

Review Article

The Intersection of Climate Change Adaptation and Smallholder Farmer Food Security: A Review of Strategies and Barriers

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Abstract: Smallholder farmers play a pivotal role in global food security; however, they remain exceptionally vulnerable to the impacts of climate change due to their reliance on natural resources and limited adaptive capacities. This narrative review synthesizes a wide range of global sources to explore the intersection of smallholder agriculture and climate adaptation strategies. The review examines adaptation practices, agroecological methods, and the adoption of climate-resilient crop varieties. It reveals that the implementation of these strategies is frequently hindered by systemic barriers such as financial constraints, limited technological access, and institutional inefficiencies. Recognizing that previous studies have addressed isolated aspects of adaptation or relied on secondary data, this review highlights research gaps and offers a comprehensive synthesis of relevant literature. This review uses a narrative synthesis model suitable for integrating evidence from agronomy, economics, and social science to capture the complex challenges faced by smallholder farmers. The review emphasizes the importance of policy frameworks and participatory approaches that empower smallholder communities. This review synthesizes current evidence to inform potential directions for targeted interventions and future field-based studies, while recognizing the limitations of relying on secondary data. These recommendations aim to facilitate integrated policy reforms and drive research initiatives, ultimately strengthening the resilience and adaptability of smallholder agriculture in the face of ongoing climate change.

Keywords: Smallholder Farmers, Adaptation, Resilience, Climate, Agriculture, Food Security**How to cite this paper:**

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1. Introduction

Smallholder farmers, including numerous small family farms, are a critical component of global food security. These farmers cultivate a majority of the world's staple crops and sustain millions of livelihoods, particularly in developing regions. Despite their significant contributions, smallholder farmers remain among the most vulnerable to the adverse impacts of climate change. Their vulnerability stems largely from an overreliance on natural resources and inherently limited adaptive capacities. As climate-related challenges intensify, the urgency to enhance the resilience of smallholder farming systems has never been greater (El Bilali et al., 2020) [1].

Given the vulnerabilities of smallholder farmers to climate change, understanding the scale of these impacts is crucial. A 2023 industry-sponsored survey by Bayer reported that over 70% of farmers across eight countries had experienced significant disruptions to their operations due to changing climate conditions; however, these findings have not been peer-reviewed and this survey should be interpreted with caution (Bayer Global,

2023) [2]. These impacts cause reduced yields due to unpredictable weather and increased frequency of extreme events such as droughts and floods. Smallholder farmers account for approximately 80% of all farms globally, yet they are among the least equipped to manage these challenges due to limited access to capital and technology. Despite their challenges, smallholder farmers produce about 35% of the world's food. This contribution is significant considering that smallholder farms account for only about 12% of all agricultural land globally (FAO, 2021) [3].

This narrative review aims to comprehensively synthesize relevant literature on climate adaptation strategies for smallholder agriculture, with a particular focus on three interrelated domains: the adaptation practices currently employed, the systemic barriers hindering effective adaptation, and the policy frameworks that can support and scale initiatives. The review also addresses critical research gaps that have emerged from prior studies, which have often focused on isolated aspects of adaptation or relied on secondary data. This fragmented evidence complicates our understanding of long-term adaptation outcomes and impedes the development of robust, actionable policy reforms.

Smallholder agriculture is characterized by diversity and complexity. Systems range from rain-fed farming in sub-Saharan Africa to market-oriented operations in parts of Asia and Latin America. These diverse systems not only underpin food security but also contribute to biodiversity and socio-economic stability in rural areas (Gitz & Meybeck, 2016) [4]. As climate change reduces crop yields, increases production risks, and undermines smallholder viability (Wheeler & von Braun, 2013) [5], there is an urgent need to explore adaptation strategies, such as crop diversification, agroecological practices, and the adoption of climate-resilient crop varieties.

Focused on frameworks related to sustainable development and resilience, this review adopts an interdisciplinary approach that integrates perspectives from agronomy, economics, social sciences, and technology studies. It critically examines the array of adaptation strategies in use, identifies barriers including financial constraints, limited access to technology, and policy inefficiencies, and evaluates the effectiveness of monitoring and evaluation (M&E) frameworks (FAO & UNDP, 2019) [6]. While many studies emphasize the design and implementation of adaptive practices, there is less focus on assessing their outcomes, which this review seeks to address through a discussion of participatory M&E approaches.

Given its focus on developing regions and its reliance on secondary data, this review sets realistic expectations by acknowledging scope limitations that affect data quality and representation. The review not only identifies current gaps in knowledge but also lays the groundwork for future, field-based, and longitudinal research initiatives that can inform integrated policy reform.

Following this introduction, Section 1 presents a detailed literature review, outlining the role of smallholder farmers in global food security, the impacts of climate change, and the variety of adaptation strategies employed. Section 2 then explores policy challenges and the necessary frameworks for supporting smallholder adaptation. Section 3 discusses monitoring and evaluation strategies, highlighting the importance of participatory methods in assessing adaptation outcomes. Finally, Sections 4 through 6 articulate targeted research recommendations, methodological approaches, and study limitations, culminating in a conclusion section that synthesizes key insights and outlines directions for future research.

This structured approach aims to provide a comprehensive synthesis of current knowledge while clearly identifying the research gaps that must be addressed to enhance the resilience of smallholder agriculture in the face of ongoing climate change.

2. Literature Review

2.1. *Introduction to Smallholder Food Security and Climate Change*

A significant contribution in this field by El Bilali et al. (2020) [1] describes how smallholder farmers play a critical role in global food security, contributing significantly to food production systems, particularly in developing regions. These smallholder farms produce over 80% of the food consumed in Asia and sub-Saharan Africa, regions where agricultural activities are often the backbone of economies (El Bilali et al., 2020) [1]. The authors present a comprehensive literature review, which is utilized extensively in this narrative. The work by El Bilali et al. (2020) [1] was selected as a key resource because it effectively analyzes food security in relation to climate change, making it highly relevant to food security research. Additionally, it demonstrates a strong theoretical foundation, integrating knowledge from key global institutions and high-impact studies, ensuring credibility.

Another indispensable resource that is utilized in many different areas of this narrative review is the evidence-based analysis by Wheeler and von Braun (2013) [5]. This work is a highly valuable source because it provides a broad, well-structured, and evidence-based analysis of how climate change impacts global food security. The authors define smallholder farmers as individuals or families that manage agricultural landholdings of less than two hectares (about 5 acres). They go on to explain how these farmers face unique challenges due to their reliance on natural resources and farming practices (Wheeler & von Braun, 2013) [5]. Their work synthesizes findings from 47 peer-reviewed studies and reports. Although it does not present new data, it provides an interdisciplinary conceptual overview of how climate change affects food security.

Smallholder farmers operate within complex agricultural systems over which they have little control. While their contributions to local and global food systems are essential for many, their production capacities are often highly vulnerable to environmental and economic changes. Historically, smallholder farmers have been forced to adapt to marginal lands and low-resource environments. However, the accelerating impacts of climate change now present unprecedented challenges to these farmers, threatening their ability to maintain food security, both regionally and globally (Morton, 2007) [7].

2.2. *Smallholder Farmers and Their Role in Global Food Production*

Despite their importance, smallholder farmers are among the most resource-constrained agricultural groups globally. Limited access to financial services and institutional support has hindered their capacity to innovate and adapt to changing conditions. These constraints are compounded by the global markets that often marginalize smallholder farmers, favoring industrial-scale farming systems (Wheeler & von Braun, 2013) [5]. Smallholder farming systems operate under intense pressure to balance productivity, sustainability, and resilience.

2.3. *The Impacts of Climate Change on Smallholder Farmers*

Climate change is one of the most significant threats to global agricultural systems. These effects are particularly severe in rain-fed agricultural systems, which characterize most smallholder operations in sub-Saharan Africa. Rising temperatures, erratic rain patterns, and an increase in extreme weather events have already disrupted agricultural productivity in many regions (El Bilali et al., 2020) [1]. These climatic disruptions have particularly strong implications for rain-fed agriculture, which is the basis for the majority of smallholder farms. For example, in sub-Saharan Africa, prolonged droughts have led

to significant declines in corn yields, which are essential staple crops for food security in the region (Siatwiinda et al., 2021) [8].

Gitz and Meybeck (2016) [4] explain that the adverse effects of climate change are not limited to crop yields. Soil degradation and pest outbreaks are becoming more frequent, increasing the challenges faced by smallholder farmers. These environmental challenges have reduced household incomes, increased malnutrition, and heightened vulnerability to food insecurity in many areas. The disproportionate impact of climate change on smallholder farmers is compounded by their precarious position within global food systems (Gitz & Meybeck, 2016) [4]. Gitz and Meybeck (2016) [4] draw from FAO reports and scientific literature to present a comprehensive policy-oriented review, but they do not present original empirical data. They acknowledge knowledge gaps and discuss both risks and potential adaptation opportunities.

2.4. The Importance of Adaptation Strategies for Food Security

Lamichhane et al. (2022) [9] explain that adaptation is widely recognized as a critical component of climate change mitigation, especially for smallholder farmers who may lack the resources to absorb the impacts of environmental changes. Effective adaptation strategies can enable smallholder farmers to improve their resilience, maintain productivity, and contribute further to food security despite adverse climate changes. These strategies involve a combination of technological, institutional, and behavioral approaches that must be tailored to local conditions and capacities. However, the authors also note that the current evidence base is constrained by several limitations. For instance, many of the underlying studies rely on cross-sectional data and self-reported measures, which can introduce reporting biases. The studies also tend to focus on specific geographic regions (Lamichhane et al., 2022) [9]. As a result, the usability of these findings across diverse smallholder contexts and over time remains uncertain.

One of the most promising adaptation strategies is the adoption of climate-resilient agricultural practices. These include approaches such as crop diversification, which can enhance ecosystem services and reduce vulnerability to climate change (Mihrete & Mihretu, 2025) [10]. For example, crop diversification not only reduces risks but also improves soil fertility and biodiversity in the long term. Agroforestry integrates trees into agricultural practices, offering multiple benefits, such as improved soil health and enhanced resilience to extreme weather events (Gitz & Meybeck, 2016) [4].

Technological and agronomic innovations also play a vital role in smallholder adaptation. The development of climate-resilient crop varieties has enabled smallholder farmers to maintain productivity under new and challenging conditions (El Bilali et al., 2020) [1]. Additionally, water conservation technologies, including drip irrigation and rainwater harvesting, have been effective in addressing water scarcity, which is a challenge for smallholder farmers in dry regions (Wheeler & von Braun, 2013) [5]. An example of successful adaptation is illustrated by smallholder farmers in the Nabdum District of Ghana, according to Amosah et al. (2023) [11], these farmers have employed a range of adaptation strategies. These include mixed cropping, integrated soil fertility management, and mixed farming, which reflect the importance of locally tailored and diverse responses to environmental stressors. In this region, the widespread use of mixed cropping by over half of surveyed farmers illustrates both the accessibility and perceived effectiveness of this approach in managing climate variability (Amosah et al., 2023) [11]. This empirical study by Amosah et al. (2023) [11] provides grounded evidence on the adaptation strategies used by smallholder farmers in Ghana, highlighting practical, context-specific responses to climate variability.

3. Barriers to Effective Adaptation

While adaptation strategies present an avenue for mitigating the impacts of climate change on smallholder farming systems, many barriers hinder their implementation. These challenges are rooted in structural, systemic, and environmental dynamics, making them complex. Smallholder farmers, particularly in developing regions, often face financial constraints, policy and institutional challenges, and fluctuating environmental and market conditions.

Recent evidence from smallholder sorghum farmers in Kenya highlights that access to climate-smart agricultural practices remains limited due to a range of interrelated barriers, including low levels of trust in climate information, limited exposure to training, and constraints related to land size and credit utilization. Although nearly all surveyed farmers had experienced climate-related shocks, the average number of adaptation practices implemented remained low, suggesting that economic hardship and institutional gaps continue to impede broader uptake. These findings demonstrate the need for more targeted and supportive interventions that address both structural and behavioral barriers to climate adaptation (Atsiaya et al., 2023) [12]. Although this empirical study by Atsiaya et al. (2023) [12] had strong analytical rigor and identified statistically significant socioeconomic and institutional factors influencing climate-smart agriculture adoption, it did not account for potential interactions between these variables, which may obscure context-dependent pathways of adaptation behavior.

3.1. Financial Constraints and Limited Access to Credit

Financial constraints are often the most significant barrier to effective climate adaptation for smallholder farmers. With their limited financial resources, smallholder farmers often lack the ability to invest in critical agricultural needs such as improved seed varieties, irrigation systems, fertilizers, and the equipment necessary to enhance their resilience (Gitz & Meybeck, 2016) [4]. For example, the costs associated with transitioning to more resilient conservation agriculture, such as purchasing no-till equipment and cover crop seeds, often make these goals unattainable for many smallholder farmers (Wheeler & von Braun, 2013) [5]. The financial challenges may be compounded by the lack of access to credit systems in developing areas.

While microfinance and subsidy programs have demonstrated positive outcomes in select cases, their reach and scalability remain limited and context-dependent. Only a small number of smallholder farmers in sub-Saharan Africa have access to credit, a fact that underscores the need for more inclusive financial systems (Tewari et al., 2023) [13]. Without adequate financial support, smallholder farmers may be unable to quickly and efficiently adopt climate-resilient practices, leaving them increasingly vulnerable to climate change.

3.2. Lack of Access to Climate-Resilient Technologies

A lack of access to agricultural technologies is another critical barrier to smallholder adaptation. These technologies include drought-tolerant crops, specialty farming tools, weather forecasting services, and water management systems. Although these tools offer significant potential, their dissemination to smallholder communities remains a challenge, often due to high costs, logistical challenges, and insufficient infrastructure in developing areas (Gitz & Meybeck, 2016) [4]. According to Friedman et al. (2024) [14], medium-scale farmers often rely on analog tools due to digital trust issues. While not directly generalizable, these findings raise relevant concerns about the accessibility of digital platforms for smaller operations globally. Even when farm management software is

available, its use is often limited or fragmented due to rural connectivity issues, interface complexity, and mistrust of cloud-based systems, factors that, without targeted support, may widen the gap between smallholders and larger, better-resourced farms (Friedman et al., 2024) [14]. This empirical study by Friedman et al. (2024) [14] offers valuable insights into the real-world data practices and barriers faced by small-to-medium farmers through in-depth interviews, but its limited sample size and regional focus may constrain the generalizability of its findings.

In South Asia, limited access to mechanized irrigation systems has prevented smallholder farmers from optimizing water use during long dry periods (Wheeler & von Braun, 2013) [5]. This challenge not only reduces the adaptive capacity of smallholder farmers but also increases existing inequalities, as larger agricultural organizations are better positioned to adopt these innovations quickly (Tewari et al., 2023) [13].

Collaborative efforts between governments, research institutions, and private sectors have been identified as a potential solution to this challenge. For example, public and private partnerships aimed at scaling up the production and distribution of climate-resilient seeds have shown promise in countries like Ethiopia and Kenya (Gitz & Meybeck, 2016) [4]. However, these initiatives need to be expanded and modified to address the specific needs and constraints of smallholder farmers.

3.3. Policy and Institutional Barriers

Beyond financial and technological limitations, structural policy and institutional inefficiencies also restrict smallholder adaptive capacity, necessitating a dedicated examination of governance and systemic barriers. Agricultural policies in many countries often favor large-scale commercial farming, neglecting the needs and challenges of smallholder farmers (Panos & Damico, 2021) [15]. This policy bias is evident in the allocation of subsidies, which disproportionately benefit larger farms while leaving smallholder farmers underserved. The literature review by Panos and Damico (2021) [15] takes a different approach from the majority of sources used in this narrative. The authors systematically review how climate change is represented in literacy education, making it relevant to the broader discussion on the understanding of climate change. The study quantifies the presence of climate change discourse in journal articles and conference presentations, supporting its claims as it critiques literacy organizations for failing to engage meaningfully with climate change (Panos & Damico, 2021) [15].

Institutional inefficiencies also play a significant role in limiting the effectiveness of adaptation efforts. In many developing countries, such as Ghana, complex or poorly designed institutional frameworks result in poor coordination among the agencies responsible for agriculture. This lack of integration leads to duplication of efforts and inefficient resource allocation (Kangah & Atampugre, 2022) [16]. In another example, in sub-Saharan Africa, overlapping mandates between ministries of agriculture and environment have resulted in conflicting policies that hinder smallholder adaptation (Gitz & Meybeck, 2016) [4].

4. Discussion on Policy

Smallholder farmers play a vital role in global food production and food security, yet their ability to adapt to climate change is hindered by many barriers that necessitate policy interventions. This section explores the policy frameworks required to support smallholder adaptation and the role of technology and innovation in facilitating resilience. It underscores the importance of integrating smallholder voices into policymaking to develop inclusive, equitable, and sustainable solutions.

Agricultural policy reforms can significantly shape the adaptive capacity of smallholder farmers, particularly through efforts aimed at improving access to markets, credit, and secure land tenure. Srinatha et al. (2024) [17] found that while policy initiatives such as microfinance programs, land rights formalization, and sustainable farming incentives have shown promise, their effectiveness is often constrained by uneven implementation, bureaucratic inefficiencies, and limited institutional capacity (Srinatha et al., 2024) [17]. A key strength of this review is its broad, multi-regional scope and its structured analysis of reform eras. Its findings show the importance of involving smallholder voices directly in both the design and execution of policy interventions to ensure that reforms are not only well-intentioned but also contextually grounded and practically viable.

4.1. Policy Frameworks to Support Smallholder Adaptation

National and International Policies Addressing Smallholder Vulnerabilities. Effective policy frameworks must recognize the unique and differing vulnerabilities of smallholder farmers and prioritize their needs in national and international agendas. National policies will need to focus on providing financial support, infrastructure development, and services tailored to the challenges faced by smallholder farmers. Internationally, frameworks like the United Nations Framework Convention on Climate Change and the Paris Agreement emphasize the importance of supporting climate adaptation in agriculture, particularly for vulnerable populations (El Bilali et al., 2020) [1]. However, the translation of these international commitments into actionable national policies remains a challenge.

Policies that promote access to affordable credit are critical for enabling smallholder farmers to invest in climate-resilient technologies and practices. For example, in sub-Saharan Africa, microfinance programs have demonstrated success in improving access to resources for smallholder farmers, though their scalability is limited (Wheeler & von Braun, 2013) [5]. Similarly, in South Asia, government initiatives to provide subsidies for climate-resilient seeds and irrigation systems have been effective but unevenly implemented (Gitz & Meybeck, 2016) [4].

Integration of Smallholder Needs into Global Food Security Agendas. Global food security agendas must integrate smallholder needs, recognizing their critical importance to food systems and their vulnerability to climate change. Organizations like the Food and Agriculture Organization (FAO) and the International Fund for Agricultural Development have highlighted the importance of empowering smallholder farmers through targeted investments, technology dissemination, and market access (WFP, 2016) [18]. For example, the FAO's "Save and Grow" initiative advocates for sustainable intensification practices that align with smallholder needs, promoting productivity while safeguarding environmental resources (Gitz & Meybeck, 2016) [4].

Despite these efforts, smallholder farmers are often underrepresented in global decision-making forums. Ensuring their inclusion in policy discussions and implementation processes is essential for developing solutions that are both effective and equitable. Participatory approaches, such as community-led policy discussions, can help bridge this gap by increasing the number of smallholder voices in this global discussion and ensuring that policies reflect their realities (Kundariati et al., 2024) [19].

A study of agricultural policy implementation in Indonesia reinforces the argument that policies promoting technology access, market integration, and climate resilience can significantly support smallholder adaptation when adequately resourced. Rahman (2023) [20] explains that while interventions such as improved seed distribution, infrastructure investment, and climate-smart agricultural programs have had positive outcomes on

yields and sustainability, persistent gaps in policy coordination continue to limit broad-based impact (Rahman, 2023) [20]. Although this study's national focus may not capture the variances between smallholder experiences across different regions, its applicability lies in its integration of farmer, policymaker, and expert perspectives, offering a well-rounded view of policy effects.

4.2. Role of Technology and Innovation

Development and Dissemination of Climate-Resilient Crops and Farming Tools. Agricultural innovation is a cornerstone of smallholder adaptation, potentially offering tools and practices to enhance resilience and productivity. The development of climate-resilient crop varieties has been transformational for smallholder farmers in regions experiencing extreme weather conditions. Research programs have played a pivotal role in developing and scaling these technologies, though their reach remains limited in some areas due to logistical and financial barriers (Kundariati et al., 2024) [19].

Precision agriculture technologies, including soil sensors, weather forecasting tools, and remote sensing, have also emerged as critical assets for smallholder farmers. These tools enable farmers to optimize resource use, improve yields, and reduce environmental impacts. However, the adoption of such technologies is often constrained by high costs (Gitz & Meybeck, 2016) [4]. Policies that promote partnerships and subsidize technology costs can help address these barriers, making innovations more accessible to smallholder farmers (Wheeler & von Braun, 2013) [5].

Leveraging Digital Platforms for Knowledge Sharing. Digital platforms have revolutionized knowledge dissemination for smallholder farmers. Mobile applications providing weather updates, market prices, and other farming information have already gained traction in regions like East Africa. For example, the "Digital Green" platform has successfully used video-based training to educate smallholder farmers on climate-smart practices, achieving significant improvements in adoption rates (Wheeler & von Braun, 2013) [5].

5. Monitoring and Evaluation of Adaptation Strategies

The success of smallholder adaptation strategies hinges not only on the implementation of innovative practices and supportive policies but also on the ability to measure and evaluate their effectiveness. M&E frameworks are tools for assessing the impacts of adaptation initiatives and identifying areas for improvement. This section focuses on the potential indicators that can be used to measure adaptation success, the role of participatory M&E in adaptation programs, and lessons learned from M&E initiatives.

5.1. Indicators for Measuring Adaptation Success

Developing indicators is a key component of effective M&E frameworks. These indicators must capture the complex nature of adaptation success, including not only productivity but also socio-economic resilience and environmental sustainability. These three key categories of indicators are commonly employed to assess adaptation strategies.

- **Yield stability:** Also known as the consistency of crop yields over time, is one of the most direct measures of the success of agricultural adaptation strategies. By tracking changes in crop yields over time, particularly during periods of climate change, stakeholders and farmers can evaluate the effectiveness of new practices (Kundariati et al., 2024) [19].

- Income resilience: Demonstrates the economic component of adaptation efforts by assessing the ability of smallholder farmers to maintain or increase income levels even in the face of climate challenges.
- Food security: The ultimate goal of the adaptation strategies for smallholder farmers and their regions. Indicators such as food diversity, caloric intake, and food availability at the household level can be used to measure progress in this area (Maziya et al., 2024) [21].

5.2. Role of Participatory M&E in Adaptation Programs

Participatory approaches to M&E have shown potential for improving the relevance and local legitimacy of adaptation strategies, although their effectiveness varies by region and implementation context. These approaches actively involve smallholder farmers in the design, implementation, and assessment of M&E frameworks, leveraging their unique knowledge and perspectives to improve program outcomes.

- Enhancing local relevance: Participatory M&E ensures that indicators and evaluation criteria reflect the realities of smallholder communities. For example, smallholder farmers in dry regions may prioritize indicators related to water availability, while those in wet areas may focus on drainage systems. By customizing M&E frameworks to local contexts, participatory approaches enhance the accuracy of findings (Kundariati et al., 2024) [19].
- Building capacity: Involving smallholder farmers in M&E processes also serves as a training exercise, equipping them with the skills and knowledge needed to monitor their own progress. Training programs that teach smallholder farmers how to use simple data collection tools, such as mobile apps, can empower them to track key indicators and make better decisions about their farming practices (Dimo et al., 2022) [22].
- Promoting accountability: Participatory M&E fosters accountability among all stakeholders, including government agencies. By engaging smallholder farmers in evaluation processes, these approaches ensure that programs remain transparent and responsive to community needs.

5.3. Lessons Learned From M&E Initiatives

Building on these insights from M&E implementation, the following section outlines specific research directions aimed at addressing persistent gaps and enhancing long-term resilience. These lessons highlight the importance of adaptability, integration, and inclusivity in designing and executing M&E systems.

- Flexibility and adaptability: M&E frameworks must be flexible enough to accommodate the unpredictable nature of smallholder farming. Seasonal variations, market fluctuations, and policy changes can all influence the outcomes of adaptation strategies, necessitating regular adjustments to evaluation criteria and methodologies (Kundariati et al., 2024) [19].
- Integration with broader development goals: Effective M&E frameworks should align adaptation efforts with broader development objectives, such as poverty reduction, gender equality, and environmental sustainability. For instance, integrated M&E systems that track both agricultural and socio-economic indicators can provide a more holistic understanding of program impacts, enabling stakeholders to address what are possibly interrelated challenges (FAO & UNDP, 2019) [6].

Evidence from donor-funded projects in Kenya reinforces the value of M&E as a tool for learning, rather than solely for accountability. The study found that project teams were more likely to engage meaningfully in M&E when stakeholder involvement began at the

project design stage and when learning was explicitly recognized as a core outcome of evaluation processes. However, the study also highlighted a significant barrier: the perception among staff that M&E results might be used punitively, which discouraged open participation. This tension underscores the need for M&E systems to establish a safe environment where project learning is prioritized and mistakes are not penalized (Kimote & Muchai, 2024) [23]. While the study's descriptive design and mixed methods approach allowed for practical, on-the-ground insights, its focus on a single county and donor-funded programs may limit the generalizability of its conclusions. Nonetheless, its findings contribute meaningfully to the argument that effective M&E depends not only on technical design, but also on building trust and shared ownership among stakeholders.

6. Research Recommendations

While previous reviews have discussed adaptation strategies in isolation or focused on individual policy contexts, this review offers an integration of adaptation mechanisms, systemic barriers, and participatory monitoring in smallholder settings. It contributes to the literature by explicitly highlighting the need to integrate traditional ecological knowledge into institutional M&E systems and by synthesizing scattered evidence on farmer-led evaluation methods into a coherent narrative.

One of the most significant outcomes of this narrative review is the establishment of targeted research recommendations. The analysis has revealed several knowledge gaps; however, the most urgent gap concerns the limited investigation into how traditional ecological practices can be methodically integrated into climate adaptation strategies. This gap encompasses not only localized agricultural knowledge but also historical and indigenous practices that have guided smallholder farming for generations.

Current research provides detailed examinations of technological, financial, and policy challenges; however, few empirical studies have assessed whether, and how, these community-specific insights can be incorporated into adaptation frameworks to enhance food security outcomes. Future investigations should concentrate on developing and rigorously testing models that deliberately capture and apply these forms of traditional knowledge. Such research would contribute to a more refined understanding of how community-generated indicators and decision-making processes can lead to measurable improvements in the climate resilience of smallholder farming systems.

6.1. Additional Knowledge Gaps in Climate Adaptation Planning

Despite significant progress in climate adaptation research, some critical knowledge gaps remain, particularly in the areas of long-term planning and the integration of smallholder needs. For instance, while the impacts of climate change on crop yields have been extensively studied, less attention has been given to the financial aspects of adaptation (Gitz & Meybeck, 2016) [4]. Addressing research gaps requires interdisciplinary research that combines agronomic, economic, and social perspectives.

Additionally, long-term climate projections need to be integrated into adaptation planning to ensure that smallholder farmers are prepared for future challenges. Emerging technologies can provide valuable insights into the potential impacts of climate change on agricultural systems, but their application in smallholder farms remains very limited (Saikanth et al., 2024) [24]. Expanding the use of these tools and customizing them to local contexts can enhance the relevance and effectiveness of adaptation strategies.

6.2. Promoting Participatory Research Approaches

Participatory research approaches are essential for developing solutions that align with the realities of smallholder farming. By involving smallholder farmers in the research process, these approaches ensure that their knowledge, experiences, and priorities are incorporated into the design and implementation of adaptation strategies (Kundariati et al., 2024) [19].

Studies have demonstrated the effectiveness of participatory research in promoting adoption and scaling of climate-smart practices. For example, in Malawi, community-led experiments on conservation agriculture techniques resulted in higher adoption rates and improved yields, demonstrating the value of involving smallholder farmers in the research process (Kundariati et al., 2024) [19].

7. Methodology

This review employs a narrative synthesis framework based on the methodological guidance outlined by Popay et al. (2006) [25]. The approach was selected due to the interdisciplinary and heterogeneous nature of the included studies, which varied widely in geographic context, disciplinary perspective, and data types. In response to this diversity, efforts were made to assess each study's methodological scope and relevance to smallholder adaptation rather than treating all sources as equivalent. Studies were reviewed iteratively for emerging themes, with special attention given to geographic distribution, source credibility, and methodological transparency. To ensure consistency and reduce bias, each source was assessed for methodological clarity, data collection approach, and stated limitations before being included in the synthesis.

To facilitate the systematic analysis of sources, the AI tool Elicit (Ought, n.d.) [26] was employed to assist in thematic organization, structured data extraction, and comparative analysis. Elicit utilizes language models to extract key methodological and conceptual information from academic texts, including details such as study objectives, sample characteristics, interventions, outcomes, and findings (Ought, n.d.) [26]. The system was used to extract structured variables relevant to the research questions, including study design, population, intervention type, and key results. Elicit allowed for the comparison of these attributes across studies, supporting the identification of patterns, differences, and areas of consensus or divergence.

Thematic analysis was conducted by grouping sources based on conceptual similarities derived from extracted content. This process enabled the identification of recurrent themes, methodological trends, and variations in findings across the literature. Particular attention was paid to identifying whether sources employed primary data collection or relied on secondary analysis, and whether their conclusions acknowledged sampling or contextual constraints. The use of Elicit supported consistency in data handling and reduced subjectivity in initial coding by providing a structured starting point for synthesis. All AI-assisted results were reviewed and validated manually to ensure relevance and accuracy before inclusion in the final analysis. Bond et al. (2024) [27] validate the use of Elicit, stating that Elicit serves as a mechanism for enhancing transparency in evidence sourcing, with researchers applying a clear verification protocol to confirm the credibility of extracted references. Although limitations were identified in Elicit's outputs, it proved useful outputs were subsequently validated through human review (Bond et al., 2024) [27].

The methodology was designed to capture a wide range of perspectives across disciplines, institutions, and regions. Considerations included the credibility of sources, thematic relevance (particularly regarding smallholder farming and climate adaptation), and the diversity of geographic contexts. Following the guidance of Popay et al. (2006) [25], findings were organized into thematic domains. This framework is appropriate for

the narrative review because it enables the systematic synthesis of diverse evidence types, including qualitative and quantitative studies, which is essential when addressing complex, interdisciplinary topics like smallholder adaptation to climate change (Popay et al., 2006) [25]. By emphasizing transparency, attention to diversity, and iterative analysis, the approach enhances the credibility of the synthesis.

7.1. Search Strategy

A broad literature search was conducted to gather peer-reviewed articles, institutional reports, and other credible works focusing on smallholder farming, climate change adaptation, and food security. Initial exploration helped define the scope, highlighting that a substantial body of research addresses climate change and food systems broadly, yet relatively fewer studies emphasize practical adaptation measures relevant to smallholder farmers.

Combinations of keywords related to the following subjects were used, ensuring coverage of the main concepts that were studied in this narrative review: smallholder farmers, climate change adaptation, food security, technology adoption and agricultural policy.

A total of twenty four publications were reviewed. Eighteen spanned from 2021 through 2025 to capture the most relevant and emerging discussions. Additionally, five sources dated between 2007 and 2020 were included to capture foundational scholarship where relevant. For additional details see [Table 1](#).

Table 1. Source Selection Summary Table

Category	Description
Total sources reviewed	17 peer-reviewed journal articles 4 institutional or intergovernmental reports 3 other: corporate press release, news article, technical report
Geographic coverage	Asia, East Africa, Ethiopia, Ghana, Indonesia, Kenya, Latin America, Malawi, South Asia, Sub-Saharan Africa, Zambia
Disciplines represented	Agronomy, Climate Science, Economics, Social Sciences, Technology Studies, Development Studies, Monitoring and Evaluation
Inclusion criteria	Peer-reviewed or official institutional; directly addressing smallholder climate adaptation; source accessibility
Exclusion criteria	Focused on industrial agriculture, unclear methodology, irrelevant geography
Date range of sources	19 sources between 2021 and 2025 6 sources between 2007 and 2020

7.2. Inclusion and Exclusion Criteria

Relevance to review: Selected publications had to directly address climate adaptation in smallholder agriculture or its effects on food security. Documents focusing solely on large-scale industrial farming or climate projections lacking specific insights for smaller farming operations were excluded.

Credibility and rigor: Priority was given to peer-reviewed journal articles, widely recognized institutional reports, and academic press publications. Any work with unclear methodology or insufficient data was excluded. In evaluating the research, attention was given to whether the original studies followed ethical standards, especially where farmer surveys or community-level data were involved. Works that included participatory

engagement with smallholder farmers were preferred, as they reflect more authentic perspectives.

Accessibility: Resources with accessible full texts were favored to promote transparency.

Geographic diversity: Priority was placed on regions where smallholder farming is highly significant (e.g., sub-Saharan Africa, South Asia, Latin America). Studies from other areas were included if they contributed policy perspectives or technological insights transferable to smallholder contexts.

7.3. Databases and Websites

The primary databases utilized in the search for journals and peer-reviewed studies included: Scopus, Web of Science, and Google Scholar.

Targeted searches on official pages of global organizations included: Food and Agriculture Organization (FAO), World Health Organization (WHO), World Food Programme (WFP). These targeted searches were used to identify reputable technical reports and policy documents.

7.4. Rationale for Core References

The recurring use of certain references reflects their close alignment with this review's objectives: they address climate adaptation challenges faced by smallholder farmers, provide strong climate change or policy insights, and have been repeatedly cited in the broader literature. These core references include:

- El Bilali et al. (2020) [1]: Offers an extensive discussion linking climate change and smallholder realities, providing a combination of theoretical and data-based insights.
- Wheeler and von Braun (2013) [5]: Provide a global perspective on food security under changing climate conditions, integrating both quantitative and qualitative data.
- Gitz and Meybeck (2016) [4]: Focus on food security issues and risk responses, emphasizing how policies and governance structures affect smallholder farmers.
- Panos and Damico (2021) [15]: Examines environmental topics from a perspective of institutional and policy limitations, relevant for the systemic barriers analyzed in this review.

These core references provide a balance of peer-reviewed studies, global policy discussions, and content variety. Their relevance to climate change adaptation, smallholder farming, and institutional dynamics made them essential to this review.

7.5. Integration of Other Sources

Other works were integrated to meet specific needs for foundational scholarship, thematic or geographic gaps, for example:

- Dimo et al. (2022) [22]: Provided insights into training and technology adoption, which informed discussions on farmer capacity-building.
- Kangah and Atampugre (2022) [16]: Explored institutional challenges in Ghana, offering a case-based perspective on local constraints and opportunities.
- Saikanth et al. (2024) [24]: Addressed the role of emerging technologies in rural development, highlighting innovation as a resource for adaptation.

Although these sources appear less frequently, they supplemented the core references with additional detailed or regional data, ensuring the narrative accounted for varied challenges.

7.6. Reasons for Excluding Certain Studies

- Some works that were considered were not included due to:
- Minimal relevance: Studies that discuss climate change without connecting to smallholder farming or adaptation approaches.
- Focus on non-comparable agriculture systems: Publications focusing on industrial farming with no alignment to smallholder contexts.
- Weak methodological foundation: Any work lacking a transparent research design that would support strong conclusions.

8. Limitations of the Study

Acknowledging the limitations of this review is critical to providing a balanced and transparent analysis. While this study has attempted to present a comprehensive analysis of existing literature on smallholder adaptation to climate change, certain constraints may influence its findings and implications.

8.1. Scope Constraints

This review primarily focuses on smallholder farming systems within developing regions, such as sub-Saharan Africa, South Asia, and Latin America. While these regions represent significant portions of the global smallholder population, the study does not comprehensively address the experiences of smallholder farmers in developed nations or other underrepresented regions. The scope is largely centered on adaptation strategies, barriers, and policy implications, potentially omitting other critical areas such as post-harvest processes, market dynamics, and other stressors that also affect smallholder resilience.

8.2. Data Limitations and Potential Biases

This study relies on secondary data from existing literature, which may inherently include gaps or biases in data collection and reporting. Additionally, many studies focus on short-term impacts, with fewer addressing the long-term effectiveness and sustainability of adaptation measures. Expanding on this issue, it is important to note that, as Wheeler and von Braun (2013) [5] have observed, the reliance on secondary data can lead to an incomplete and sometimes skewed understanding of climate change impacts on food security. Their analysis highlights that available datasets often vary significantly in quality and granularity, particularly when comparing regions with established and high quality data collection systems to those where monitoring is less systematic. This discrepancy means that the experiences of smallholder farmers in remote or low-resource areas may be underrepresented, thereby biasing conclusions drawn from the literature toward regions that are better documented (Wheeler & von Braun, 2013) [5].

In the context of this narrative review, acknowledging data limitations is essential. Wheeler and von Braun (2013) [5] support the cautious interpretation of current findings but also reinforce the need for future research that prioritizes primary data collection and long-term studies. The predominance of short-term studies in the existing body of research can obscure long-term trends and skew the effectiveness of adaptation strategies. Without a consistent long-term perspective, it is challenging to fully assess how adaptation measures perform over time and under varying climatic conditions. This limitation is critical because the dynamic nature of climate change demands an understanding of both immediate and long-term impacts on smallholder agriculture. Variations in sample sizes, data collection techniques, and analytical frameworks

compound these biases and hinder the development of a unified picture of adaptation success (Wheeler & von Braun, 2013) [5].

8.3. Temporal Limitations

Climate adaptation is a very dynamic and evolving field, with new technologies, policies, and practices emerging continuously. This review represents a snapshot of the current state of knowledge rather than a definitive summary. Some findings may become outdated as additional research is conducted or as climate conditions change. Some technologies assessed in this review, like precision agriculture and digital tools for knowledge sharing, while promising, are still in the early stages of adoption in many regions, and their long-term impacts remain uncertain (Wheeler & von Braun, 2013) [5].

9. Conclusion

This review provides a novel synthesis by linking participatory M&E approaches with traditional knowledge integration, an area not well-documented in prior reviews. The framework applied here, guided by Popay et al. (2006) [25], offers a transparent basis for future empirical research designs and policy planning. The review has integrated existing literature on climate adaptation strategies for smallholder farmers, explaining both the promise of innovative practices and the persistent systemic challenges that limit their resilience. Smallholder agriculture is undeniably central to global food security; yet, these farming communities remain exceedingly vulnerable due to financial constraints, limited access to modern technologies, and policy inefficiencies.

The reliance on secondary data and methodological inconsistencies across studies complicates our understanding of long-term adaptation outcomes. These limitations not only affect the interpretation of existing research but also impede the translation of findings into actionable, context-specific policy interventions. Considering these challenges, a concerted effort is needed to improve data collection, foster interdisciplinary research, and implement pilot projects that validate innovative adaptation frameworks.

9.1. Synthesis of Key Findings and Broader Limitations

Adaptation strategies, including crop diversification, agroecological practices, and the deployment of climate-resilient crop varieties, demonstrate the potential for mitigating climate impacts on smallholder systems. However, systemic barriers continue to constrain their widespread adoption. A critical limitation of the current literature is its heavy reliance on secondary data, which often suffers from methodological inconsistencies, variable quality, and underrepresentation of remote or low-resource regions. These limitations reveal the need for primary, longitudinal research that captures the nuanced realities of smallholder agriculture over extended periods. These data constraints hinder the effective translation of research insights into policy measures, particularly in diverse global contexts where monitoring systems differ widely. Acknowledging these challenges provides a broader perspective on the global difficulties in climate adaptation research and frames the urgency for improved research methodologies and data quality.

9.2. Policy Implications and the Need for Interdisciplinary Collaboration

The insights drawn from this review carry significant policy implications. National and international policy frameworks must be reoriented to prioritize smallholder farmers through enhanced access to affordable credit, climate-resilient technologies, and targeted support services. It is essential that smallholder perspectives are integrated into the

policy-making process to ensure that interventions are both culturally and contextually appropriate.

Collaboration among experts in agronomy, economics, social sciences, and technology studies is crucial for developing innovative monitoring and evaluation frameworks that accurately assess both short and long-term outcomes. Integrated, cross-disciplinary efforts will be instrumental in formulating equitable policy interventions and promoting sustainable, inclusive growth within smallholder agriculture.

9.3. Future Research Directions and a Call to Action

This review calls for targeted future research to address critical gaps. First, there is an urgent need to develop and rigorously test innovative, field-based monitoring and evaluation frameworks that combine traditional ecological knowledge with modern adaptation technologies. Pilot projects and controlled field experiments are essential to validate these new approaches in real-world settings. Second, future studies should explore the scalability of emerging technologies, such as precision agriculture and digital platforms for knowledge sharing, leveraging strategic partnerships and innovative financing mechanisms. Third, interdisciplinary, longitudinal research is vital to unravel the complexities between environmental changes, technological adoption, and socio-economic resilience in smallholder farming systems. Finally, community engagement must remain at the forefront; participatory research methods can ensure that adaptation strategies are both grounded in local realities and sustainable over the long term.

As climate change continues to threaten global agricultural systems, researchers, policymakers, and practitioners are needed to act swiftly and collaboratively. Only through coordinated, globally relevant efforts can we ensure that smallholder agriculture not only endures but thrives, contributing to a more resilient and equitable global food system.

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