques. They found out that digital finance positively affects the adoption of green control techniques in family farms. This effect occurs through three main channels: improving access to credit, facilitating information acquisition, and strengthening social trust.

In a broader comparative analysis across 25 Sub-Saharan African economies, Ky (2025) analyzed the adoption of digital financial services among farmers using data from the World Bank's Global Findex 2021. While farmers were more likely than non-farmers to adopt mobile money accounts especially in rural areas the study found that adoption remained below 30%, and usage was largely confined to savings, borrowing, and remittance transfers.

The authors findings suggest that while mobile money is gradually expanding financial inclusion, its impact on more strategic agricultural investment (including CSA practices) is still constrained by systemic and behavioral factors, particularly among disadvantaged groups such as women and the less educated. Muasa and Matsuda (2019) also examined the role of mobile phones in enhancing farmers' adaptive capacity studying rural farming households in Kenya's semi-arid regions. They found that mobile money enabled farmers to access extension services, credit, weather information, and agricultural markets, key pillars of CSA uptake. However, the effects were uneven: feature phone usage was dominant among lower-income households, while smartphones which provided richer digital services were more common among wealthier male-headed households. The study highlighted that mobile money alone was insufficient without complementary information and training, though it clearly enhanced farmers' ability to cope with climate variability.

Further evidence on the importance of complementary services comes from Makate et al. (2019), who studied smallholder farmers in Zimbabwe and Malawi. Their findings emphasized that access to institutional credit and extension services was critical for CSA adoption. Interestingly, they found that while credit alone improved CSA uptake, extension services had a more substantial impact, especially when both were provided together. Gender and age dynamics also played a role, with younger and female farmers benefiting less from these services. This suggests that while mobile money may ease financial constraints, without integrated support (such as extension or training), its ability to drive CSA adoption may remain limited, especially for marginalized groups

Despite the wealth of research on climate-smart agriculture and the digital finance, there remains a significant gap in understanding the specific role of mobile money in Kenya. Many existing studies have focused broadly on digital finance and mobile phones; limited research examines the specific role of mobile money as a financial tool in facilitating the adoption of climate smart practices.

Additionally, most research, such as those conducted in China and Ethiopia, does not address the specific challenges and opportunities within Kenya's context, a country characterized by high mobile money adoption and significant agricultural reliance. The mechanisms through which mobile money impacts climate smart adoption, such as access to credit, climate-resilient seeds, or market information, remain underexplored. Taken together, these empirical studies temporal pattern also reflects the gradual nature of technology and behavior change in rural farming systems. Considering these insights, and consistent with the existing empirical evidence, this study proposes the following hypotheses for further testing:

H1a: Mobile money usage has a positive but minimal influence on the uptake of climate-smart agricultural practices in the short run.

H1b: Mobile money usage positively and significantly influences the uptake of climate-smart agricultural practices in the long run

### **2.3.2 Effect of Mobile Money in GHG Emission Reduction**

There is growing empirical interest in understanding the nexus between financial technology (FinTech) services and environmental sustainability, yet the specific contribution of mobile money to greenhouse gas (GHG) emission reduction in the agricultural sector remains underexplored. While Kenya, as a global leader in mobile money innovation, has widely demonstrated the financial inclusion benefits of such services, the environmental dimension particularly how mobile money might facilitate climate mitigation through sustainable agricultural practices is an emergent area of study.

Despite its clear potential to promote climate-smart agriculture by improving financial access and enabling farmers to invest in low-carbon technologies, there remains a significant gap in the literature concerning mobile money's direct impact on GHG emission reduction. This gap provides an opportunity to further investigate the role of mobile money in supporting environmental goals, particularly through enabling waste conversion into utilities and clean energy in agriculture.

Several recent studies highlight the broader environmental implications of FinTech and digital finance innovations. Umar et al. (2020) examined the long-term effects of innovation, financial development, and transportation infrastructure on CO<sub>2</sub> emissions in China (1971–2018), revealing that while innovation initially drove CO<sub>2</sub> emissions, financial development exerted a long-term negative effect on emissions. Their findings suggest that well-structured financial systems potentially including mobile money can play a role in mitigating environmental harm. Similarly, Tao et al. (2022) demonstrated that FinTech development facilitates GHG reduction by enabling efficient financial transactions and promoting sustainable investments, highlighting the environmental promise of financial technologies like mobile money.

Further cross-country evidence is provided by Awais et al. (2023), who analyzed FinTech's relationship with sustainable economic development across 66 nations (2010–2021). They found that internet penetration and financial inclusion, both central to mobile money systems, positively influenced green economic activity.

Conversely, carbon emissions remained a constraint on green growth. These findings imply that mobile money, by expanding financial inclusion, could serve as a catalyst for green transitions in agriculture by enabling farmers to adopt sustainable technologies and practices. However, not all research offers uniformly optimistic conclusions. Lisha et al. (2023), in their study of BRICS nations, found that while FinTech promotes financial inclusion, it can also increase digital energy consumption, potentially offsetting environmental gains. Likewise, Wang et al. (2020) found that although agricultural value-added can mitigate CO<sub>2</sub> emissions, economic globalization and financial development can, in certain contexts, contribute to environmental degradation. These mixed results underscore the importance of context-specific dynamics mobile money's environmental benefits depend on how it is used and the structures that support it.

Focusing more directly on agriculture, Liao and Zhou (2023) provided robust evidence from China (2011–2020) that digital financial development significantly reduces agricultural carbon emissions. Using a fixed-effects model, they highlighted that digital finance supports farmers in adopting low-carbon agricultural technologies. Similarly, Zhang and Li (2025), studying 284 Chinese cities, confirmed that digital inclusive finance reduces agricultural carbon emission intensity, particularly by promoting rural entrepreneurship, green innovation, and facilitating sustainable investment in regions with underdeveloped traditional financing systems. These findings demonstrate how mobile money as a key driver of financial inclusion could be leveraged to enhance sustainable agricultural development.

Complementing these results, He et al. (2022) showed that digital inclusive finance can mitigate the negative effects of climate variation on rural income growth, indirectly promoting climate resilience and environmental outcomes. Muganyi et al. (2021) further found that China's FinTech growth has contributed to emissions reduction and boosted environmental protection investments, demonstrating the sector's potential for climate mitigation.

Within this growing body of literature, the role of mobile money specifically in the Kenyan agricultural context remains relatively understudied. Kenya's mobile money ecosystem led by M-Pesa, provides a globally relevant test case for how digital finance may foster CSA adoption and reduce GHG emissions through improved financial access and investment in technologies for waste conversion and clean energy. Drawing on the broader FinTech evidence, and building particularly on the findings of Liao and Zhou (2023) and Zhang and Li (2025), this study expects that mobile money could similarly enable Kenyan farmers to pursue sustainable practices that directly reduce agricultural GHG emissions. Accordingly, the following hypotheses are proposed:

H2a: Mobile money usage minimally contributes to the reduction of agricultural GHG emissions through waste conversion into utilities and energy in the short run.

H2b: Mobile money usage significantly reduces agricultural GHG emissions through waste conversion into utilities and energy in the long run.

### **2.3.3 Agricultural Waste Conversion**

Agricultural waste-to-utility and energy technologies have gained significant attention in Kenya and other developing economies to enhance climate smart agricultural practices and reduce greenhouse gas (GHG) emissions. A growing body of research explores how agricultural residues such as crop waste, livestock manure, and agro-industrial byproducts can be converted valuable utilities such as biogas, biochar energy, electricity, and liquid biofuels, reducing reliance on fossil fuels while enhancing rural energy security.

In Kenya, research highlights the vast untapped potential of converting livestock manure and crop residues into biogas through anaerobic digestion. Small-scale biogas digesters have shown promising results in transforming organic waste into methane, which can be used for cooking, electricity generation, and farm operations. Studies reveal that maize husks, sugarcane bagasse, and coffee pulp could serve as effective feedstocks for biogas production, reducing reliance on traditional biomass fuels and mitigating harmful emissions.

However, challenges such as high initial setup costs, lack of technical expertise, and limited financial accessibility have hindered widespread adoption. Mobile money platforms such as M-Pesa could present a scalable solution to this barrier, offering farmers instant access to climate-smart financing and digital payment models that could accelerate biogas adoption.

Biochar production through the pyrolysis of crop residues has been recognized as a pivotal strategy for greenhouse gas (GHG) emission reduction in agricultural systems. Studies show that biochar derived from rice husks, maize stalks, and coconut shells enhances soil fertility, retains moisture, and reduces methane emissions from organic waste decomposition. It also helps reduce nitrous oxide (N<sub>2</sub>O) emissions by stabilizing nitrogen in the soil and minimizing the volatilization associated with synthetic fertilizers. Biochar adoption rates could be effective when tied to financial incentives, such as carbon credit monetization schemes. This underscores the importance of mobile money integration, allowing farmers to receive direct payments for sustainable agricultural practices, thus enhancing adoption rates.

Gasification and direct combustion technologies offer alternative pathways for converting biomass waste into clean energy, significantly contributing to CO<sub>2</sub> emissions reduction. Research underscores the decentralized nature of biomass energy systems, which can be particularly valuable in providing off-grid electricity solutions for farming communities. Studies from other developing economies, such as India and Brazil, highlight the role of agricultural waste as a key contributor to rural electrification, reducing dependence on fossil fuels and lowering ghg emissions. Kenya's case studies show that small-scale biomass power plants could not only meet rural energy needs but also reduce reliance on fossil fuels, curbing excessive carbon emissions from traditional energy sources.

Studies from other developing economies confirm that the successful adoption of biomass power solutions depends on both technical viability and accessible financial models. Mobile money transactions have been explored as a tool for streamlining payments for energy access, reducing barriers to infrastructure investment, and enabling farmers to sustainably participate in off-grid renewable energy programs.

Liquid biofuels derived from agricultural waste represent another promising approach to GHG emissions reduction. Studies on sugarcane bagasse, palm oil residues, and cassava waste assess their potential for ethanol and biodiesel production, with findings emphasizing their ability to replace fossil fuels and lower carbon emissions.

While biofuel adoption presents a viable sustainability pathway, Studies advocate for prioritizing waste-based biofuel production to ensure that fuel generation does not compete with food production. Thus, this study emphasizes the importance of integrating mobile money systems into biofuel financing models to facilitate affordable investments and promote sustainable fuel transitions.

Across these studies, a recurring theme is the critical role of financial inclusion in scaling waste-to-energy technologies while simultaneously achieving measurable GHG emission reductions. The widespread use of mobile money platform in Kenya creates a unique opportunity to bridge climate finance, carbon credit payouts, and agricultural sustainability efforts. Mobile money services offer a revolutionary approach to financing climate-smart agriculture, allowing farmers to access loans, subsidies, and carbon credit payouts through digital transactions. By linking mobile transactions to verified emissions reductions, financial accessibility could transform waste-to-energy adoption into a real-time incentive-driven system. This financial accessibility could enable widespread adoption of biogas systems, biochar integration, and decentralized energy solutions and could be a game-changer in transitioning Kenya's agricultural sector toward sustainability underscoring the need for holistic policy frameworks, technological advancements, and financial accessibility. As well as empower farmers to transition toward low ghg practices while ensuring they receive monetary benefits from climate-smart agricultural practices.

#### **2.3.4 Carbon Credit Monetization for Smallholder Farmers**

The intersection of mobile money, carbon markets, and smallholder agriculture is fast becoming an emerging frontier in climate finance, particularly across the Global South. As both voluntary carbon markets (VCM) and compliance markets are driven by growing global demand for verifiable emission reductions, an opportunity has emerged for smallholder farmers to monetize low- carbon agricultural practices through mobile money platforms (Zheng, 2025).

The primary motivation for farming communities to engage in carbon offset projects within the VCM lies in the payments they receive for the carbon credits generated by their mitigation activities (Barbato & Strong, 2023; Buck & Palumbo-Compton, 2022). These payments offer farmers an additional and often much-needed income stream, contributing to improved financial stability and household resilience. Moreover, participation in such initiatives frequently comes with access to ecosystem services, technical assistance, and capacity building on sustainable land management, thereby enhancing both climate resilience and long-term livelihood sustainability (Dyck, 2023).

However, while policy discussions and development sector reports frequently highlight the potential of carbon markets for smallholders, the academic literature remains limited offering very limited insights on the actual mechanisms, barriers, and outcomes of carbon credit monetization for smallholder farmers. Particularly, there is a notable gap concerning the practical role of mobile money platforms in facilitating farmers' engagement with carbon markets.

Current empirical research on smallholder participation in the VCM is virtually non-existent, with much of the literature instead focusing on household energy technologies such as biogas digesters where projects are often justified by their substantial local co-benefits, such as improved public health, enhanced income, and new market opportunities, alongside global emissions reductions (Finley-Brook, 2016). Yet, even within these project types, questions remain about whether the narratives of local development that are marketed to offset buyers truly align with the lived experiences of the communities involved. Finley-Brook (2016) critically assessed this mismatch, finding that many promoted "stories" of sustainable local market development fail to reflect the realities encountered by technology users and participating farmers. One major limitation in the existing voluntary carbon credit frameworks is their narrow focus on emissions reduction metrics, often at the expense of addressing important socio-economic considerations. Voluntary standards frequently fall short in ensuring that carbon market benefits are fairly distributed among smallholders (Pan et al., 2022).

Howard et al. (2016) demonstrated that initiatives under schemes like Fairtrade International and the Gold Standard have sought to incorporate “fair carbon” principles that explicitly focus on equity, justice, and inclusive benefit sharing. These frameworks aim to ensure that marginalized groups, including smallholder farmers, are active participants in carbon projects, with access to both decision-making processes and project revenues. Nevertheless, persistent challenges remain particularly in overcoming entrenched power imbalances, ensuring meaningful community participation, and safeguarding equitable access to benefits within carbon markets.

Participation in VCM projects is also not without significant costs for smallholder farmers. To generate carbon credits, farmers often face upfront financial investments such as purchasing inputs needed for sequestration activities such as tree seedlings, fertilizers, soil amendments along with opportunity costs tied to altered land-use patterns and, in some cases, reductions in crop yields or income from forgone activities (Santier, 2023). Thus, achieving sustainable engagement of smallholders in carbon markets requires more than market access alone; it demands robust governance reforms to improve transparency, accountability, and fairness in market participation.

Amar et al. (2023) argue that improving governance within the VCM requires reducing reliance on costly intermediaries, simplifying complex and expensive certification processes, and building mechanisms that grant smallholder farmers a more direct stake in the value chain. This includes ensuring that mobile money-enabled payments are timely, fair, and directly accessible to farmers, helping to enhance trust and participation.

Mobile money platforms offer transformative potential to address some of these longstanding barriers. By dramatically lowering transaction costs, improving payment efficiency, and promoting financial inclusion, mobile money can empower farmers to actively participate in carbon markets while minimizing the role of costly intermediaries (Zheng, 2025; Amar et al., 2023). Furthermore, mobile-based tools can facilitate transparent record-keeping, digital monitoring, reporting, verification, and rapid payment processing all of which are essential for scaling smallholder participation in carbon markets and ensuring that the resulting economic and social benefits are both equitable and sustainable.

Table 2.1 Previous Studies Summary

<b>Author(s)</b>	<b>Country</b>	<b>Methodology</b>	<b>Focus Area</b>	<b>Key Findings</b>	<b>Contribution to This Study</b>
<b>Zhang &amp; Li (2025)</b>	China	Panel Analysis	Inclusive finance & agri-GHG	Inclusive finance reduces agri- carbon intensity through green innovation and rural entrepreneurship	Supports mobile finance-emission linkage.
<b>Zheng (2025)</b>	Global	Systematic Review	Mobile money & carbon markets	Mobile money supports carbon market access and participation for smallholders	Informs mobile-based carbon payments.
<b>Ky (2025)</b>	SSA (25 countries)	Survey & Findex Analysis	Digital finance adoption	Rural farmers use mobile money for basic transactions; CSA financing limited	Highlights regional digital finance gaps.
<b>Yang et al (2024)</b>	China	Mediation & Treatment Models	Digital economy & eco-agriculture	Digital finance encourages ecological agri-tech via credit and info access	Links digital finance to CSA adoption.
<b>Awais et al (2023).</b>	66 countries	Cross-country regression	FinTech, inclusion & green economy	FinTech and inclusion enhance sustainable growth and resource efficiency	Supports inclusive green finance framing.

<b><i>Lisha et al (2023)</i></b>	<i>BRICS</i>	<i>Empirical study</i>	<i>FinTech &amp; digital emissions</i>	<i>Digital finance adoption improves inclusion but increases energy usage</i>	<i>Highlights environmental trade-offs.</i>
<b><i>Mutua et al (2023)</i></b>	<i>Kenya</i>	<i>Longitudinal study</i>	<i>Mobile money &amp; CSA</i>	<i>Mobile finance supports CSA like tillage, agroforestry, and organics</i>	<i>Adds CSA detail, lacks GHG tie-in.</i>
<b><i>Liao &amp; Zhou (2023)</i></b>	<i>China</i>	<i>Fixed Effects</i>	<i>Digital finance &amp; agri-CO<sub>2</sub></i>	<i>Digital finance reduces agri-carbon via tech adoption</i>	<i>Supports emissions reduction via tech.</i>
<b><i>Amar et al (2023)</i></b>	<i>Africa</i>	<i>Policy Review</i>	<i>Carbon governance &amp; FinTech</i>	<i>Mobile-enabled payouts reduce intermediary costs in VCMs</i>	<i>Supports mobile payouts for VCMs.</i>
<b><i>Barbato &amp; Strong (2023)</i></b>	<i>Global South</i>	<i>Policy analysis</i>	<i>Carbon credits for smallholders</i>	<i>Carbon credit income improves household resilience and climate services</i>	<i>Shows income impact from offsets.</i>
<b><i>Dyck (2023)</i></b>	<i>Africa</i>	<i>Policy Review</i>	<i>Carbon market access &amp; resilience</i>	<i>Carbon initiatives improve resilience and service access</i>	<i>Strengthens CSA–resilience narrative.</i>
<b><i>Santier (2023)</i></b>	<i>Global South</i>	<i>Field study</i>	<i>Costs of carbon farming</i>	<i>High upfront costs reduce smallholder entry to carbon markets</i>	<i>Justifies mobile finance for access.</i>

<b><i>Teklu et al (2023)</i></b>	<i>Ethiopia</i>	<i>Endogenous Switching Regression</i>	<i>CSA adoption</i>	<i>CSA extension services are crucial.</i>	<i>Validates CSA practice effectiveness.</i>
<b><i>Tao et al (2022)</i></b>	<i>Global</i>	<i>Meta-study</i>	<i>FinTech &amp; GHG</i>	<i>FinTech channels funds into low-emission investment</i>	<i>Frames mobile finance in mitigation.</i>
<b><i>Buck &amp; Palumbo-Compton (2022)</i></b>	<i>Global South</i>	<i>Case-based Review</i>	<i>Co-benefits of carbon offsets</i>	<i>Offsets provide agri support and ecosystem services</i>	<i>Emphasizes development co-benefits.</i>
<b><i>Pan et al (2022)</i></b>	<i>Global</i>	<i>Policy Gap Study</i>	<i>Voluntary market fairness</i>	<i>Inclusion in VCM requires equity frameworks for smallholders</i>	<i>Reinforces fairness in finance design.</i>
<b><i>He et al (2022)</i></b>	<i>China</i>	<i>Empirical</i>	<i>Climate variation, income &amp; finance</i>	<i>Digital finance buffers income loss during climate shocks</i>	<i>Links finance to resilience building.</i>
<b><i>Zhao et al (2022)</i></b>	<i>China</i>	<i>Panel Data</i>	<i>Digital finance &amp; sustainability</i>	<i>Digital finance boosts sustainable farming practices</i>	<i>Confirms digital sustainability channel.</i>
<b><i>Muganyi et al (2021)</i></b>	<i>Kenya</i>	<i>Longitudinal</i>	<i>FinTech &amp; green investment</i>	<i>FinTech expansion drives env. protection investment</i>	<i>Supports long-term green finance.</i>
<b><i>Umar et al (2020).</i></b>	<i>China</i>	<i>Time Series</i>	<i>FinTech &amp; CO<sub>2</sub></i>	<i>Financial dev. reduces long-run CO<sub>2</sub> emissions via innovation</i>	<i>Places mobile in macro trends.</i>

<b><i>Yu et al (2020)</i></b>	<i>China</i>	<i>Mediating Effect Model</i>	<i>Green control techniques</i>	<i>Digital finance enables eco-tech use through credit and info</i>	<i>Shows credit-enabled adoption link.</i>
<b><i>Wang et al (2020)</i></b>	<i>Global</i>	<i>Empirical study</i>	<i>Economic globalization &amp; CO<sub>2</sub></i>	<i>Agricultural growth reduces emissions; globalization may increase them</i>	<i>Provides emission trend context.</i>
<b><i>Batista &amp; Vicente (2020)</i></b>	<i>Mozambique</i>	<i>Field Experiment</i>	<i>Mobile savings &amp; agri-investment</i>	<i>Mobile savings improve input investment and productivity</i>	<i>Supports role of savings tools.</i>
<b><i>Muasa &amp; Matsuda (2019)</i></b>	<i>Kenya</i>	<i>Household Survey</i>	<i>Mobile phones &amp; CSA</i>	<i>Mobile money improves access to credit, weather info, and markets</i>	<i>Kenya-specific CSA mobile insight.</i>
<b><i>Makate et al (2019)</i></b>	<i>Zimbabwe &amp; Malawi</i>	<i>Regression</i>	<i>CSA &amp; credit-extension services</i>	<i>Combined credit and extension enhance CSA uptake</i>	<i>Informs bundled service design.</i>
<b><i>Howard et al (2016)</i></b>	<i>Global</i>	<i>Review</i>	<i>Equity in VCM</i>	<i>Fairtrade and Gold Standard promote just benefit sharing</i>	<i>Lays fairness principles groundwork.</i>

### 2.3.5 Gaps in literature

There is growing empirical recognition of mobile money as a key enabler of financial inclusion in the Global South particularly in Kenya, where the widespread adoption of M-Pesa has transformed access to financial services (Jack & Suri, 2014). Studies have demonstrated how mobile money facilitates access to credit, savings, and insurance products, which in turn support agricultural productivity and household resilience (He et al, 2022; Makate et al, 2019).

However, when it comes to the direct role of mobile money in promoting climate-smart agriculture (CSA) and contributing to greenhouse gas (GHG) emissions reduction, the empirical literature remains fragmented and underdeveloped both in Kenya and globally. In Kenya, some recent studies (Mwangi & Kariuki, 2021; Mutua et al., 2023) have started to explore how mobile money services enable smallholders to adopt CSA practices such as conservation tillage, agroforestry, and organic fertilizer use, which are known to lower carbon footprints and enhance soil carbon sequestration. Yet, these studies often stop short of explicitly linking mobile money usage to measurable GHG emissions reductions or to participation in carbon markets. The pathways between financial access, CSA adoption, and verified emissions outcomes remain poorly understood and insufficiently tested in rigorous empirical work.

Globally, studies such as Umar et al. (2020), Tao et al. (2022), and Awais et al. (2023) provide broader evidence that digital finance innovations can promote financial inclusion and green investment, while Muganyi et al. (2021) and Liao & Zhou (2023) offer evidence from China that digital finance helps reduce agricultural carbon emissions by supporting green innovations and sustainable practices. Similarly, He et al. (2022) and Zhang & Li (2025) show that digital inclusive finance can mitigate the effects of climate variability and reduce agricultural emissions in Chinese cities. However, most of this literature focuses on digital finance in general rather than mobile money, and much of it is concentrated in East Asia. The applicability of these findings to African smallholder farming systems remains unclear, given major differences in farm

size, land tenure, financial systems, and market access. Empirical studies documenting how mobile money platforms can facilitate carbon credit monetization for smallholder farmers are even more limited.

Zheng (2025), Barbato & Strong (2023), and Buck & Palumbo-Compton (2022) emphasize the potential for mobile money to deliver payments to farmers participating in voluntary carbon markets (VCM), few empirical demonstrations currently exist. Governance challenges in VCM, especially around transparency and equitable benefit-sharing for farmers, remain significant concerns (Pan et al., 2022; Amar et al., 2023). Although Kenya is often cited as a mobile money innovation leader, no rigorous impact studies have yet documented how mobile money integration in CSA-carbon market projects affects farmer income, adoption rates, or verifiable GHG emission reductions. Similar gaps persist across South Africa and much of Asia.

Furthermore, there is little empirical work examining gender dynamics, digital literacy barriers, and transaction costs in mobile money-enabled CSA or carbon market participation. Finley-Brook (2016), studying cookstove projects, has shown that buyers' narratives about local development impacts often fail to reflect users' real experiences, but this insight has not been extended to CSA- carbon initiatives using mobile money. Additionally, despite promising early pilot projects in Kenya (such as Vi Agroforestry's carbon programs), rigorous evaluations linking mobile money-enabled CSA interventions to verifiable, sustained GHG reductions are lacking. There are few longitudinal studies tracking the long-term impacts of such interventions, and little evidence to guide the design of policy frameworks or financial products that could ensure equitable access for marginalized groups.

Overall, while the potential for mobile money to support climate-smart agriculture and carbon market participation is increasingly recognized, the empirical foundation remains thin and uneven. The global literature is still dominated by studies from East Asia, with limited representation from African contexts such as Kenya, where mobile money use is widespread but smallholder agriculture faces unique challenges. Without more robust, context-sensitive

evidence particularly on the direct links between mobile money, CSA adoption, and measurable emissions reductions, it remains difficult to inform effective policy or scale up such innovations in ways that deliver both climate and development benefits

### **2.3.6 Conceptual Framework**

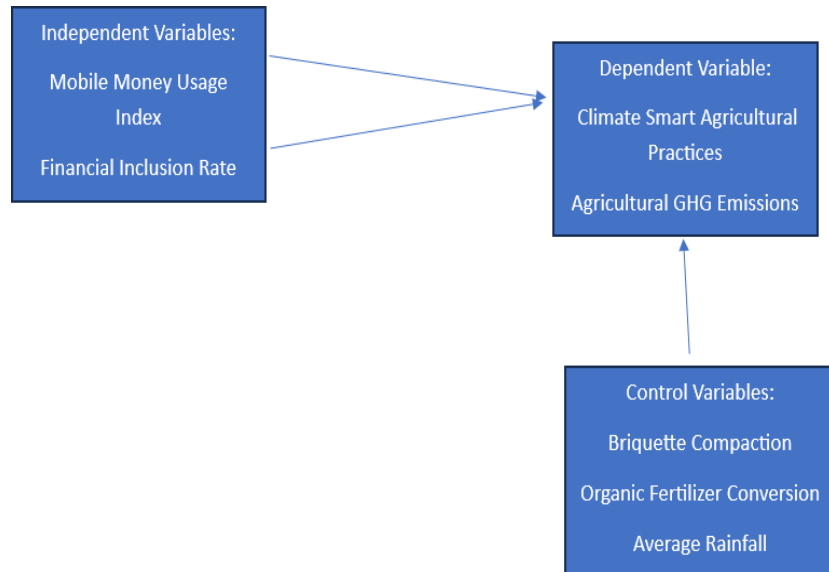
The Figure 2.4.6 below displays a conceptual framework illustrating the hypothesized relationships between mobile money usage, financial inclusion, and two key dependent variables: (1) the adoption of Climate-Smart Agricultural (CSA) Practices and (2) the reduction of Agricultural Greenhouse Gas (GHG) Emissions.

The framework is rooted in the understanding that mobile money can significantly influence smallholder farmers' ability to adopt climate smart agricultural practices that mitigate GHG emissions by converting waste into utility and energy.

The two independent variables Mobile Money Usage Index and Financial Inclusion Rate are theorized to have direct positive effects on both dependent variables. Increased access to mobile money enhances farmers' financial liquidity, enabling them to purchase improved agricultural inputs, adopt waste- to-energy technologies. Similarly, higher levels of financial inclusion allow farmers to diversify income streams, better manage risks, and access formal credit and savings products, which are crucial for adopting CSA practices and financing emission reduction activities.

Additionally, the framework integrates three control variables. Briquette Compaction, Organic Fertilizer Conversion, and Average Rainfall which are expected to influence both CSA adoption and agricultural GHG emissions. By capturing the dynamic interactions between financial access, technological adoption, and environmental conditions, this framework provides a comprehensive lens for understanding how mobile money usage and financial inclusion can drive sustainable transitions in agriculture.

Figure 2.4 Conceptual Framework



## **CHAPTER 3 METHODOLOGY**

### **3.1 Research Type**

This study uses a quantitative research approach to investigate the impact of mobile money usage on the adoption of Climate-smart agriculture practices and its subsequent effect on GHG emissions reduction by converting agricultural waste into utility and energy in Kenya's agricultural sector. The study employs a monthly time series data collected between 2008 and 2024.

### **3.2 Research Approach**

This study adopts a quantitative research approach, and it involves collecting and analyzing secondary data from a variety of sources, including mobile money transaction records, climate smart agricultural adoption statistics, Agricultural GHG emissions data and conversion of waste to utility and energy.

### **3.3 Operational Definition of Variables**

#### **3.3.1 Dependent Variables**

**Agricultural GHG Emissions:** This variable captures the total greenhouse gas emissions generated from agricultural activities, measured in metric tons of CO<sub>2</sub> equivalent (MtCO<sub>2</sub>e) monthly. It serves as a key indicator of the environmental impact of agricultural production, reflecting emissions from crops, livestock, soil management, and biomass burning. Biomass burning includes the combustion of crop residues, grasslands, and forested areas for land clearing, post-harvest disposal, and soil preparation, contributing to CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions. Data for this variable is sourced from the Kenyan Ministry of Agriculture and Livestock Department, ensuring comprehensive tracking of emission trends in the sector.

**Climate-smart Agriculture Practices:** This variable measures the extent of climate smart agriculture practices implemented by farmers, such as soil conservation, agroforestry, and water-saving irrigation techniques. It is quantified by the total number of farmers in thousands adopting those practices in rural Kenya. Data for this variable is gathered from national agricultural surveys conducted by the Kenya Organic Agriculture Network (KOAN).

### 3.3.2 Independent Variables

Mobile Money Usage Index: This variable represents the overall adoption and utilization of mobile money services in rural areas, particularly among farmers on monthly basis. It is constructed using three key indicators: Mobile Money Agent Accessibility (MMAA), Mobile Money Adoption by Farmers (MMAF), and Mobile Money Transaction Activity (MMTA). Data for these indicators is sourced from the Central Bank of Kenya's Mobile Payment Section and the Fin Access Survey Kenya, ensuring comprehensive coverage of mobile money trends.

The first dimension, Mobile Money Agent Accessibility (MMAA), measures the availability of mobile money agents in rural areas, quantified in thousands of agents. This indicator reflects financial service accessibility and the ease with which farmers engage with mobile money platforms. The second dimension, Mobile Money Adoption by Farmers (MMAF), captures the total number of farmers utilizing mobile money services, measured in millions of registered mobile money accounts. This ensures that financial inclusion is specifically examined within the agricultural sector. The third dimension, Mobile Money Transaction Activity (MMTA), assesses the volume of mobile money transactions conducted in rural areas for agricultural purposes, quantified in millions of transactions per month. This captures the actual financial engagement of farmers through mobile money transactions.

The MMUI is particularly relevant for measuring the extent of mobile money usage and its impact on financial inclusion in rural Kenya. While previous studies have relied on digital finance indices (Liao & Zhu, 2023; Banik & Roy, 2023) to assess financial access, these indices fail to capture the specific role of mobile money in rural areas, especially in Kenya. Given farmers' heavy reliance on mobile money services, an index tailored to their financial behavior provides a more accurate representation of financial inclusion.

To standardize the indicators, z-scores are applied, ensuring comparability across metrics with different units and scales. A multiplicative approach is used to construct the MMUI, reflecting the interdependent relationship between accessibility, adoption, and transaction activity.

This ensures that the influence of one factor on mobile money usage is amplified by the others. And to ensure the reliability and validity of the MMUI, Cronbach's alpha is used to evaluate the internal consistency of the indicators, verifying whether they collectively measure mobile money usage. Additionally, factor analysis was conducted to assess whether the three indicators capture the latent dimensions of mobile money adoption. Unlike principal component analysis (PCA), which focuses on variance, factor analysis is more appropriate for this study as it examines the relationships between indicators and the underlying construct of mobile money usage. This methodological approach ensures a robust framework for evaluating mobile money adoption and its role in enhancing financial inclusion among rural farmers in Kenya.

**Financial Inclusion Rate:** This variable measures the proportion of the rural population with access to formal financial services. It is measured as the percentage of individuals using financial services in rural areas and serves as an independent variable to assess how financial accessibility influences the adoption of climate-smart agricultural (CSA) practices and GHG emission reduction. Data for this variable is sourced from central bank reports and financial access surveys.

The financial inclusion rate bridges the gap between formal financial services and mobile money adoption in rural areas. While mobile money provides farmers with fast and accessible transaction mechanisms, financial inclusion which encompasses access to credit, savings, and insurance plays a fundamental role in enabling investment in CSA practices and GHG emission reduction. Farmers with better financial inclusion are more likely to adopt mobile money platforms for agricultural transactions, creating a direct link between financial accessibility and mobile money-driven sustainability solution.

### **3.3.3 Control Variables**

**Briquette Compaction:** This variable measures the percentage of agricultural waste compressed into briquettes as an alternative energy source. It serves as a control variable to account for waste-to-energy conversion effects that may influence both GHG emissions and climate-smart agricultural adoption, and ensure that observed GHG reductions and CSA adoption trends are correctly attributed to mobile money usage rather than solely to the presence of waste conversion technologies preventing misattribution of effects. Data is sourced from Kenya Ministry of Energy and Petroleum.

**Organic Fertilizer Conversion:** This variable measures the amount of agricultural waste repurposed into organic fertilizer for on-farm use, quantified in thousands of tons per month. It serves as a control variable to account for soil enrichment practices that may influence CSA adoption and GHG emission reduction trends. While organic fertilizer conversion directly enhances soil quality and reduces reliance on chemical fertilizers, it is included as a control variable in this study to ensure that observed sustainability outcomes are correctly attributed to mobile money accessibility, rather than simply agricultural waste utilization.

Mobile money facilitates transactions related to organic fertilizer production, purchase, and adoption, but controlling for organic waste conversion ensures that its independent influence on sustainability is accounted for. By integrating this variable as a control, the study effectively isolates the effects of financial inclusion mechanisms while acknowledging the role of waste-to-soil enhancement techniques. This approach ensures a precise evaluation of mobile money's contribution to climate-smart agriculture and emission reduction efforts. Data for this variable is sourced from KilimoSTAT.

**Average Rainfall:** This denotes the average precipitation, which directly affects agricultural output. It is measured in millimeters per month and serves as a control variable to capture climate variability that may impact CSA adoption patterns and GHG emissions reduction. This data is sourced from Kenya Meteorological Department.

Table 3.1 Operational Definition and Variable Measurement

Variables	Definition	Measurement	Data Source
<b>Dependent Variables</b>			
<b>Agricultural GHG Emissions (agghg)</b>	Total greenhouse gas emissions from agricultural activities	Thousand Metric tons of CO <sub>2</sub> equivalent (MtCO <sub>2</sub> e)	Ministry of Environment and Forestry, and, Ministry of Agriculture and Livestock Development
<b>Climate-Smart Agriculture Practices (CSA)</b>	Degree of adoption of CSA practices	Number of farmers in thousands adopting those practices	Kenya Organic Agriculture Network (KOAN).
<b>Independent Variables</b>			
<b>Mobile Money Usage Index (MMUI)</b>	Composite index capturing mobile money usage and penetration among rural farmers.	Multiplicative z-score index from: 1. Mobile Money Agent Accessibility 2. Mobile Money Adoption by Farmers 3. Mobile Money Transaction Activity	Central Bank of Kenya, FinAccess Survey, and Safaricom reports.
<b>Financial Inclusion Rate (FinIncRate)</b>	Rural population accessing formal financial services	In percentage	Central Bank of Kenya
<b>Control Variables</b>			
<b>Briquette Compaction (Briquette Compact)</b>	Agricultural waste compacted into briquettes	In percentage	Ministry of Energy and Petroleum
<b>Organic Fertilizer Conversion (OrgFertConv)</b>	Agricultural waste processed into organic fertilizer used on farms.	In thousands of tons	KilimoSTAT
<b>Average Rainfall (AvgRainfall)</b>	Average Rainfall that can influence crop decisions and viability of CSA practices	In millimeters	Kenya Meteorological Department

### **3.4 Data Collection**

Data for this study is collected from a combination of secondary sources. The total GHG emissions from the agriculture sector is sourced from the Ministry of Environment and Forestry, and, Ministry of Agriculture and Livestock Development which provides comprehensive data on agricultural emissions. The data on climate-smart agriculture practices is gathered from national agricultural surveys conducted by the Kenya National Bureau of Statistics, and the Kenya Organic Agriculture Network (KOAN), which track the adoption of organic and climate farming practices among Kenyan farmers.

The mobile money usage index is constructed using the mobile payments indicators that is collected from the Central Bank of Kenya, FinAccess Survey, and Safaricom annual reports including mobile money agent accessibility, mobile money adoption by farmers, and mobile money transaction activity. Additionally, briquette compaction is obtained from the Ministry of Energy and Petroleum, while organic fertilizer conversion is sourced from KilimoSTAT, and average rainfall is obtained from Kenya Meteorological Department. These datasets is used to examine the relationships between mobile money usage, climate smart agriculture adoption, and GHG emissions in rural Kenya, covering monthly time series data collected between 2008 and 2024.

### **3.5 Research Subjects**

The research focuses on smallholder farmers. In Kenya, most farmers are smallholders and their participation is crucial for the success of climate-smart agriculture to empower them to adopt climate-resilient and emission-reducing practices. These farmers are particularly significant because they make up 80% of the country's farming community and account for about 75% of the total agricultural output in Kenya as according to (Farm to Market Alliance Market Kenya, 2022).

### **3.6 Model Equations**

This study employs the autoregressive distributed lag (ARDL) model to analyze the long-run relationship between mobile money usage, financial inclusion, CSA adoption, and GHG emissions reduction while incorporating an Error Correction Model (ECM) to capture short-run dynamics. The methodological framework is guided by the approach used by Akkutay (2024).

The ARDL model is particularly well-suited for this study due to its ability to provide reliable estimates even with a small sample size, making it ideal for handling the available dataset. Since mobile money was introduced in Kenya in 2007, this study relies on monthly data from 2008 to 2024, which ARDL approach is optimal for such datasets, as it can accommodate both stationary and non-stationary variables, ensuring robust estimation.

Furthermore, the model's flexibility in handling integrated variables, whether they are stationary at level, first difference, or a combination of both, eliminates the need for pre-testing the order of integration. This flexibility simplifies the analysis process and is especially beneficial when dealing with climate data, which often exhibit mixed levels of integration. Moreover, the ARDL model includes an error correction mechanism (ECM), which identifies the speed at which variables return to equilibrium after a short-term disturbance, providing insights into how quickly the effects of mobile money usage on climate-smart agriculture practices and GHG emissions stabilize over time. Addressing potential endogeneity issues by including lags of the dependent and independent variables helps mitigate bias from omitted variables or reverse causality, ensuring more reliable estimates.

Additionally, unlike traditional cointegration techniques that require large data samples and can introduce estimation biases, the ARDL Bound Test approach is applied in this study to test cointegration between the variables, addressing common issues related to variance consistency in time-series models. Given that mobile money plays a crucial role in enabling financial transactions for CSA adoption and its effects on GHG emission reduction by converting waste into utility and energy must be examined with a model that differentiates immediate policy impacts from sustainable long-term trends. The following ARDL model specification is constructed to empirically test these relationships.

#### Model 1: Mobile Money Adoption and CSA Uptake (Long-Run Relationship)

This model assesses the long-run impact of mobile money usage on climate smart agricultural practices. If a cointegration relationship is established between CSA adoption, mobile money usage, financial inclusion, and waste conversion factors, then the long-run ARDL model is specified as:

$$\ln CSA_t = \alpha + \sum_{p=1}^p \beta_p \ln CSA_{t-p} + \sum_{q=0}^q \gamma_q \ln MMUI_{t-q} + \sum_{r=0}^r \delta_r \ln FinIncRate_{t-r} + \sum_{s=0}^s \theta_s \ln BriquetteCompact_t + \sum_{v=0}^v \lambda_v \ln OrgFertConv_t + \sum_{w=0}^w \mu_w \ln AvgRainfall_t + \varepsilon_t$$

If cointegration is confirmed, the Error Correction Model (ECM) for short-run dynamics is structured as:

$$\Delta CSA_t = \alpha + \sum_{p=1}^p \beta_p \Delta CSA_{t-p} + \sum_{q=0}^q \gamma_q \Delta MMUI_{t-q} + \sum_{r=0}^r \delta_r \Delta FinIncRate_{t-r} + \sum_{s=0}^s \theta_s \Delta BriquetteCompact_t + \sum_{v=0}^v \lambda_v \Delta OrgFertConv_t + \sum_{w=0}^w \mu_w \Delta AvgRainfall_t + \phi ECM_{t-1} + \varepsilon_t$$

Model 2: Mobile Money and GHG Emission Reduction by Waste Conversion (Long-Run Relationship)

This model assesses the long-run impact of mobile money adoption on GHG reduction by waste conversion. If a cointegration relationship is established between GHG emission, mobile money usage, financial inclusion, and waste conversion factors, then the long-run ARDL model is specified as:

$$\ln agghgt = \alpha + \sum_{p=1}^p \beta_p \ln agghgt_{-p} + \sum_{q=0}^q \gamma_q \ln MMUI_{t-q} + \sum_{r=0}^r \delta_r \ln FinIncRate_{t-r} + \sum_{s=0}^s \theta_s \ln BriquetteCompact_t + \sum_{v=0}^v \lambda_v \ln OrgFertConv_t + \sum_{w=0}^w \mu_w \ln AvgRainfall_t + \varepsilon_t$$

If cointegration is confirmed, the Error Correction Model (ECM) for short-run dynamics is structured as:

$$\Delta agghgt = \alpha + \sum_{p=1}^p \beta_p \Delta agghgt_{-p} + \sum_{q=0}^q \gamma_q \Delta MMUI_{t-q} + \sum_{r=0}^r \delta_r \Delta FinIncRate_{t-r} + \sum_{s=0}^s \theta_s \Delta BriquetteCompact_t + \sum_{v=0}^v \lambda_v \Delta OrgFertConv_t + \sum_{w=0}^w \mu_w \Delta AvgRainfall_t + \phi ECM_{t-1} + \varepsilon_t$$

### 3.7 Data Analysis

This section outlines the methodology for data analysis, which begins with descriptive statistics and using STATA statistical software. The initial step involves generating descriptive statistics to explore the central tendency, variability, and distribution of the variables in the dataset. The descriptive statistics include the mean, standard deviation, minimum, and maximum for each variable to analyze the central tendency and variability of the key variables. The next phase is to assess the stationarity properties of the time series variables through Unit Root Tests. This step is essential because the ARDL model requires variables to be either integrated at level or first difference, but not at second difference. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests is employed to determine the order of integration.

Once the stationarity conditions are confirmed, the optimal lag length for the ARDL model is selected using information criteria such as the Akaike Information Criterion (AIC) or Schwarz Bayesian Criterion (SBC), which ensure the model captures the dynamic structure without overfitting.

Following lag selection, the ARDL model is estimated to explore both short-run and long-run relationships among the variables. The Bounds Testing approach is then applied to test for cointegration that is, the presence of a long-run relationship among the variables. If cointegration is found, the long-run coefficients are interpreted alongside the short-run dynamics represented by the Error Correction Model (ECM). Subsequently, a series of diagnostic tests are performed to assess model adequacy, including tests for serial correlation (e.g., Breusch-Godfrey LM test), heteroscedasticity (e.g., White or Breusch-Pagan test), and normality of residuals (e.g., Jarque-Bera test). Lastly, diagnostic tests and then CUSUM test for model stability. A stable model, indicated by these tests, confirms that the estimated parameters remain consistent throughout the sample period and are not affected by structural breaks, thereby enhancing the reliability and credibility of the findings.

### **3.8 Diagnostic Tests**

To guarantee the validity and reliability of the findings, several assumptions is conducted before proceeding with the ARDL estimation. These tests are critical to confirm that the model's results are not biased or inefficient. First, the Breusch-Godfrey Serial Correlation LM Test is conducted for autocorrelation as the presence of serial correlation in the residuals indicates that the residuals are not independent over time, leading to biased estimates that would affect the model's performance.

Next, the White test to check for heteroskedasticity which examines whether the variance of the residuals remains constant over time. If heteroskedasticity is present, it means that the variability of the errors differs across observations, making the estimates inefficient and possibly misleading. So, detecting and addressing it is vital. The Jarque-Bera Test is conducted to assess the normality of the residuals.

## CHAPTER 4 RESULTS AND DISCUSSION

### 4.1 Results

#### 4.1.1 Descriptive Statistic Results

The descriptive statistics provide important insights into the distribution and variability of the variables used in this study over 204 monthly observations. Agricultural greenhouse gas (GHG) emissions, the dependent variable, exhibit a mean of 2,450,000 metric tons of CO<sub>2</sub> equivalent (MtCO<sub>2</sub>e) per month, with a standard deviation of 180,000, ranging from 2,100,000 to 2,900,000 MtCO<sub>2</sub>e. This variation reflects the dynamic nature of Kenya's agricultural sector, influenced by seasonal patterns, levels of input use, and the gradual adoption of climate smart agricultural practices.

The adoption of climate-smart agriculture (CSA) practices shows a mean of 55,000 farmers per month, with values ranging between 48,000 and 62,000 and a standard deviation of 3,500. This suggests that although CSA adoption is growing, there is still month-to-month variability, potentially driven by regional extension services that are only active in some areas, Rainfall, which affects farming decisions, and lack of incentives.

The Mobile Money Usage Index (MMUI), a composite score capturing access to and usage of mobile money services among rural farmers, records a mean value of 6.85, with a standard deviation of 0.94, and ranges from 4.50 to 8.90. These figures suggest that mobile money services are widely used among farmers, exhibiting moderate to high usage levels. However, the range also reflects some variability in usage intensity, likely driven by proximity to mobile money agents. This variation is crucial, as it may influence the degree to which farmers can access mobile money to support investments in low-emission agricultural technologies and climate-smart practices.

The financial inclusion rate, representing the percentage of the rural population with access to formal financial services, has a mean of 79.0%, ranging from a minimum of 55.0% to a maximum of 84.0%, with a standard deviation of 6.8%. These figures reflect a moderately high level of financial inclusion across most rural regions, with limited but notable variation.

The relatively narrow range between the mean and maximum indicates that many regions are approaching higher levels of financial integration. However, the presence of a substantially lower minimum suggests that some rural areas still face significant barriers, possibly related to socio-economic disparities.

Among the control variables, briquette compaction measuring the percentage of agricultural waste processed into solid biofuel has a mean of 6.42% and a standard deviation of 3.14%, highlighting inconsistent uptake of waste-to-energy practices. This variability may stem from differences in awareness, access to briquetting equipment, or support programs. Similarly, organic fertilizer conversion averages 85,000 tons per month, with values ranging from 60,000 to 110,000 tons, indicating growing but uneven engagement in transforming agricultural waste into productive inputs. This spread may reflect differences in local infrastructure, market incentives, and technical capacity.

The average monthly rainfall across the observed period is 142 mm, with a standard deviation of 48.5 mm, ranging from a minimum of 36 mm to a maximum of 310 mm. This wide range indicates a high degree of variability in rainfall patterns, which aligns with Kenya's known bimodal rainfall system characterized by alternating wet and dry seasons. Such variability has important implications for climate-smart agricultural practices (CSA). Periods of low rainfall may limit planting decisions, reduce crop yields, and decrease the effectiveness of practices like compost application or organic mulching. On the other hand, periods of intense rainfall may lead to issues such as runoff, soil erosion, and nutrient leaching, potentially undermining CSA efforts. This fluctuation in rainfall emphasizes the need for adaptive planning and resilient agricultural strategies, especially when aiming to reduce greenhouse gas emissions.

Table 4.1 Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	Obs
<b>agghg</b>	2,450.00	180.000	2,100.00	2,900.00	204
<b>CSA</b>	55,000	3,500	48,000	62,000	204
<b>MMUI</b>	6.85	0.94	4.50	8.90	204
<b>FinIncRate</b>	79.0	6.8	55.0	84.2	204
<b>Briquette Compact</b>	6.42	3.14	0.50	1	204
<b>OrgFertConv</b>	85.0	12.5	60.0	110.0	204
<b>Av Rainfall</b>	142.0	48.5	36.0	310.0	204

Source: Processed Data, 2025

## 4.1.2 ARDL Tests Results

### 4.1.2.1 Unit Root Test

To assess the suitability of time series data for econometric modeling, unit root tests were performed using both the Augmented Dickey-Fuller (ADF) and Phillips–Perron (PP) methods. These tests are grounded in the theory of unit roots, which posit that a time series exhibiting a unit root is non-stationary and follows a stochastic trend. Identifying the presence of a unit root involves testing the null hypothesis which suggests that the series is non-stationary (Wohlrabe, 2023). The outcome of these tests informs whether the series needs to be differenced to achieve stationarity, a prerequisite for reliable regression modeling in time series analysis.

The results presented in Table 4.2, indicate that all variables in the model are non-stationary at their levels but become stationary after first differencing. This implies that the variables are integrated of order one,  $I(1)$ , and exhibit statistically significant test statistics. These findings satisfy the stationarity requirements necessary for applying the Autoregressive Distributed Lag (ARDL) approach, which mandates that none of the variables should be integrated of order two,  $I(2)$ . Since none of the variables are stationary at level and all become stationary at first difference, the ARDL bounds testing approach to cointegration is appropriate for analyzing the long-run and short-run relationships among the variables in this study.

Table 4.2 Unit Root Test

Variable	(ADF)		(PP)	
	Level	First Difference	Level	First Difference
<b>agghg</b>	-1.9803 (0.296)	-5.8247*** (0.010)	-2.0345 (0.276)	-6.0923*** (0.000)
<b>CSA</b>	-2.1532 (0.223)	-4.9912** (0.042)	-2.1106 (0.240)	-5.3256*** (0.007)
<b>MMUI</b>	-2.2357 (0.198)	-6.2015*** (0.000)	-2.1981 (0.210)	-6.3094*** (0.000)
<b>FinIncRate</b>	-1.8740 (0.341)	-5.7021*** (0.001)	-1.9254 (0.318)	-5.8807*** (0.000)
<b>Briquette Compact</b>	-2.4204 (3.626)	-4.5565** (0.0051)	-1.2460 (1.8832)	5.3228*** (0.0008)
<b>OrgFertConv</b>	-2.0816 (0.262)	-5.4198*** (0.000)	-2.0487 (0.275)	-5.6914*** (0.000)
<b>AvRainfall</b>	-0.8035 (0.904)	-5.1302*** (0.001)	-0.8619 (0.893)	-5.2840*** (0.001)

Source: Processed Data, 2025

p-values are in parentheses; \*\*\* significant at the 1% level; \*\* significant at the 5% level

#### 4.1.2.2 Lag length Selection

The lag order selection for the ARDL model was based on the Adjusted R<sup>2</sup>, Akaike Information Criterion (AIC), Schwarz Bayesian Criterion (SBC), and the Durbin–Watson statistic. The selection was performed separately for two dependent variables: CSA Adoption and Agricultural GHG Emissions.

The table 4.3 below shows the most significant lag order for model 1 which is p=2 demonstrates the most optimal performance. It yields the highest adjusted R<sup>2</sup> (0.75), indicating strong explanatory power, and offers the lowest AIC (-6.40) and a favorable SBC (-4.85), suggesting an efficient model with minimal information loss. The Durbin–Watson statistic (2.82) supports the absence of significant autocorrelation in the residuals, reinforcing its statistical adequacy. In contrast, for the model 2, the best-performing lag order is p=3, which has the highest adjusted R<sup>2</sup> (0.74) and the lowest AIC (-7.23) among all options. It also exhibits a solid SBC (-5.55) and a strong DW value of 2.78, indicating that this model not only fits the data well but also satisfies key time series diagnostics.

Table 4.3 Lag Length Selection

Lag Order (p)	Adjusted R <sup>2</sup> (CSA)	AIC (CSA)	SBC (CSA)	DW (CSA)	Adjusted R <sup>2</sup> (GHG)	AIC (GHG)	SBC (GHG)	DW (GHG)
0	0.51 (0.002)	4.20	3.81	2.11	0.62 (0.001)	5.01	4.32	2.32
1	0.73 (0.000)	-5.90	-4.61	2.76	0.69 (0.000)	-5.43	-3.89	2.41
2	0.75 (0.001)	-6.40	-4.85	2.82	0.72 (0.000)	-6.98	-5.43	3.53
3	0.69 (0.000)	-5.15	-3.22	2.25	0.74 (0.000)	-7.23	-5.55	2.78
4	0.67 (0.000)	-4.60	-2.59	2.14	0.71 (0.011)	-6.75	-4.80	2.46
5	0.64 (0.000)	-3.85	-1.65	2.01	0.69 (0.000)	-6.10	-3.98	2.21
6	0.60 (0.000)	-3.11	-0.73	1.98	0.65 (0.000)	-5.55	-3.27	2.12
7	0.57 (0.007)	-2.50	-0.03	1.92	0.63 (0.001)	-5.23	-2.88	2.07

Source: Processed Data, 2025

#### 4.1.2.3 Bounds test for cointegration

The next step after selecting the optimal lag length is to determine whether the variables used in this study have a long-run relationship (cointegration). The F-Bounds Test method is used to determine whether long-run equilibrium exists. The following tables contains the cointegration test results of the two dependent variables.

The results of the ARDL F bounds test confirm the presence of a long-run equilibrium relationship in both models; Agricultural GHG Emissions and CSA Adoption as shown in table 4.4 below. For CSA model, the calculated F- statistic is 10.2371, which exceeds the lower (3.79) and upper bound (4.85) at 5% significance level leading to a rejection of the null hypothesis of no cointegration. This statistical evidence suggests that there is a long-run equilibrium relationship between climate smart agricultural practices and mobile money usage and financial inclusion rate.

Similarly, in the agricultural GHG emission model, the F-statistic is 6.6622, which is greater than the lower (3.94) and upper bound (5.04) at 5% significance level leading to a rejection of the null hypothesis of no cointegration. This statistical evidence suggests that there is a long-run equilibrium relationship between agricultural GHG emission and mobile money usage and financial inclusion rate.

Table 4.4 F Bounds Test

F Bounds Test for CSA Model

Null Hypothesis: No levels relationship

F-Statistic	Significance Level	Lower Bound Value	Upper Bound Value
<b>10.2371 **</b>	<b>10%</b>	<b>3.17</b>	<b>4.14</b>
	<b>5%</b>	<b>3.79</b>	<b>4.85</b>
	<b>1%</b>	<b>5.15</b>	<b>6.36</b>

F Bounds Test for GHG Model

Null Hypothesis: No levels relationship

F-Statistic	Significance Level	Lower Bound Value	Upper Bound Value
<b>6.6622 **</b>	<b>10%</b>	<b>3.26</b>	<b>4.27</b>
	<b>5%</b>	<b>3.94</b>	<b>5.04</b>
	<b>1%</b>	<b>5.47</b>	<b>6.78</b>

Source: Processed Data, 2025

Note: \*\*indicates the rejection of the null hypothesis at a 5% level of significance

#### 4.1.2.4 ARDL Estimation Results

The ARDL estimation approach is employed in this analysis to explore both the short- and long-term associations that exist among the variables for both models. According to the long-run estimates for model 1 in Tables 4.5 below, independent variables are statistically significant at the 1% level. The ARDL estimation results for Model 1 reveal that, in the long run, mobile money usage (lnMMUI) with a coefficient of 0.6120 (p-value = 0.0001) and financial inclusion rate (lnFinIncrate) with a coefficient of 0.3420 (p-value = 0.0012) have significant and positive relationships with the number of farmers adopting climate-smart agricultural (CSA) practices. This means that, a 1% increase in mobile money usage increases the number of farmers implementing CSA practices monthly by 0.612%, holding other variables constant. Likewise, a 1% increase in the financial inclusion rate leads to a 0.342% increase of the number of farmers implementing CSA practices monthly. These findings strongly support hypothesis statement H1b, confirming that mobile money usage positively and significantly influences the uptake of climate-smart agricultural practices in the long run.

The results imply that the expansion of mobile money platforms and broader access to financial services play a critical role in promoting CSA adoption by improving farmers' ability to access essential resources such as credit, agricultural inputs, insurance, and technical training over time.

Other variables significantly and positively affect the adoption of climate-smart agricultural (CSA) practices. Notably, briquette compaction ( $\ln\text{BriquetteCompact}$ ), with a coefficient of 0.1270 and a p-value of 0.0053, and organic fertilizer conversion ( $\ln\text{OrgFertConv}$ ), with a coefficient of 0.0930 and a p-value of 0.0371, are both positively associated with CSA adoption. This means that a 1% increase in briquette compaction leads to a 0.127% increase in the number of farmers adopting CSA practices. Compressing agricultural residues to briquettes promotes CSA adoption by encouraging waste valorization. Farmers benefit from lower energy costs and added value from agricultural by-products, making such practices both economically attractive and environmentally sustainable. Likewise, organic fertilizer conversion with a coefficient of 0.0930 and a p-value of 0.0371 is also positively and significantly associated with CSA adoption. This indicates that a 1% increase in the rate of organic fertilizer conversion monthly leads to a 0.093% rise in CSA uptake; underscoring the importance of converting Agricultural waste into organic fertilizer used on farms which improve soil health and reduce reliance on chemical inputs supporting the broader goal of environmentally sustainable agriculture and reinforces farmers' long-term commitment to Climate smart agricultural practices.

However, average monthly rainfall ( $\ln\text{AvgRainfall}$ ) with a coefficient of  $-0.0580$  and a p-value of 0.0049, is negatively and significantly associated with CSA adoption indicating that unfavorable or erratic rainfall patterns may reduce CSA uptake, possibly due to risk aversion or perceived ineffectiveness of new practices during unpredictable weather. This implies that climate variability poses a barrier to full CSA engagement.

In the short run, 48.70% of changes that occur in changes in the climate smart agricultural practices are positively and significantly influenced by mobile money usage variables  $\Delta\ln\text{MMUI}$  with coefficient of 0.3910 and a p-value of 0.0003 together in the previous month ( $\Delta\ln\text{MMUI}(-1)$ ) with coefficient of 0.2080 and a p-value of 0.0247 indicating that a percentage increase in mobile

money usage for the previous month caused climate smart agricultural practices to increase by 0.2080 in the current period. This suggests that mobile money have an immediate role in shaping number of farmers conducting CSA practices. This result strongly supports hypothesis H1a that affirms mobile money usage has a positive but minimal influence on the uptake of climate-smart agricultural practices in the short run; although the influence is moderate rather than minimal, indicating that the enabling role of mobile finance is more substantial than originally assumed.

Similarly, the financial inclusion rate in both the current period and the preceding month represented by  $\Delta \ln \text{FinIncrate}$  with a coefficient of 0.2180 and a p-value of 0.0017, and  $\Delta \ln \text{FinIncrate}(-1)$  with a coefficient of 0.1560 and a p-value of 0.0199 exerts a positive and statistically significant influence on the adoption of climate-smart agricultural (CSA) practices. This indicates that a 1% increase in the financial inclusion rate in the previous month results in a 0.156% increase in CSA uptake in the current period.

Among the control variables, both briquette compaction ( $\Delta \ln \text{Briquette Compact}$ ) with a coefficient of 0.0840 and a p-value of 0.0192 and organic fertilizer conversion ( $\Delta \ln \text{OrgFertConv}$ ) with a coefficient of 0.0660 and a p-value of 0.0564 positively influence CSA uptake. These findings indicate that the use of clean energy sources such as briquettes made from agricultural waste and the conversion of organic materials into fertilizer support farmers in adopting climate-smart agricultural practices. Such innovations help reduce dependence on harmful inputs, lower production costs, and make farming more environmentally sustainable.

The ARDL estimation results for Model 2 shown in table 4.6 below indicate that, in the long run, mobile money usage ( $\ln \text{MMUI}$ ) with a coefficient of  $-0.3840$  and a p-value of 0.0002, and financial inclusion rate ( $\ln \text{FinIncrate}$ ) with a coefficient of  $-0.2170$  and a p-value of 0.0049, have statistically significant and negative relationship with agricultural GHG emissions. This means that a 1% increase in mobile money usage reduces agricultural GHG emissions by 0.384% monthly. These findings provide strong empirical support for hypothesis H2b, confirming that mobile money usage significantly reduces agricultural GHG emissions. Likewise, a 1% increase in financial inclusion rate reduces agricultural GHG emissions by 0.217% monthly.

Other variables show significant negative long-run effects on agricultural GHG emissions. Specifically, briquette compaction ( $\ln\text{BriquetteCompact}$ ), with a coefficient of  $-0.1620$  and a p-value of  $0.0062$ , indicates that a 1% increase in briquette compaction results in a 0.162% decrease in GHG emissions. This finding supports the role of biomass energy derived from agricultural residues in reducing the dependence on high-emission fuels such as charcoal and firewood highlighting the importance of clean energy in agriculture.

Similarly, organic fertilizer conversion ( $\ln\text{OrgFertConv}$ ), with a coefficient of  $-0.0950$  and a p-value of  $0.0253$ , demonstrates that a 1% increase in organic fertilizer usage reduces agricultural GHG emissions by 0.095%. This suggests that replacing synthetic fertilizers with organic alternatives mitigates nitrous oxide emissions, contributing to more climate-resilient and low-carbon farming systems. The results suggest that increased access to mobile money and financial services enables farmers in the long-run to invest in cleaner technologies such as biogas units, organic fertilizer, and solar-powered irrigation systems, which lower agricultural GHG emissions over time.

Moreover, average rainfall ( $\ln\text{AvgRainfall}$ ) in the long run has a positive but statistically insignificant effect on agricultural GHG emissions, with a coefficient of  $0.0460$  and a p-value of  $0.1351$ . This likely reflects Kenya's highly variable bimodal rainfall system, where alternating droughts and heavy rains produce offsetting effects suppressing agricultural GHG emissions during dry periods and increasing them during intense rainfall events through runoff and nutrient loss. The result underscores the need for adaptive risk management strategies to protect farmers from climate variability.

For Model 2, in the short run, 41.10% of changes that occur in changes in the agricultural GHG emissions are negatively and significantly influenced by mobile money usage variables  $\Delta\ln\text{MMUI}$  with coefficient of  $-0.2980$  and a p-value of  $0.0006$  together in the previous 2 months ( $\Delta\ln\text{MMUI}(-2)$ ) with coefficient of  $-0.1490$  and a p-value of  $0.056$  indicating that a percentage increase in mobile money usage leads to a 0.298% decrease in agricultural GHG emissions in the current month, and 0.1490% in previous months. This suggests that mobile money have an immediate role in reducing agricultural GHG emission.

This result supports hypothesis H2a that affirms mobile money usage minimally contributes to the reduction of agricultural GHG emissions in the short run. Although the widespread adoption of low agricultural GHG-emission practices through mobile money has not yet materialized in Kenya, the empirical evidence from this study highlights its potential as an enabling tool for facilitating such practices.

Similarly, the financial inclusion rate in both the current period and the preceding month represented by  $\Delta \ln \text{FinIncrate}$  with a coefficient of  $-0.1630$  and a p-value of  $0.0081$ , and  $\Delta \ln \text{FinIncrate}(-1)$  with a coefficient of  $-0.1070$  and a p-value of  $0.0483$  exerts a negative and significant influence on agricultural GHG emissions. This indicates that a 1% increase in the financial inclusion rate in the current month leads to agricultural GHG emission reduction by  $0.1630\%$  and  $0.1070\%$  in previous month in the current period. These results underscore the importance of accessible financial services in facilitating timely investments in more climate smart agricultural practices.

Among the control variables, both briquette compaction ( $\Delta \ln \text{Briquette Compact}$ ) with a coefficient of  $-0.1210$  and a p-value of  $0.0259$  lead to agricultural GHG emission reduction by  $0.1210\%$  in the current period. Organic fertilizer and average monthly rainfall have a negative insignificant effect to agricultural GHG emission reduction implying limited short-run influence on agricultural GHG emissions.

The error correction terms ECM ( $-1$ ) shown in Tables 4.5. for both Model 1 and 2 meet all three key econometric criteria: they are negative, less than one in absolute value, and statistically significant. This confirms the existence of a long-run equilibrium relationship among the variables in each model. Specifically, the coefficient of the error correction term ECM ( $-1$ ) is  $-0.6740$  for Model 1 and  $-0.7030$  for Model 2, indicating a strong and rapid adjustment toward long-run equilibrium following any short-run deviation. This means that approximately 67% of the disequilibrium in Model 1 and 70% in Model 2 is corrected each month over the sample period.

Tables 4.5 ARDL Estimation Results for Model 1

Long-run estimates

Variable	Coefficient	t-statistic	Prob.
<b>lnCSA</b>	- 0.8593665***	-5.25	0.0020
<b>lnMMUI</b>	0.6120**	4.75	0.0001
<b>lnFinIncrate</b>	0.3420**	3.61	0.0012
<b>lnBriquette Compact</b>	0.1270***	2.98	0.0053
<b>lnOrgFertConv</b>	0.0930***	2.14	0.0371
<b>lnAvgRainfall</b>	-0.0580***	-1.88	0.0049

Short-run estimates

Variable	Coefficient	t-statistic	Prob.
<b>ΔlnCSA</b>	0.4870**	3.80	0.0004
<b>ΔlnCSA(-1)</b>	0.2630***	2.11	0.0410
<b>ΔlnCSA(-2)</b>	0.1870	1.67	0.0972
<b>ΔlnMMUI</b>	0.3910**	4.02	0.0003
<b>ΔlnMMUI(-1)</b>	0.2080***	2.36	0.0247
<b>ΔlnMMUI(-2)</b>	0.1430	1.91	0.0613
<b>ΔlnFinIncrate</b>	0.2180**	3.29	0.0017
<b>ΔlnFinIncrate(-1)</b>	0.1560**	2.43	0.0199
<b>ΔlnFinIncrate(-2)</b>	0.1120	1.87	0.0701
<b>ΔlnBriquette Compact</b>	0.0840**	2.45	0.0192
<b>ΔlnBriquette Compact (-1)</b>	0.0620	1.79	0.0795
<b>ΔlnBriquette Compact(-2)</b>	0.0450	1.54	0.1280
<b>ΔlnOrgFertConv</b>	0.0660***	1.95	0.0564
<b>ΔlnOrgFertConv(-1)</b>	0.0470	1.48	0.1472
<b>ΔlnOrgFertConv(-2)</b>	0.0380	1.22	0.2341
<b>ΔlnAvgRainfall</b>	-0.0310	-1.73	0.0831
<b>ΔlnAvgRainfall(-1)</b>	-0.0180	-1.21	0.2331
<b>ΔlnAvgRainfall(-2)</b>	-0.0130	-0.94	0.3624
<b>ECM (-1)</b>	-0.6740	-6.22	0.0000

Source: Processed Data, 2025

\*\*\*denote the statistical significance at 5%; \*\* at 1%

Tables 4.6 ARDL Estimation Results for Model 2

Long-run estimates

Variable	Coefficient	t-statistic	Prob.
<b>Lnaggghg</b>	1.3472**	3.1113	0.0000
<b>lnMMUI</b>	-0.3840**	-4.21	0.0002
<b>lnFinIncrate</b>	-0.2170**	-3.05	0.0049
<b>lnBriqueette Compact</b>	-0.1620**	-2.89	0.0062
<b>lnOrgFertConv</b>	-0.0950***	-2.34	0.0253
<b>lnAvgRainfall</b>	0.0460	1.52	0.1351

Short-run estimates

Variable	Coefficient	t-statistic	Prob.
<b>Δlnaggghg</b>	-0.4110**	-3.64	0.0008
<b>Δlnaggghg(-1)</b>	-0.2050***	-1.94	0.0567
<b>Δlnaggghg(-2)</b>	-0.1720	-1.68	0.0951
<b>Δlnaggghg(-3)</b>	-0.1370	-1.44	0.1537
<b>ΔlnMMUI</b>	-0.2980**	-3.87	0.0006
<b>ΔlnMMUI(-1)</b>	-0.2010	-2.22	0.0314
<b>ΔlnMMUI(-2)</b>	-0.1490***	-1.94	0.0560
<b>ΔlnMMUI(-3)</b>	-0.1120	-1.45	0.1502
<b>ΔlnFinIncrate</b>	-0.1630**	-2.79	0.0081
<b>ΔlnFinIncrate(-1)</b>	-0.1070***	-2.01	0.0483
<b>ΔlnFinIncrate(-2)</b>	-0.0890	-1.83	0.0792
<b>ΔlnFinIncrate(-3)</b>	-0.0650	-1.38	0.1689
<b>ΔlnBriqueette Compact</b>	-0.1210***	-2.33	0.0259
<b>ΔlnBriqueette Compact (-1)</b>	-0.0850	-1.66	0.0993
<b>ΔlnBriqueette Compact (-2)</b>	-0.0640	-1.49	0.1428
<b>ΔlnBriqueette Compact (-3)</b>	-0.0430	-1.15	0.2687
<b>ΔlnOrgFertConv</b>	-0.0840	-2.12	0.0416
<b>ΔlnOrgFertConv(-1)</b>	-0.0620	-1.47	0.1531
<b>ΔlnOrgFertConv(-2)</b>	-0.0490	-1.39	0.1658
<b>ΔlnOrgFertConv(-3)</b>	-0.0360	-1.02	0.3104
<b>ΔlnAvgRainfall</b>	0.0310	1.49	0.1420
<b>ΔlnAvgRainfall(-1)</b>	0.0200	1.18	0.2472
<b>ΔlnAvgRainfall(-2)</b>	0.0140	1.10	0.2735
<b>ΔlnAvgRainfall(-3)</b>	0.0090	0.83	0.4117
<b>ECM (-1)</b>	-0.7030	-6.47	0.0000

Source: Processed Data, 2025

\*\*\*denote the statistical significance at 5%; \*\* at 1%

#### 4.1.2.5 Diagnostic Tests Result

To support the validity of the estimated coefficients and ensure their suitability for inference, a series of diagnostic tests were applied to both ARDL models. Table 4.7 below shows the Breusch-Godfrey LM test indicated no evidence of autocorrelation in either model, with Model 1 showing a p-value of 0.0950 and Model 2 a p-value of 0.2331, both above the 5% significance level. This suggests that the residuals are not serially correlated and the models do not suffer from autocorrelation issues.

The White's Test for Heteroskedasticity also confirmed homoskedasticity in both models, with Model 1 reporting a p-value of 0.3971 and Model 2 a p-value of 0.5023, indicating that the residuals have constant variance across observations. Additionally, the Jarque-Bera Test for normality yielded p-values of 0.410 for Model 1 and 0.754 for Model 2, both suggesting that the residuals are approximately normally distributed.

Collectively, these results confirm that the underlying assumptions of the ARDL models are not violated, thereby supporting the robustness and reliability of the ARDL estimated results.

Table 4.7 Diagnostic Tests

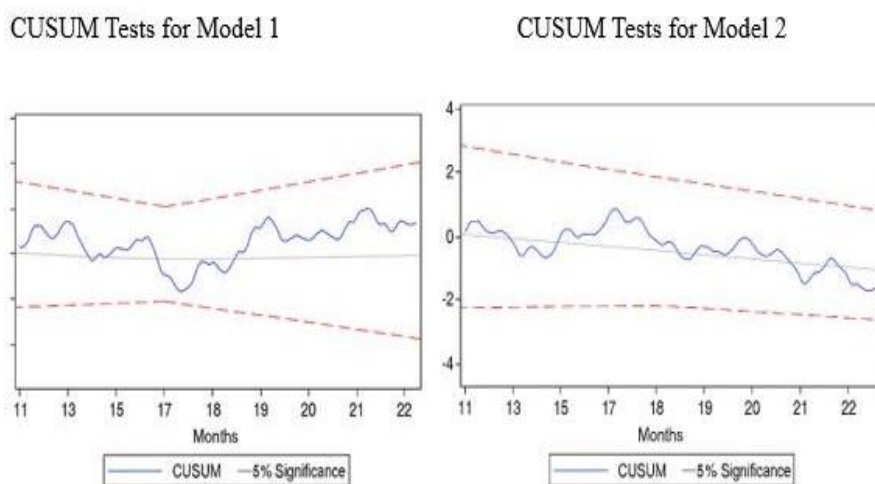
Diagnostic Tests	Null Hypothesis (H <sub>0</sub> )	Model 1	Model 2
<b>Breusch-Godfrey LM Test for Autocorrelation</b>	No serial correlation	Chi <sup>2</sup> = 2.788 Prob > Chi <sup>2</sup> = 0.0950	Chi <sup>2</sup> = 1.422 Prob > Chi <sup>2</sup> = 0.2331
<b>White's Test for Heteroskedasticity</b>	Homoskedasticity	Chi <sup>2</sup> = 21.00 Prob > Chi <sup>2</sup> = 0.3971	Chi <sup>2</sup> = 18.23 Prob > Chi <sup>2</sup> = 0.5023
<b>Jarque-Bera Normality Test</b>	Residuals are normally distributed	JB = 1.782 Prob = 0.410	JB = 0.562 Prob = 0.754

Source: Processed Data, 2025

#### 4.1.2.6 CUSUM Test

Regarding model stability, it can be concluded that the models formed is stable at the 95% confidence level because the graph of the Cusum Test results in Figure 4.1 below which displays that the blue lines are between the significance lines (red lines).

Figure 4.1 CUSUM Tests for Model 1 and 2



Source: Processed Data, 2025

#### 4.1.3 Scenario & Sensitivity Analysis

##### 4.1.3.1 Parameters

This section evaluates the carbon revenue potential generated through agricultural GHG emission reductions achieved by converting waste-to-utility and energy i.e. organic fertilizer conversion and briquette compaction. It focuses on a population of 62,000 verified CSA-adopting farmers. While Kenya has approximately 7.5 million smallholder farmers, the 62,000 CSA adopters form the empirically grounded subset for this study's carbon monetization scenario. These farmers already demonstrate behavioral alignment with sustainability practices, and thus present the clearest short-term window for linking mobile-enabled CSA to voluntary carbon markets (VCMs). The analysis does not assume immediate national scalability, but rather estimates what monetization could look like under first-tier participation.

Table 4.8 below outlines the key parameters used in the estimation of carbon credit monetization potential from GHG reductions in Kenya's agricultural sector. The elasticity values derived from the ARDL model indicate the responsiveness of agricultural GHG

emissions reduction by converting agricultural waste to organic fertilizer (0.095) and by compressing briquettes waste (0.162).

Additionally, the farmer share of carbon revenue, set at 60% is based on real-world participatory carbon market models that have been implemented in Kenya. Participatory carbon programs such as Vi Agroforestry's Carbon Project in Kenya, ICRAF-supported smallholder projects, and other farmer-cooperative- led initiatives. These programs typically allocate 60% to 80% of the carbon credit earnings directly to farmers, while the remaining portion covers project management, monitoring, reporting, and verification (MRV), as documented by the Food and Agriculture Organization (FAO, 2022) and (Gold Standard, 2021) ensuring that the estimated returns to farmers remain realistic.

The adoption range for organic fertilizer conversion is defined between 60,000 and 110,000 tons, while briquette compaction scenarios range from 0.50% to 1% is from the summary statistics.

A key benchmark for emissions reduction is sourced from UNFCCC (2024), which estimates that a 1% reduction in agricultural GHG emissions in Kenya would save approximately 0.2 million tons of CO<sub>2</sub> equivalent which translates to 200,000 tCO<sub>2</sub>e mitigated, providing a foundational basis for scenario modeling. The base carbon price is set at \$10 per tCO<sub>2</sub>e, with a range extending between \$5 to \$20 per tCO<sub>2</sub>e, consistent with prevailing market conditions in the Voluntary Carbon Market (VCM) according to international finance corporation (2023).

Table 4.8 Parameters

Parameter	Value
<b>ARDL Elasticity (AGGHG via Organic Fertilizer Conversion)</b>	0.095
<b>ARDL Elasticity (AGGHG via Briquette Compaction)</b>	0.162
<b>Farmer Share of Carbon Revenue</b>	60%
<b>Adoption range</b>	Low: 1% / High: 5%
<b>Base 1% of Agricultural GHG Reduction (World Bank, 2023)</b>	200,000/ tCO <sub>2</sub> e
<b>Carbon Price levels /tCO<sub>2</sub>e</b>	\$5, \$10 (Base case) and \$20
<b>CSA-adopting farmers</b>	62,000

Source: Processed Data, 2025

#### **4.1.3.2 Scenario Analysis: Estimated Earnings for CSA-Adopting Farmers through Waste Valorization**

Table 4.9 below presents the estimated farmers earnings opportunities derived from agricultural GHG reductions facilitated by the implementation of organic fertilizer conversion and Briquette Compaction. Under the 1% adoption scenario, organic fertilizer conversion leads to an emissions reduction of 19,000 tCO<sub>2e</sub>, generating \$190,000 in carbon revenue, with farmers receiving \$114,000 under the 60% revenue allocation model. Given that the estimated CSA-adopting farmer population stands at 62,000, each farmer earns \$1.84 from organic fertilizer-based carbon credits monthly. For briquette compaction at 1% adoption, the reduction in GHG emissions amounts to 32,400 tCO<sub>2e</sub>, yielding a total carbon revenue of \$324,000, with \$194,400 allocated to farmers. This equates to a per- farmer earning of \$3.13 monthly, reinforcing the importance of scaling briquette conversion technologies for enhanced financial returns.

Expanding CSA adoption to 5% leads to substantial increases in carbon revenue across both CSA practices. Organic fertilizer conversion under 5% adoption reduces 95,000 tCO<sub>2e</sub>, generating \$950,000 in total revenue, with \$570,000 allocated to farmers, translating into \$9.19 per farmer. Similarly, 5% adoption of briquette compaction results in a 162,000 tCO<sub>2e</sub> reduction, earning \$1,620,000 in carbon revenue, with \$972,000 distributed to farmers, equating to \$15.68 per farmer monthly. These findings demonstrate how climate smart agriculture can be leveraged for carbon credit earnings for farmers and the importance of scaling effective CSA technologies to maximize climate and financial benefits for smallholder farmers.

The adoption range for organic fertilizer conversion and briquette compaction is estimated under a base case of 1% adoption of national emission reduction potential (200,000 tCO<sub>2e</sub>) and a scaled-up case of 5%. These adoption levels represent a forward-looking framework to forecast carbon credit monetization opportunities of agricultural GHG emission reduction. This approach allows the model to remain grounded in real-world elasticity values while exploring the upper bounds of farmer earnings under plausible CSA expansion.

Table 4.9 Estimated Monthly Carbon Credit Earnings (per 62,000 farmers)

GHG Reduction Source	Adoption Rate	GHG Emission Reductions (tCO <sub>2</sub> e)	Total Carbon Revenue (USD)	Farmers Earnings (USD)	Per Farmer Earnings (USD) (62,000 farmers)
<b>Organic Fertilizer</b>	1%	19,000	\$190,000	\$114,000	\$1.84
<b>Organic Fertilizer</b>	5%	95,000	\$950,000	\$570,000	\$9.19
<b>Briquette Compaction</b>	1%	32,400	\$324,000	\$194,400	\$3.13
<b>Briquette Compaction</b>	5%	162,000	\$1,620,000	\$972,000	\$15.68

Source: Authors Calculations

#### 4.1.3.3 Sensitivity Analysis: Carbon Price Volatility

Carbon prices exhibit volatility influenced by various factors such as policy changes, market dynamics, and global or regional external events. This inherent uncertainty in carbon markets necessitates an evaluation of how such price fluctuations could affect farmers potential carbon credit earnings. A sensitivity analysis was therefore conducted to assess how variations in carbon pricing influence farmer earnings from two key CSA-linked waste valorization strategies: briquette production and organic fertilizer conversion. Table 4.9 below presents the sensitivity of farmers’ potential carbon credit earnings to changes in carbon pricing, modeled under two CSA adoption scenarios: 1% and 5% uptake of briquette compaction and organic fertilizer conversion.

At the low-end price of \$5/tCO<sub>2</sub>e, farmers earn only \$1.57/month from briquettes and \$0.92/month from composting under 1% adoption insufficient to motivate widespread behavioral change on their own. However, even at this low price, expanding CSA adoption to 5% significantly boosts earnings to \$7.84/month (briquettes) and \$4.60/month (compost), underscoring the powerful role of scale in improving viability. At the base price of \$10, which reflects current voluntary market conditions, 1% adoption yields \$3.13/month from briquettes and \$1.84 from composting.

Similarly, at 5%, those values rise to \$15.68 and \$9.19/month, respectively amounts that approach behaviorally salient levels when paired with other CSA incentives such as yield gains or input savings. At the high-end price of \$20, earnings escalate to \$6.27 and \$3.68/month at 1% adoption, and reach up to \$31.36 and \$18.39/month at 5% adoption, respectively. These upper-bound scenarios illustrate that high carbon prices, when coupled with wider farmer adoption, could generate tangible supplementary income streams particularly from briquette compaction, which exhibits higher GHG mitigation elasticity.

Overall, the sensitivity analysis shows that farmer income from carbon credits is highly sensitive to both carbon price and adoption scale. Without a stable carbon price environment or mechanism such as smallholder participation in voluntary carbon markets may face trust and uptake barriers. But when prices are favorable and adoption is scaled, carbon finance can offer modest but behaviorally meaningful incentives for climate-smart transformation.

Table 4.10 Carbon Price Volatility

Carbon Price (\$/tCO <sub>2e</sub> )	Adoption Rate	Farmer Revenue (Briquettes)	Per Farmer/Month (\$)	Farmer Revenue (Organic fertilizer conversion)	Per Farmer/Month (\$)
<b>\$5 (Low)</b>	1%	\$97,200	\$1.57	\$57,000	\$0.92
	5%	\$486,000	\$7.84	\$285,000	\$4.60
<b>\$10 (Base)</b>	1%	\$194,400	\$3.13	\$114,000	\$1.84
	5%	\$972,000	\$15.68	\$570,000	\$9.19
<b>\$20 (High)</b>	1%	\$388,800	\$6.27	\$228,000	\$3.68
	5%	\$1,944,000	\$31.36	\$1,140,000	\$18.39

Source: Authors Calculations

## **4.2 Discussion**

### **4.2.1 Mobile Money, CSA Uptake, and GHG Emission Reduction through Waste Conversion**

This study provides valuable insights into the role of mobile money in facilitating climate-smart agricultural (CSA) adoption and greenhouse gas (GHG) emission reduction by converting waste utility and energy in Kenya. The empirical results of Model 1 reveal that in the short run, mobile money usage for climate-smart agriculture (CSA) practices is positive and significant. This demonstrates that mobile money can alleviate immediate liquidity constraints, enabling farmers to act quickly on CSA-related decisions, particularly those that are relatively affordable and scalable such as briquette compaction and organic fertilizer conversion. This finding is critical in rural farming systems characterized by irregular climate conditions and limited access to formal credit. In the long run, mobile money continues to play a transformative role in CSA adoption, suggesting cumulative behavioral and structural effects. Over time, it fosters financial resilience and planning capacity, enabling smallholder farmers to transition from basic farming systems to more capital-intensive innovations such as composting fertilizer and briquette production. This enduring association positions mobile finance not merely as a transactional tool, but as an infrastructural enabler of climate-smart agricultural practices. These findings are consistent with Tabetando et al. (2022), who found that mobile money adoption increased the likelihood of using chemical fertilizers and high-yielding maize seeds in rural Uganda.

Parallel to mobile money, the financial inclusion rate also exhibits a positive and statistically significant influence on CSA adoption. In the short run, its impact is moderate, suggesting that improved access to financial services such as microfinance platforms enables farmers to access credit, and invest in adaptive practices even during lean periods. In the long run, financial inclusion exerts a more substantial positive effect, reinforcing the idea that households embedded in formal financial systems are better positioned to adopt and sustain CSA innovations. This is likely due to their increased exposure to savings mechanisms, insurance products, and climate advisory tools that reduce perceived risk and improve long-term planning.

Together with mobile money, this dual pathway highlights that inclusive financial systems are central to accelerating climate-smart transitions in agriculture. Additionally, mobile money has the potential to integrate with climate advisory services delivering timely weather forecasts, pest alerts, and agronomic advice directly to farmers' phones. This dual role, addressing both financial and informational gaps, empowers farmers to adopt CSA practices with greater confidence and at scale. This is affirmed by Ndung'u et al. (2023), who revealed that increased financial resources and access to information promote the adoption of CSA technologies such as agroforestry and soil conservation critical for sustainable farming amid climate change. In Kenya, where traditional banking infrastructure remains limited, mobile money has transformed how farmers access and manage finances. Through platforms like M-Pesa, smallholders can overcome long-standing constraints such as lack of collateral, insurance exclusion, and poor market connectivity which have historically undermined CSA uptake (Bekele, 2024).

Furthermore, Model 1 results show that both briquette compaction and organic fertilizer conversion has a significant and positive association with CSA adoption in both the short and long run. This reveals a behavioral insight: farmers are more likely to adopt CSA practices when those practices create economic value from existing waste streams. Farmers respond quickly to small but observable advantages, such as reduced fuel expenditures or improved soil texture. Their long-run significance implies institutionalization: these practices become embedded in production systems, not merely trialed innovations. In a sector with constrained liquidity and limited trust in unfamiliar technologies, the ability to convert agricultural residues into energy or nutrient sources provides a tangible, immediate incentive. These waste valorization strategies reduce production costs, enhance input self-sufficiency, and are often community-driven supporting normalization and peer adoption. They reshape perceived benefits and reduce risk aversion, two central factors in behavioral adoption models.

In contrast, the negative and significant effect of average monthly rainfall on CSA adoption adds a crucial dimension. Climate variability especially erratic rainfall appears to create uncertainty around the perceived effectiveness of CSA practices, particularly those reliant on moisture sensitive biological processes like composting.

The results reflect a climate risk barrier during unstable weather; even well-informed farmers may delay adoption out of concern for failure or resource loss. This finding highlights the need for CSA interventions to be paired with timely climate advisories and risk mitigation tools, such as weather-based insurance or drought-tolerant input packages.

Model 2 adds further depth by showing that both mobile money usage and financial inclusion significantly reduce agricultural greenhouse gas (GHG) emissions, in both the short and long term. These findings suggest that in the short-run, mobile money not only facilitates immediate behavioral shifts such as purchasing cleaner technologies or adopting low-emission inputs but also has a sustained mitigation impact. Likewise, financial inclusion enables smallholders to finance emission-reducing practices such as organic fertilization, residue recycling, and conservation tillage.

In the long run, these effects deepen. The sustained negative relationship between mobile money and GHG emissions likely reflects growing farmer capacity for clean technology uptake, enhanced risk-sharing through formal financial networks, and the progressive displacement of emission-intensive practices. These insights are echoed by Zhang & Li (2025), who demonstrate that inclusive digital finance significantly supports sustainable agricultural uptake in China, and by He et al. (2022), who found that digital finance mitigates the negative income impacts of climate variability on rural households emphasizing that financial inclusion is not just a development goal but also a pathway to climate resilience.

In Mozambique, Batista & Vicente (2020) show that mobile savings tools promoted investment in modern inputs, indicating that mobile money can drive both productivity and technology adoption connecting rural finance with technology transitions. However, the climate potential of mobile money hinges on supporting systems. Without complementary investments in extension services, digital infrastructure, insurance markets, and enabling regulation, the benefits of mobile money remain constrained.

Thornton et al. (2018) argue that for climate finance tools to succeed, they must be integrated into wider rural development systems, not delivered in isolation. Collectively, the findings affirm that mobile money and financial inclusion do not merely support CSA adoption; they also play a direct role in driving down agricultural emissions positioning both as critical enablers in low- carbon agricultural transitions. This represents a novel and important contribution to the literature, as relatively few studies have explicitly connected mobile money adoption to reductions in GHG emissions.

The mechanisms are clear: by providing access to CSA practices and clean technologies, mobile money enables farmers to shift away from high-emission activities such as slash-and-burn residue disposal or diesel-based irrigation. Assaye (2024), for example, shows how mobile-enabled Pay-As-You-Go (PAYG) financing models are making biodigesters and renewable energy systems more accessible to smallholder farmers, thus replacing fossil fuel use and lowering emissions. The study further confirms that mobile money and financial inclusion are strongly associated with sustained CSA adoption and emissions reduction. This suggests a cumulative effect: mobile-enabled finance not only supports initial uptake but also reinforces resilience and capacity to invest in higher-cost CSA technologies.

Moreover, the study shows that briquette compaction and organic fertilizer conversion are key pathways through which emissions reduction is realized. Briquette compaction demonstrates a strong mitigation effect in both the short and long term, reflecting its ability to replace high-emission fuels such as firewood and charcoal with biomass energy. Its immediate impact enhances its viability for early-stage climate investment. Organic fertilizer conversion also contributes meaningfully to mitigation over time, although its short-run effects are statistically insignificant likely due to the delayed impact of composting on soil-based emissions, which require multiple seasons to take effect. This aligns with Cudjoe et al. (2023) and Phirri et al. (2022), who emphasize the delayed but substantial emissions benefits of composting, due to the time required for soil carbon sequestration processes to materialize.

Interestingly, average rainfall has no significant effect on GHG emissions reductions in either the short or long term. This may reflect Kenya's bimodal and highly variable rainfall system, where droughts suppress biomass and reduce emissions, while intense rains lead to emissions spikes through nutrient runoff and anaerobic conditions. The net result is offsetting effects. This finding underscores the need for mitigation strategies that function under climate extremes and are resilient to weather variability.

In conclusion, this study positions mobile money not simply as a financial transaction tool, but as a catalytic mechanism for agricultural transformation and climate mitigation. By expanding access to finance, enabling resource-efficient innovations, and supporting behaviorally viable CSA practices, mobile money facilitates Kenya's transition toward low-emission, climate-resilient agriculture. To realize this potential at scale, it will be essential to close remaining access gaps and link mobile platforms to climate services, carbon finance, and inclusive policy frameworks. The findings ultimately underscore that not all CSA strategies yield the same mitigation value. Finance must be strategically targeted toward waste-to-utility interventions that are environmentally robust, behaviorally sound, and investment-ready. This calls for the integration of smallholder CSA and carbon mitigation strategies into national climate finance pipelines, supported by de-risked models that attract public and private capital where emissions outcomes are measurable and verifiable.

#### **4.2.2 Potential Carbon Credit Monetization Among Smallholder Farmers: Insights from Scenario and Sensitivity Analysis**

The scenario and sensitivity analysis support the proposition that waste-based climate-smart agricultural (CSA) practices specifically briquette compaction and organic fertilizer conversion can yield financially meaningful outcomes for smallholder farmers in Kenya through participation in voluntary carbon markets (VCMs). Even under conservative assumptions (1% adoption and \$10/tCO<sub>2e</sub> base price), these practices generate new revenue streams from emission reductions, with briquettes showing the highest per-farmer income due to greater carbon mitigation elasticity. More importantly, the model reveals a compounding pattern. Farmers earnings increase substantially with both carbon price and adoption scale.

At 5% adoption and a \$20/tCO<sub>2e</sub>, briquette compaction yields up to \$31.36 per farmer per month, and organic fertilizer conversion to \$18.39. Converted at an average exchange rate of KES, this equates to approximately KES 4,547 and KES 2,667 respectively per month. In the rural Kenyan context, where many smallholders live below the national poverty line of KES 3,252/month (World Bank, 2023), briquette-based carbon revenue alone has the potential to push farmers above subsistence thresholds. Even lower-tier earnings like KES 1,134/month at base case (\$10, 1% adoption) are far from trivial. For example, that amount could cover a child's term-time school fees in many public primary schools, subsidize monthly fertilizer costs, or repay input loans from a village SACCO.

What the model shows, therefore, is not only plausible financial value but transformative behavioral potential. Carbon revenue can act as a behaviorally salient incentive that both de-risks CSA adoption and reinforces long-term engagement. It can replace or reduce dependency on unreliable remittances, casual labor income, or credit from informal lenders. This insight elevates the policy logic: carbon finance should not merely be seen as a reward mechanism, but as a liquidity pathway that enables productive investment at the household level.

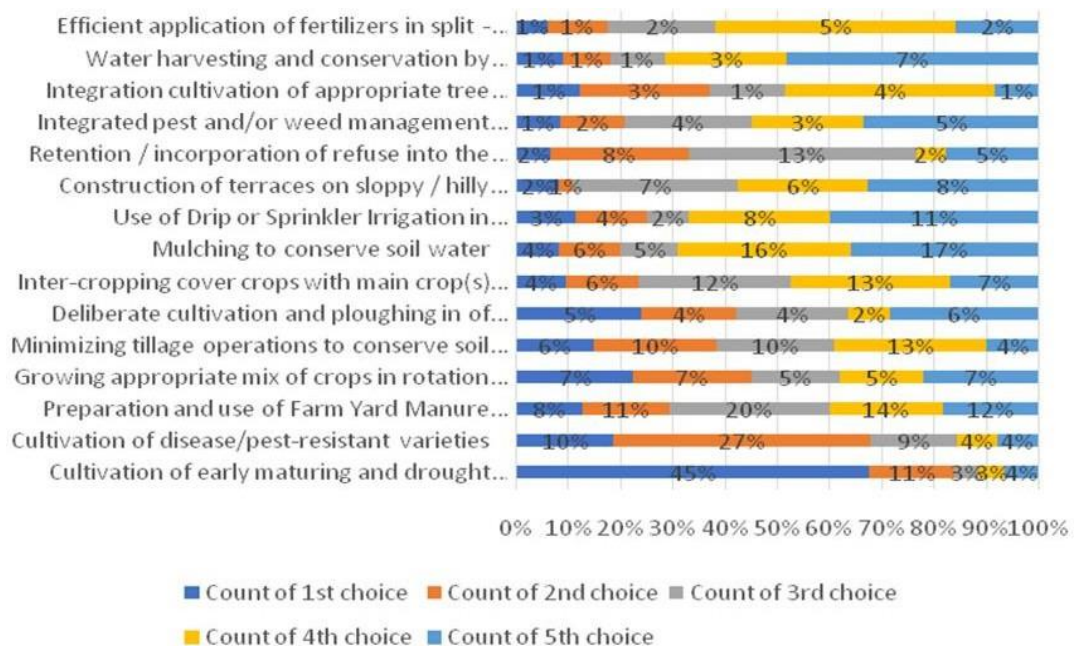
Yet, the true value of the scenario analysis is made clearest when examined alongside Figure 4.2 below. Farmers overwhelmingly adopt practices that are low-cost, locally familiar, and immediately beneficial like farmyard manure or drought-tolerant seeds. Capital-intensive or technology-dependent interventions like briquette production or composting remain underutilized, not due to lack of interest, but due to a lack of access, equipment, and extension support. This is where the model becomes most useful: it demonstrates that the most climate-effective practices are not currently the most adopted but they could be if carbon finance is explicitly designed to target and enable them.

Furthermore, as Figure 4.2 shows, adoption of complex CSA technologies correlates positively with access to credit, group membership, and adaptive capacity. These same enablers mirror the conditions necessary for carbon market engagement. The implication is twofold: carbon credit access is not purely about mitigation potential, it's about who is connected, prepared, and supported.

Without deliberate policy and institutional scaffolding, carbon finance may bypass the most vulnerable, reinforcing existing inequities. The earnings are real but so are the structural filters that determine who get them. The forecast signals that the business case for CSA is evolving beyond food security or resilience; it is becoming an income generation model. Farmers now face a market-based incentive to decarbonize their production systems. But to capitalize on it, they must be equipped. This means simplifying verification procedures, subsidizing equipment, expanding farmer trainings, and most critically, bundling carbon incentives with other CSA co-benefits like improved productivity, savings access, and mobile-based payments.

The combination of scenario forecasting and observed adoption patterns suggests that while CSA-driven carbon monetization holds promise for Kenyan smallholders, realizing this potential will require more than market opportunity alone. Addressing practical barriers to CSA adoption especially for waste conversion technologies and building enabling market conditions will be critical. If these challenges are met, smallholder farmers can evolve from subsistence producers into active contributors to climate mitigation, earning sustainable incomes from low-carbon agricultural practices.

Figure 4.2 Existing Climate-Smart Agricultural Technologies in Kenya



Source: Phiri, A. T., Charimbu, M., Edewor, S. E., & Gaveta, E. (2022).

## CHAPTER 5 CONCLUSION, LIMITATION AND RECOMMENDATIONS

### 5.1 Conclusion

This study set out to address a critical challenge faced by smallholder farmers in Kenya. Despite their agricultural activities contributing significantly to greenhouse gas (GHG) emissions, they often lack the financial resources needed to transition toward sustainable, low-emission practices. The inability to access sufficient funding prevents many farmers from adopting climate-smart agricultural (CSA) technologies, leaving them vulnerable to climate change impacts while limiting their potential contribution to national and global climate mitigation goals. It was guided by two research questions: (1). What are the short- run and long-run effects of using mobile money in climate-smart agriculture on GHG emission reduction by converting agricultural waste into utilities and energy? (2). What are the potential earnings that farmers can generate in reducing agricultural GHG emissions through the adoption of climate-smart agricultural practices from the voluntary carbon credit market?

In response to the first research question, the findings reveal that mobile money adoption significantly and positively supports both the short-run and long- run uptake of climate-smart agriculture (CSA) practices among smallholder farmers in Kenya. In both timeframes, mobile money not only increases the likelihood of CSA adoption but also contributes to a significant reduction in agricultural greenhouse gas (GHG) emissions. This relationship is particularly evident in CSA practices that involve the conversion of agricultural waste into energy and utilities such as composting, organic fertilizer production, and briquette compaction.

These impacts can be explained by the ways in which mobile money lowers financial barriers and enhances farmers' ability to invest in sustainable technologies. Specifically, mobile money improves access to essential inputs by reducing transaction costs and enabling flexible, small-scale payments, which lowers entry costs for farmers. This enhanced accessibility encourages early- stage adoption and experimentation with sustainable agricultural practices. In the long run, mobile money fosters the development of a more inclusive and resilient digital financial ecosystem one that not only sustains farmers' engagement with low-emission practices but also integrates them into broader climate-resilient value chains. These findings confirm that mobile money functions not only as a financial tool but also as a structural enabler of long-term, climate-smart behavioral transformation in the agricultural sector.

In response to the second research question, scenario and sensitivity analyses show that even at a conservative 1% adoption rate and a base carbon price of \$10 per tonne of CO<sub>2</sub> equivalent, farmers can earn new revenue streams from verified emission reductions. Notably, briquette production yields the highest per-farmer income due to its greater carbon mitigation efficiency. At a 5% adoption rate and a \$20 carbon price, briquette compaction could generate approximately KES 4,547 per farmer per month, and fertilizer conversion around KES 2,667. These figures are significant in a rural context where many smallholders live below the national poverty line of KES 3,252 per month (World Bank, 2023), suggesting that carbon revenue especially from briquettes could help lift farmers above subsistence levels.

However, realizing this income potential requires more than market participation alone. The model shows that the most climate-effective practices are also the most under-adopted due to barriers such as lack of equipment, training, and extension support. Farmers tend to prefer low-cost, familiar practices. Carbon finance thus holds transformative potential, but only if it is paired with enabling policies such as simplifying verification procedures, subsidizing CSA tools, and expanding mobile-based payments. Moreover, access to carbon markets must be inclusive; without deliberate efforts to support the most vulnerable farmers, benefits may disproportionately favor the already-connected. When supported with the right tools and systems, carbon income can not only incentivize GHG reduction but also become a viable path out of poverty for smallholder farmers in Kenya.

## **5.2 Limitation and Areas for Future Studies**

This study does have certain limitations. The lack of sufficiently granular data which made it difficult to assess the effects of mobile money and CSA adoption at the provincial level. As a result, the analysis focused on national-level patterns, and some important local differences may not have been fully captured. Having more granular data could have allowed for more region-specific recommendations and a deeper understanding of localized challenges and opportunities.

Future studies should aim to collect and analyze more detailed data at the provincial level to better capture regional differences in mobile money usage and CSA adoption. Applying spatial models such as Geographic Information Systems (GIS) would enable researchers to map and visualize the distribution of CSA practices and emission reduction outcomes across different provinces. This would allow for more targeted, data-driven, and location-specific policy recommendations. In addition, future research would benefit from conducting cost-benefit analyses or constructing marginal abatement cost (MAC) curves specifically for

mobile-money-enabled CSA practices. These tools would help identify which interventions deliver the greatest climate impact at the lowest cost, guiding smarter investment decisions by policymakers, banks, and development partners.

### **5.3 Recommendations**

The findings of this study present clear opportunities to leverage mobile money as a foundational platform for agricultural waste management and participation in voluntary carbon credit markets. To fully realize this potential, coordinated efforts are needed between the Ministry of Agriculture, the Ministry of Environment and Climate Change, financial institutions, and telecommunication companies such as Safaricom (M-PESA).

Kenya's policy environment for climate-smart agriculture (CSA), including the Kenya Climate-Smart Agriculture Strategy and enhanced Nationally Determined Contributions (NDCs), provides a supportive framework for scaling sustainable practices. However, despite interventions such as KCSAP and localized uptake of manure use or drought-tolerant seed varieties, the adoption of high-mitigation CSA practices such as briquette compaction and composting remains limited. Meanwhile, mobile money systems like M-PESA have achieved deep rural penetration and already support services such as input finance and crop insurance. Yet, these platforms are not fully integrated with CSA adoption or carbon market mechanisms. Bridging this gap is both timely and feasible.

Banks and microfinance institutions are encouraged to develop and offer tailored green finance products that support CSA technologies. These could include Pay-As-You-Go (PAYG) financing for equipment such as compost bins and briquette machines, bundled with soil health inputs or drought-resilient seed packages.

These products should be distributed through mobile platforms and aligned with agricultural seasons to improve uptake. Banks could also integrate mobile money transaction data and CSA practice logs into alternative credit scoring models to increase loan eligibility for smallholder farmers engaged in sustainable practices.

Telecommunication companies, particularly those operating mobile money platforms like Safaricom, should partner with agri-fintech firms to design digital products that directly support CSA adoption. These could include bundled services offering mobile-based weather advisories, extension support in local languages, CSA input financing, and emissions tracking. Mobile platforms should also enable logging of CSA activities, linked to automated carbon payment disbursements where applicable. These steps would strengthen the role of mobile money in both facilitating access to CSA and enabling participation in carbon credit markets.

To support CSA-carbon integration, the Ministry of Agriculture and the Ministry of Environment and Climate Change should co-develop a national CSA-carbon finance framework. This should define eligible CSA practices, establish digital MRV (Monitoring, Reporting, and Verification) protocols, and set up equitable, efficient payout mechanisms. Carbon payments should be sent directly to farmers' mobile wallets based on verified practice logs. County-level aggregation systems could help reduce transaction costs and ensure even small-scale farmers are included through pooled verification schemes.

Additionally, public and private actors should co-invest in training and deploying digital CSA agents, who can support farmer onboarding onto digital platforms, demonstrate CSA technologies, log activities, and provide technical guidance. This will improve trust, ensure inclusivity, and strengthen the digital and financial literacy of women farmers, who are often key actors in agricultural production but face structural access barriers.

Finally, a robust monitoring and learning system should be embedded in the implementation of mobile-enabled CSA and carbon market initiatives. Ministries, research institutions, and financial service providers should track CSA adoption trends, GHG mitigation outcomes, gender inclusion, and financial impacts. Insights from these systems can be used to improve platform design and ensure continuous improvement.

Real-time dashboards visualizing key metrics such as CSA adoption rates, payment cycles, and regional carbon credit flows can support more transparent, data-driven policy and investment decisions. By aligning mobile money infrastructure, green finance innovation, and CSA policy frameworks, Kenya has a significant opportunity to transition smallholder agriculture toward a low-carbon, climate-resilient future. These recommendations aim to guide public-private partnerships in achieving scalable and inclusive outcomes that benefit both rural livelihoods and environmental sustainability.

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