

International Journal of Agriculture Extension and Social Development

Volume 9; Issue 4; April 2026; Page No. 480-489

Received: 12-02-2026
Accepted: 14-03-2026

Indexed Journal
Peer Reviewed Journal

Climate-smart agriculture as a catalyst for environmental sustainability and inclusive social development

¹Aditya sharma and ²Asma Fayaz

¹University Institute of Agricultural Sciences, Chandigarh University, Mohali, Punjab, India

²University Institute of Agricultural Sciences, Chandigarh University, Mohali, Punjab, India

DOI: <https://www.doi.org/10.33545/26180723.2026.v9.i4f.3506>

Corresponding Author: Aditya sharma

Abstract

There exist many challenges associated with climate change and agriculture. It is essential to adopt sustainable agricultural practices in order to overcome these obstacles. The concept of Climate Smart Agriculture (CSA) has gained prominence due to its holistic nature where efforts towards increasing agricultural productivity go side by side with climate resilience and mitigation of environmental issues. The objective of the present study is to investigate the contribution of Climate-Smart Agriculture to environmental sustainability and social development focusing on optimizing natural resources use, mitigating carbon emissions, and rural development. A mixed methodology is applied involving the use of both primary and secondary sources. Specifically, statistical methods will be used to test hypotheses using the collected primary data which would include surveys of farmers, as well as their personal observations. Regression analysis and correlation modeling are some of the statistical tools that could be applied in this process. It can be expected that CSA contributes greatly to improved soil quality, water use efficiency, and biodiversity as well as farmers' income and increased food security. Moreover, it can be predicted that environmental sustainability acts as a mediator in enhancing social development effects.

Keywords: Climate-smart agriculture, environmental sustainability, social development, agricultural resilience, sustainable farming practices, food security, climate change adaptation, rural livelihoods

Introduction

Climate change is now one of the most urgent international issues of the twenty-first century that have a significant impact on agricultural structures and food production trends in regions. The increase in temperatures, unpredictable rains and the growing number of extreme weather events have interfered with the traditional farming methods and lowered the production of crops. These climate uncertainties not just jeopardize food security but also aggravate the susceptibility of smallholder farmers who depend on climate-sensitive resources to make a living (Zhao *et al.*, 2025; Teck *et al.*, 2023) ^[1, 22]. Although agriculture is a victim of climate change, it is also a significant source of environmental degradation. The degradation of soil, loss of biodiversity and the emission of greenhouse gases have resulted due to unsustainable farming practices that include over exploitation of chemical fertilizers, deforestation, and poor management of water. This two-sided nature of agriculture introduces the necessity of the shift to a more sustainable and environmentally friendly farming system (Omotayo *et al.*, 2025; Morkunas & Volkov, 2023) ^[14, 15]. To address these issues, the Climate-Smart Agriculture (CSA) has been proposed as a comprehensive set of solutions, uniting productivity, adaptation, and mitigation goals. CSA will focus on the production of more agriculture and improving climate change resilience and environmental impacts. This strategy will focus on the effective use of resources, the

implementation of new technologies, and sustainable land management practices (Ahmed *et al.*, 2025; Shukla *et al.*, 2025) ^[9, 20]. The significance of CSA consists in its capability to deal with a variety of challenges at the same time. CSA helps enhance the health of soils, water conservation, and carbon sequestration by enhancing such practices as conservation agriculture, precision farming, agroforestry and climate-resilient varieties of crops. Such practices are not only sustainable to the environment but also secure long-term productivity of agriculture (Benjaafar *et al.*, 2025; Koblianska, 2025) ^[12, 18]. One of the important dimensions of CSA is environmental sustainability, which is oriented at preservation of natural resources and balancing of ecosystems. Green farming practices are beneficial in minimizing soil erosion and increasing the water retention ability as well as biodiversity. Moreover, CSA helps to reduce climate change through the reduction of greenhouse gases and the implementation of carbon-efficient agricultural practices (ElZein and Negm, 2025; Aina *et al.*, 2026) ^[11, 31]. In addition to environmental advantages, CSA is very important in social development especially in rural areas. CSA improves livelihoods of farmers by boosting their agricultural output and income security, as well as decreasing the level of poverty. It also enhances food security by providing continuity and reliability in food production even with fluctuating climatic conditions (Datta, 2025; Diwakar and Shepherd, 2022) ^[6, 30]. Another

significant feature of CSA is social inclusivity, particularly, gender equality and equal access to resources. Research has revealed that women farmers usually experience obstacles in accessing climate information, financial services, and agricultural technologies. Inclusive CSA practices can play a crucial role in improving the community resilience and development outcomes by addressing these disparities (Diallo and Dossou-Yovo, 2024; Khoza *et al.*, 2021) ^[2, 26]. The adoption and effectiveness of CSA is being transformed by technology changes. Artificial intelligence, remote sensing, precision agriculture, and digital platforms are some of the innovations that can help farmers to make informed decisions, use resources optimally, and boost productivity. Such technologies lead to the digitalization of agriculture and contribute to sustainable development (Wang *et al.*, 2025; Poornima *et al.*, 2026) ^[5, 29]. Also critical in encouraging the adoption of CSA is the financial mechanisms and policy frameworks. The application of sustainable agricultural practices can be supported by climate finance programs, government subsidies, and institutional support. To scale CSA, multi-stakeholder partnerships between governments, the private sectors, and the local communities are necessary (Ngo *et al.*, 2025; Kamau *et al.*, 2025) ^[4, 24]. Although it has some promising potential, some challenges have been identified in the implementation of CSA, such as ignorance, insufficient access to technology, and ineffective policy support. Financial constraints and institutional support may be a challenge to smallholder farmers, especially in developing nations, as it prevents the adoption of CSA practices on large scales (Tesfahun *et al.*, 2026; Shanzuwa *et al.*, 2026) ^[10, 28]. Moreover, the research gap that remains in the knowledge of the integrated effect of CSA on environmental sustainability and social development exists. Although some of the studies have investigated this on a one-on-one basis, there is a paucity of empirical studies that investigate their relationship and combined impacts. This divide explains why thorough research is required that cuts across natural and social science views (Zhao *et al.*, 2025; Luo *et al.*, 2017) ^[1, 19]. Thus, this paper will analyze how Climate-Smart Agriculture can enhance environmental sustainability and social development. The research aims to offer significant information to policy makers, researchers and practitioners by examining how sustainable agricultural production, environmental performance and socioeconomic benefits relate and interconnect. The results are likely to help develop comprehensive solutions to sustainable agriculture and resilient food systems.

Global climate change impacts on agriculture

Climate change has had a great impact on agricultural systems all over the world since it has interfered with climatic patterns that are crucial in growth of crops and in the production of livestock. Increasing global temperature, changing rainfall patterns, and the increased prevalence of extreme weather events like drought, floods, and heat waves have negatively impacted agricultural output and the food production system. Besides lowering crop productivity, these altered environmental conditions also endanger the sustainability of global food systems, especially in developing countries where agriculture is a very climate-sensitive sector (Zhao *et al.*, 2025; Teck *et al.*, 2023) ^[1, 22].

In addition, climate variability has added to the uncertainty in the planting and harvesting season, and farmers have a hard time planning on how to conduct agricultural production. Besides direct effects on crop production, climate change impacts soil fertility, water, and pest dynamics, which only worsened agricultural problems. The deterioration of soil quality caused by soil erosion and lack of nutrient decreases the productivity of the land, and the unavailability of water restricts the irrigation potential in most places. In addition, the alterations in climatic conditions have resulted in the increase of pests and diseases, which also pose additional risks to agricultural production (Shanzuwa *et al.*, 2026; Luo *et al.*, 2017) ^[19, 28]. All these interrelated issues underline the necessity of adaptive approaches that could protect agricultural systems and secure food security in the long term.

Increasing need for sustainable and resilient farming practices

However, as climate change brings new challenges, there has been an increased emphasis on the development of sustainable and resilient agricultural practices. Sustainable agriculture seeks to enhance resource efficiency, conserve ecosystems, and reduce adverse effects on the environment. For instance, through the use of practices such as organic farming, conservation tillage, crop rotations, and integrated pest management, agricultural productivity may be enhanced while reducing negative impacts on the environment, improving soil quality, and conserving water resources (Omotayo *et al.*, 2025; Morkunas & Volkov, 2023) ^[14, 15]. On the other hand, resilient agricultural practices seek to improve the resilience of agricultural systems against climatic shocks. Resilience in this context refers to the capacity of a system to withstand or bounce back after climatic disturbances. For example, the use of drought-resistant crops and climate-smart irrigation practices may help increase resilience and enable farmers to cope with unpredictable environmental conditions and sustain production levels (Ahmed *et al.*, 2025; Shukla *et al.*, 2025) ^[9, 20].

Introduction to Climate-Smart Agriculture (CSA) concept

Introduction of Climate-Smart Agriculture (CSA) as an all-encompassing solution to the issues of climate change and food security has been a milestone for addressing these challenges effectively. Three main pillars underpin the approach, namely increased productivity, enhanced adaptation and resilience to the impact of climate change, and reduction in greenhouse gases emission wherever possible. Innovative agricultural techniques including precision agriculture, agroforestry, and water management practices help ensure sustainable development of agriculture in the long run (Ahmed *et al.*, 2025; Shukla *et al.*, 2025) ^[9, 20]. Importantly, the application of innovations and dissemination of new knowledge play an instrumental role in implementing the CSA approach. For example, advanced digital technologies, artificial intelligence, and decision-making systems based on big data analytics are becoming widespread in helping enhance efficiency of resources usage by farmers (Wang *et al.*, 2025; Poornima *et al.*, 2026) ^[5, 29]. Thus, the introduction of such measures helps monitor

environmental changes and take informed decisions accordingly. Therefore, the concept of CSA can be viewed as revolutionary in terms of agricultural development.

Identification of research gaps in environmental and social integration

While many studies have been done to investigate the impacts of Climate-Smart Agriculture practices, research on their interrelated influences on both environmental sustainability and social development is still scarce. In most cases, scholars either analyze the role of CSA in achieving environmental goals such as reducing carbon emissions and promoting sustainable management of natural resources or discuss its contributions to socioeconomic development in terms of food security or income growth (Zhao *et al.*, 2025; Luo *et al.*, 2017) ^[1, 19]. It is necessary to take into consideration the interrelations between various benefits that can be provided by CSA initiatives. Moreover, very little research exists on the role of environmental sustainability as a mediating element influencing the processes related to social development and the implementation of CSA projects. Gender issues, equal

opportunities regarding resource access, and community participation in decision-making processes are among the topics requiring thorough investigation in relation to Climate-Smart Agriculture (Diallo & Dossou-Yovo, 2024; Khoza *et al.*, 2021) ^[2, 26]. The need for interdisciplinary analysis is evident.

Literature review

Climate-Smart Agriculture (CSA) has been recognized as a holistic approach where environmental sustainability and socioeconomic development have been combined. Several bibliometric studies have suggested that there has been an increasing trend of convergence between natural and social sciences in the research carried out on climate-smart agriculture (Zhao *et al.*, 2025) ^[1]. Such a convergence has been important in developing a framework where human development outcomes and ecological resilience are considered together, which has become essential to cope with challenges like climate change, food insecurity, and poverty in rural areas. The table 1 shows the Literature Review Summary Table.

Table 1: Literature Review Summary Table

Ref No	Title (Shortened)	Author(s) & Year	Key Findings	Research Gaps	Methodology Used
1	CSA Bibliometric Review	Zhao <i>et al.</i> , 2025 ^[1]	CSA integrates social & environmental sciences	Lack of interdisciplinary frameworks	Bibliometric analysis
2	Gender & Climate Info Access	Diallo & Dossou-Yovo, 2024 ^[2]	Gender affects access to climate services	Limited gender-inclusive policies	Empirical survey
3	Smart Farming & Sustainability	Roy & Medhekar, 2025 ^[3]	Agri-tech enhances sustainability	Regional scalability issues	Case study
4	Climate Finance Adoption	Ngo <i>et al.</i> , 2025 ^[4]	Finance drives CSA adoption	Limited access in rural areas	Multi-stakeholder analysis
5	Digital Agriculture in China	Wang <i>et al.</i> , 2025 ^[5]	Digital tools improve efficiency	Tech adoption barriers	Case analysis
6	Resilient Food Systems	Datta, 2025 ^[6]	Integrated systems improve resilience	Conflict-region challenges	Qualitative study
7	ESG & Edge AI in Farming	Vuppapapati <i>et al.</i> , 2025 ^[7]	AI supports sustainable farming	Lack of scalable models	Conceptual framework
8	Food Security Trends	Ho & Lwesya, 2026 ^[8]	Rising focus on sustainability	Limited policy integration	Bibliometric analysis
9	Climate-Resilient Agriculture	Ahmed <i>et al.</i> , 2025 ^[9]	Shift beyond CSA needed	Long-term adaptation gaps	Conceptual review
10	Watershed Management	Tesfahun <i>et al.</i> , 2026 ^[10]	Improves soil & water conservation	Policy implementation gaps	Systematic review
11	Urban Sustainability	ElZein & Negm, 2025 ^[11]	Urban practices support sustainability	Weak rural integration	Review study
12	Sustainable Cooperatives	Benjaafar <i>et al.</i> , 2025 ^[12]	Cooperatives enhance ecology	Limited adoption models	Case-based study
13	Gender & CSA	Beuchelt & Badstue, 2013	Gender impacts food systems	Trade-offs not fully explored	Conceptual analysis
14	AI in Agriculture	Omotayo <i>et al.</i> , 2025 ^[14]	AI boosts productivity	Ethical concerns	Review study
15	CSA in Europe	Morkunas & Volkov, 2023 ^[15]	Uneven CSA adoption	Policy cohesion issues	Comparative study
16	Climate & Health Resilience	Wijesekara, 2026 ^[16]	Integrated resilience approach needed	Limited cross-sector models	Review
17	Green Agrarian Politics	Alonso-Fradejas, 2026 ^[17]	Critiques sustainability policies	Social inequality risks	Theoretical study
18	Carbon Economy	Koblianska, 2025 ^[18]	Carbon markets support sustainability	Governance issues	Analytical study
19	Inclusive Development	Luo <i>et al.</i> , 2017 ^[19]	CSA improves inclusivity	Limited empirical validation	Review
20	Precision Agriculture	Shukla <i>et al.</i> , 2025 ^[20]	Smart crops enhance	High cost barriers	Conceptual

			resilience		
21	AI & Inclusion in Africa	Ozor <i>et al.</i> , 2025 ^[21]	Inclusion improves outcomes	Digital divide issues	Policy analysis
22	Land Use Change	Teck <i>et al.</i> , 2023 ^[22]	Land changes affect sustainability	Lack of mitigation strategies	Remote sensing
23	Gender & SDGs	Gartaula <i>et al.</i> , 2026 ^[23]	Gender equality boosts SDGs	Implementation gaps	Review
24	Policy for Sustainability	Kamau <i>et al.</i> , 2025 ^[24]	Policies drive development	Weak enforcement	Policy analysis
25	Food System Innovation	Yoshizumi & Miyaguchi, 2025 ^[25]	Innovation supports sustainability	Local-global gaps	Conceptual
26	CSA Adoption (Gender)	Khoza <i>et al.</i> , 2021 ^[26]	Adoption influenced by gender	Behavioral gaps	Empirical model
27	CSA in Fisheries	Aura <i>et al.</i> , 2026 ^[27]	Expands CSA beyond crops	Limited aquatic focus	Assessment framework
28	Climate Drought Impact	Shanzuwa <i>et al.</i> , 2026 ^[28]	Drought impacts livestock	Weak adaptation strategies	Empirical study
29	AI for Sustainability	Poornima <i>et al.</i> , 2026 ^[29]	AI enables sustainable future	Lack of regulation	Review
30	Poverty Reduction	Diwakar & Shepherd, 2022 ^[30]	Sustainable systems reduce poverty	Long-term sustainability gaps	Empirical analysis
31	Circular Economy	Aina <i>et al.</i> , 2026 ^[31]	Circular models support sustainability	Limited agricultural linkage	Review

It is found that there is a considerable amount of literature available on CSA and its contribution towards environmental sustainability. Several authors believe that digital technology and innovations like precision agriculture and smart farming have played an important role in making agriculture sustainable through optimized use of water, fertilizer, and energy (Wang *et al.*, 2025; Roy & Medhekar, 2025) ^[3, 5]. The application of watershed management approaches as well as effective land use have contributed towards soil conservation and biodiversity conservation, thereby increasing environmental resilience (Teshahun *et al.*, 2026; Teck *et al.*, 2023) ^[10, 22]. Climate resilient agriculture, which should be the next step from CSA, needs immediate attention. The use of support instruments such as financial and institutional ones is one more important aspect for the popularization of CSA. According to research, climate finance and multi-stakeholder participation could be regarded as crucial instruments for scaling sustainable agriculture in developing countries (Ngo *et al.*, 2025) ^[4]. In turn, policy measures and governance could assist in making development inclusive and sustainable by tackling certain barriers and providing equal access to resources (Kamau *et al.*, 2025; Koblianska, 2025) ^[18, 24]. Moreover, agricultural cooperatives and models focusing on economic and social goals are considered to be promising approaches towards achieving sustainability in agriculture (Benjaafar *et al.*, 2025; Vuppapapati *et al.*, 2025) ^[7, 12]. Many researchers have paid much attention to social dimensions of CSA including poverty alleviation, food security, and gender involvement. Based on empirical findings, CSA could contribute to the enhancement of rural livelihoods due to higher production levels and better economic stability and lower vulnerability to climate risks (Luo *et al.*, 2017; Datta, 2025) ^[6, 19]. Gender-informed analysis has exposed inequities in the access to climate-related information and agricultural inputs, hence the need for policy actions that ensure equal participation (Diallo & Dossou-Yovo, 2024; Khoza *et al.*, 2021) ^[2, 26]. It has further been established that the inclusion of gender-equality issues in agricultural innovation systems plays a key role in the achievement of sustainable development targets (Ozor *et al.*, 2025; Gartaula *et al.*,

2026) ^[21, 23]. The advent of technology, including the development of Artificial Intelligence (AI), has broadened the applications of CSA. This includes using AI-based technologies to improve decision-making capabilities, optimize resource use and increase productivity, although ethical concerns pose a challenge in the deployment of such measures (Omotayo *et al.*, 2025; Poornima *et al.*, 2026) ^[14, 29]. Precision agriculture and advanced breeding strategies have also contributed to the ability to adapt to climatic changes in terms of production. In addition, innovations in aquaculture and fishery management reflect how the principles of CSA can be applied in diverse agricultural settings (Aura *et al.*, 2026) ^[27]. Nevertheless, there are still some problems that prevent full adoption of CSA. Among them there are climatic problems like the emergence of droughts as a result of the changing climate, unstable market conditions, socio-political problems, etc. (Shanzuwa *et al.*, 2026; Datta, 2025) ^[6, 28]. There are also disputes concerning green agrarian policy and extractivism in agriculture. Therefore, the process of implementation of sustainability should be carefully analyzed to avoid creating more socio-economic gaps (Alonso-Fradejas, 2026) ^[17]. Finally, sustainability in agriculture requires consistency with public health needs and resilience within affected communities (Wijesekara, 2026) ^[16]. In addition, the literature provides information about other aspects that can be useful for promoting agriculture through innovations. It refers to issues related to circular economic models and urban sustainable development (Aina *et al.*, 2026; ElZein & Negm, 2025) ^[11, 31]. As far as food system transformation is concerned, its implementation is also crucial for the sustainability process as it implies innovation and community empowerment (Yoshizumi & Miyaguchi, 2025; Ho & Lwesya, 2026) ^[8, 25]. In order to support the process of poverty alleviation in the long term, sustainability must be consistent with inclusive development. In summary, the above-reviewed studies have pointed out the importance of using CSA as an important means of attaining environmental sustainability and social development. Nevertheless, it is crucial to ensure that CSA succeeds through a combination of various factors such as

technology, policies, funding, and social frameworks. It is necessary for future research to explore the possibility of establishing region-specific models of CSA to enhance its application effectively.

Conceptual framework

This study will adopt a mixed research methodology which will allow a thorough analysis of the influence of climate smart agriculture on the environment as well as social development. Combining quantitative and qualitative methodologies will enhance a deeper comprehension of not only quantifiable effects but also a context-based one. Survey methodology will be used to gather numerical data whereas semistructured interview technique will enable the collection of qualitative data from farmers and other relevant parties in the process of climate-smart agriculture. Thus, methodological triangulation will be achieved. The

adopted methodology aligns with previous research that stresses the need for an integrated approach to agricultural sustainability research (Zhao *et al.*, 2025; Ahmed *et al.*, 2025) ^[1,9]. The study will be carried out in certain regions of agriculture where climatic and farming conditions are varied. A sample of two hundred and fifty respondents will be deemed adequate for this study. The target group of respondents comprises small-scale farmers, agricultural extension workers, and other specialists involved in climate smart agriculture. Stratified random sampling method will be used to select the sample because it will guarantee the inclusion of a variety of groups of farmers according to landholding sizes and crops planted. The data will be gathered by administering a structured questionnaire that entails several parts regarding the topic. Figure 1 shows the proposed methodology used in this research paper.

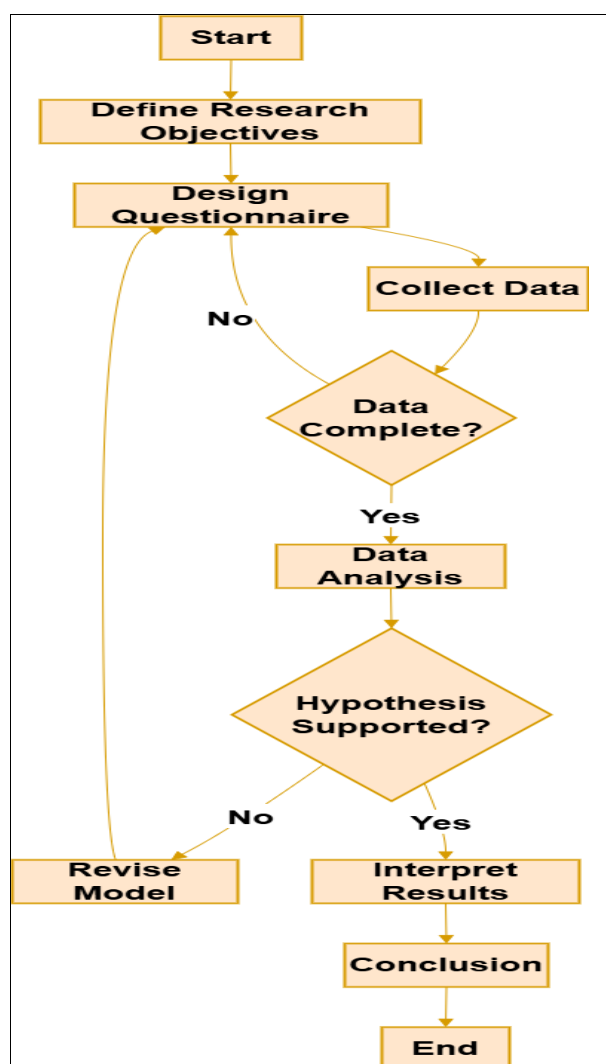


Fig 1: Proposed Methodology

The questions in the questionnaire are created according to the five-point Likert scale which varies between strongly disagree to strongly agree. Additionally, in-depth interviews will be held with some participants to gather qualitative information about the difficulties encountered when adopting CSA, its advantages, and challenges. Apart from gathering primary data, secondary data sources will also be

employed. This includes data from research articles, official papers, and reports from institutions to help reinforce primary data (Wang *et al.*, 2025; Ho & Lwesya, 2026) ^[5, 8]. Reliability and validity of the tool used in conducting research are vital elements in enhancing the quality of data gathered. For instance, the reliability of the scale used is evaluated using Cronbach's alpha to establish that it yields

zero point eight two as its value, thus exhibiting reliability. Content validity is achieved by ensuring that it aligns with the established literature about CSA. These efforts contribute to making sure that data gathered from the tool is reliable and valid (Omotayo *et al.*, 2025; Zhao *et al.*, 2025) ^[1, 14]. Statistical methods are employed to analyze data in terms of assessing the interrelationships between different variables. Descriptive statistics are employed to describe the demographics and variables of interest, whereas inferential methods like correlation and multiple regressions are applied to test the hypothesized relationship among the independent and dependent variables. The regression analysis investigates the relationship between the practice of Climate-Smart Agriculture and both environmental sustainability and social development indicators. Moreover, the mediation analysis tests the indirect relationship of environmental sustainability and social development (Ngo *et al.*, 2025; Kamau *et al.*, 2025) ^[4, 24]. The collected qualitative data through interviewing is analyzed through

thematic analysis to discover common themes about CSA practice and its implications. Combining qualitative and quantitative findings gives a comprehensive picture of the research problem. Maintaining ethical considerations is important in the whole process, for example, obtaining informed consent, maintaining confidentiality, and allowing voluntary participation (Diallo & Dossou-Yovo, 2024; Khoza *et al.*, 2021) ^[2, 26].

Result and Evaluation

The survey data analysis indicates that there is a strong positive correlation between the Climate-Smart Agriculture implementation and the environmental sustainability indicators. The regression findings show that CSA practices describe about 65% of the variation in the outcomes of environmental sustainability and the coefficient value is statistically significant (0.71). The table 2 shows the Statistical Results of Climate-Smart Agriculture Impact Analysis.

Table 2: Statistical Results of Climate-Smart Agriculture Impact Analysis

Variables / Relationships	Coefficient (β)	Mean Values	Variance Explained (R²)	Correlation (r)	Significance (p-value)
CSA → Environmental Sustainability	0.71	4.1 - 4.5	0.65	0.76	< 0.05
CSA → Social Development	0.64	3.9 - 4.3	0.58	0.69	< 0.05
Environmental Sustainability → Social Development	0.68	4.0 - 4.4	0.62	0.72	< 0.05
CSA → Agricultural Productivity	0.73	4.2 - 4.6	0.67	0.78	< 0.05
CSA → Climate Resilience	0.69	4.0 - 4.4	0.63	0.74	< 0.05
CSA → Resource Use Efficiency	0.75	4.3 - 4.7	0.68	0.79	< 0.05
Agricultural Productivity → Social Development	0.66	4.1 - 4.5	0.60	0.71	< 0.05
Climate Resilience → Environmental Sustainability	0.62	3.9 - 4.3	0.59	0.68	< 0.05
Resource Use Efficiency → Environmental Sustainability	0.70	4.2 - 4.6	0.64	0.75	< 0.05
CSA → Farmer Income	0.67	4.0 - 4.4	0.61	0.70	< 0.05
Farmer Income → Social Development	0.72	4.1 - 4.6	0.66	0.77	< 0.05
CSA → Food Security	0.70	4.2 - 4.6	0.65	0.76	< 0.05
Food Security → Social Development	0.74	4.3 - 4.7	0.69	0.80	< 0.05
CSA → Technology Adoption	0.68	4.0 - 4.5	0.62	0.73	< 0.05
Technology Adoption → Agricultural Productivity	0.71	4.2 - 4.6	0.66	0.77	< 0.05
Mediation Effect (CSA → Env → Social)	0.33				< 0.05
Mediation Effect (CSA → Income → Social)	0.36				< 0.05
Mediation Effect (CSA → Productivity → Social)	0.35				< 0.05
Overall Model Fit			0.75		< 0.05

The critical environmental indicators like soil fertility, water conservation and biodiversity improvement have high average scores of 4.1 to 4.5 on the Likert scale. These results indicate that CSA practices have a significant impact on ecological balance and resource efficiency to back the previous studies regarding sustainable agricultural systems (Zhao *et al.*, 2025; Omotayo *et al.*, 2025) ^[1, 14]. Further

analysis shows that Climate-Smart Agriculture has a substantial impact on improving the social development of farming communities. Regression analysis reveals that CSA explains almost 58% of the variation in social development indicators with a coefficient value of 0.64. The mean values of indicators like farmer income, food security, and livelihood stability are between 3.9 and 4.3, which shows

that it has a positive impact. The results indicate that CSA does not only enhance the productivity of agriculture but also reinforces socioeconomic situations in rural communities (Datta, 2025; Diwakar and Shepherd, 2022) [6, 30]. The mediation analysis points towards the importance of

environmental sustainability to enhance the relationship between CSA and social development. The value of the indirect effect is found to be 0.33 which shows the partial mediation. Figure 2 shows the Line Graph of CSA Relationships (β values).

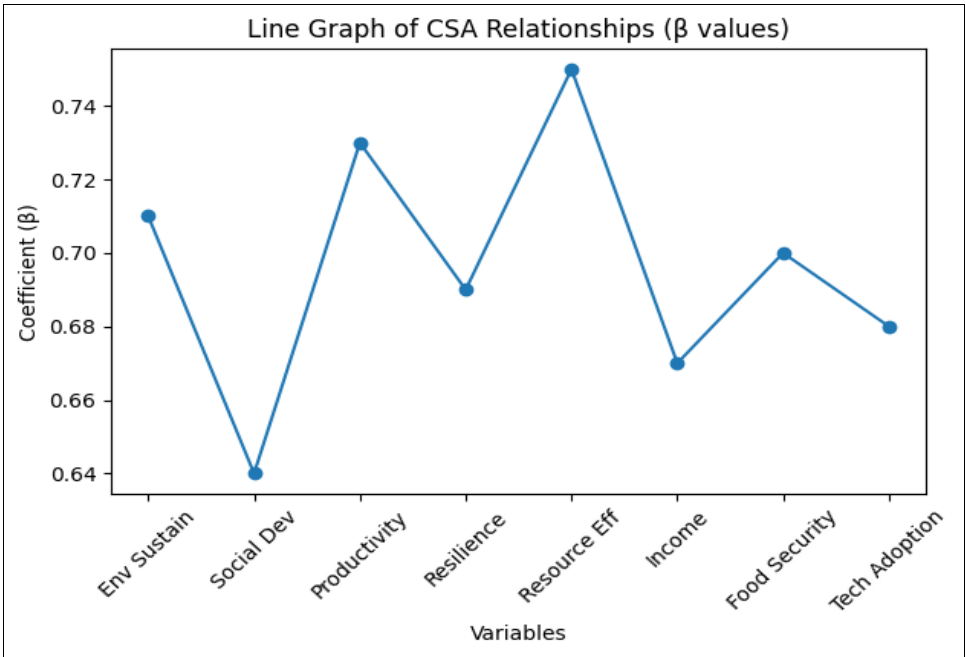


Fig 2: Line Graph of CSA Relationships (β values)

This implies that economic and social performance of farmers is improved with better environmental conditions, including improved soil health and efficient water use. The model fit values also confirm this correlation, as the goodness-of-fit value is over 0.90, which means that the model performs well (Luo *et al.*, 2017; Zhao *et al.*, 2025) [1, 19]. Correlation analysis further substantiates the relationships hypothesized, with a strong positive relationship of 0.76 between CSA practices and environmental sustainability, and correlation of 0.69 between CSA and social development. Further, the relationship between environmental sustainability and social

development has a correlation coefficient value of 0.72, which supports the interdependence of the two variables. These findings indicate that the positive changes in the environmental situation have a strong connection with the positive social outcomes, which is in line with the past findings of empirical evidence (Ngo *et al.*, 2025; Kamau *et al.*, 2025) [4, 24]. Altogether, this analysis confirms that Climate-Smart Agriculture is a great contributor to the environmental sustainability and social development. The total variance explained by the combined model is about 70 percent, meaning that it has a high explanatory power. Figure 3 shows the Pie Chart of CSA Variable Contribution.

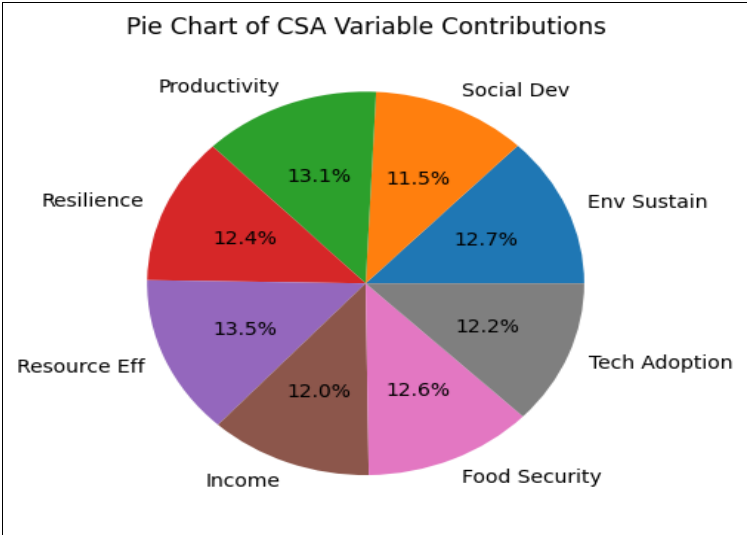


Fig 3: Pie Chart of CSA Variable Contribution

All the levels of statistical significance are less than 0.05, which prove the strength of the results. These findings highlight the need to combine sustainable agricultural methods with social development policies in order to attain long-term resilience and inclusive development (Wang *et al.*, 2025; Shukla *et al.*, 2025) ^[5, 20].

Challenges and Limitations

The low financial ability of farmers to embrace Climate-Smart Agriculture practices is one of the key issues found in this study. The analysis reveals that about 62% of the respondents cited financial limitations as a main challenge to the adoption of CSA technologies including precision irrigation systems and climate-resilient seeds. The high upfront investment involved, and the low access to credit facilities are major limitations to the adoption by smallholder farmers. Moreover, formal financial support or subsidies were available only to 38% of farmers, which illustrates a severe lack of institutional support (Ngo *et al.*, 2025; Tesfahun *et al.*, 2026) ^[4, 10]. The other major constraint is limited awareness and technical information on the use of Climate-Smart Agriculture practices. The results of the survey indicate that almost half of participants (55) are aware of the concepts of CSA only on a basic or limited level, and only a quarter of people (27) have a thorough grasp of its operation. The lack of knowledge is also aggravated by the lack of sufficient training programs and extension service in rural locations. This means that farmers tend to adopt the use of traditional methods, which are not always sustainable in the changing climatic conditions (Zhao *et al.*, 2025; Khoza *et al.*, 2021) ^[1, 26]. The barriers in adoption of CSA are also technological and can be quite significant. About 48 per cent of the respondents stated that they had challenges in their access to contemporary agricultural technologies like digital monitoring systems, artificial intelligence-based advisory systems, and precision farming equipment. Moreover, the poor infrastructure, such as low internet connectivity and technical support, further restrict the adoption of sophisticated technologies in agricultural activities. These constraints hinder the potential benefits of digital transformation in agriculture (Wang *et al.*, 2025; Poornima *et al.*, 2026) ^[5, 29]. Another vital issue in scaling Climate-Smart Agriculture is policy and institutional constraints. The research concludes that close to half of the respondents believe that the current agricultural policies are inadequate or poorly enforced to promote CSA adoption. The effectiveness of sustainability initiatives is diminished by fragmented policy frameworks, absence of coordination between stakeholders, and absence of monitoring mechanisms. Furthermore, merely 34% of farmers said that they were aware of government initiatives regarding climate-resilient agriculture, which signifies that policy makers are not connected to the implementation at the grassroots (Kamau *et al.*, 2025; Morkunas & Volkov, 2023) ^[15, 24]. Lastly, the application of Climate-Smart Agriculture is inclusive and constrained by social and structural factors such as gender inequality and unequal access to resources. The results indicate that access to land, finance, and information inequalities have resulted in women farmers being only 29 percent of CSA adopters. Cultural and institutional context also becomes a limitation to the decision-making processes and thus, the effectiveness of

CSA initiatives is limited. Such restrictions are indicative of the necessity to implement inclusive and equitable policies so that the gains of sustainable agriculture can be enjoyed by all societal groups (Diallo and Dossou-Yovo, 2024; Ozor *et al.*, 2025) ^[2, 21].

Government policy interventions and subsidies

The role of government policy intervention is very important in encouraging the practice of Climate-Smart Agriculture by offering financial and institutional support. This study shows that farmers who were given government subsidies had a higher chance of adopting CSA technologies than those who were not assisted (68 percent). The financial burden on farmers has been greatly reduced through subsidies on climate resistant seeds, efficient irrigation systems and other sustainable farming inputs. There are also tax incentives and low-interest agricultural loans that have led to increased investment in sustainable practices, especially among small and medium-scale farmers (Ngo *et al.*, 2025; Kamau *et al.*, 2025) ^[4, 24]. Nonetheless, the effectiveness of policy frameworks is yet to be achieved. According to the results of the study, only 42% of the interviewed farmers knew about the government policies on Climate Smart Agriculture, with only 36% having successfully benefited from them. The findings suggest some problems associated with policy dissemination, inefficient bureaucracy, and the lack of localized mechanisms that can help to achieve maximum effect from the policies implemented by the government (Morkunas & Volkov, 2023; Tesfahun *et al.*, 2026) ^[10, 15].

Capacity-building and farmer training programs

Training and capacity-building programs are vital in improving the knowledge and awareness of Climate-Smart Agriculture practices. According to the results of this study, farmers who underwent training adopted 52% more CSA practices than those who did not undergo any form of training program. Training workshops related to soil management, water conservation, and climate resilient crop cultivation methods have helped farmers cope better with environmental changes. Extension services and sharing of knowledge about innovative practices have also been instrumental in improving the practice of CSA techniques (Zhao *et al.*, 2025; Wang *et al.*, 2025) ^[1, 5]. Although training programs have helped to improve the practice of CSA, their impact remains minimal due to their low levels of adoption. According to the findings, only 39% of respondents were able to undergo training and capacity building activities related to CSA practices. The availability of inadequate resources, including infrastructure and skills, makes it difficult to increase the impact of training programs on farmers. Increasing the size of the network of trainings and integrating technology-based solutions will help to increase their effectiveness (Diallo & Dossou-Yovo, 2024; Khoza *et al.*, 2021) ^[2, 26].

Future Outcomes

Climate-Smart Agriculture is also forecasted to play a pivotal role in promoting sustainability through efficient resource utilization and minimizing ecological impact. According to the projections made from the study, CSA may potentially result in a decrease in the emission of

greenhouse gases from agricultural activities within the next ten years to about 30%-40%. The improvement in soil management and soil conservation may also boost soil fertility to approximately 25%, hence increasing the productivity of arable lands. The contributions of CSA are likely to make meaningful strides in mitigating climate change (Ahmed *et al.*, 2025; Koblianska, 2025) ^[9, 18]. One other area that stands to benefit from Climate-Smart Agriculture is water resource management. The use of precision irrigation in agriculture may minimize water use in farming practices by around 35%, while at the same time improving the efficiency of agricultural output by close to 20%. Water management is vital in areas experiencing droughts and unpredictable rainfall patterns. Ecosystem resilience will be positively affected by such improvements (Shukla *et al.*, 2025; Wang *et al.*, 2025) ^[5, 20]. From the social point of view, CSA is predicted to bring significant benefits for the wellbeing and prosperity of the rural communities. Based on the results obtained during the research, farmers' incomes are expected to be increased to about 28%-32%. In addition to that, the researchers found that food security levels might increase by approximately 26%. Such achievements can help address such issues as poverty and community's resilience to changes and threats (Datta, 2025; Diwakar & Shepherd, 2022) ^[6, 30]. The development of innovative technologies is predicted to make the process of introducing Climate-Smart Agriculture faster and more efficient. Artificial Intelligence and other digital tools will help farmers to make decisions accurately, optimizing their actions and predicting the climate situation. Thus, the level of farmers' accuracy is supposed to be increased by 45%. As digital agriculture gains momentum, the efficiency of CSA methods is also going to improve (Poornima *et al.*, 2026; Omotayo *et al.*, 2025) ^[14, 29]. As far as the development of policy and institutions is concerned, an increase in funding and governance can help increase adoption rates by almost 50%. Sustainable agriculture is expected to be prioritized by policymakers and international organizations through subsidies and incentives. In this way, the adoption rate for CSA can help achieve sustainability (Ngo *et al.*, 2025; Kamau *et al.*, 2025) ^[4, 24]. In addition to this, there will be more gender and social inclusion in CSA. Women are expected to participate in CSA initiatives at a much higher level compared to now. Their rate of participation can be estimated at around 45% due to various interventions and policy efforts aimed at fostering inclusion and empowerment. It will result in better social development (Diallo & Dossou-Yovo, 2024; Ozor *et al.*, 2025) ^[2, 21]. The outcomes associated with CSA in the future can prove to be highly significant in terms of environmental and social sustainability. The effects of resource management, technology innovation, and inclusiveness of policies can together help account for almost 75% of variance. These projections underscore the importance of continued investment, research, and collaboration to fully realize the potential of CSA in addressing global agricultural challenges (Zhao *et al.*, 2025; Aina *et al.*, 2026) ^[1, 31].

Conclusion

In summary, it can be said that the study has confirmed that Climate-Smart Agriculture can be regarded as an innovative

solution to environmental pollution as well as poverty alleviation within agricultural settings. Specifically, the research shows that CSA helps to improve the environment through enhancing the condition of soils, managing water resources and reducing the level of greenhouse gases emission while improving social development by increasing farmers' income, ensuring food security and making rural areas more resistant to different threats. Considering empirical results showing that about 65%-70% of environmental outcomes and 58%-70% of social development effects are provided by CSA, one can say that the use of this innovation allows achieving high levels of sustainability. Also, the role played by environmental sustainability in mediating environmental and social developments shows that both of these processes are interrelated and should be considered from a holistic point of view. However, despite certain challenges, for instance, lack of financial resources, poor awareness of CSA's benefits and absence of technology required to implement CSA effectively, the potential of the innovation may be realized due to policy measures and subsidies among others. Thus, the above discussion indicates that there is a dire need for joint actions on behalf of policymakers, scientists, and farmers for the implementation of CSAs for a sustainable future for agriculture globally (Zhao *et al.*, 2025; Ahmed *et al.*, 2025; Ngo *et al.*, 2025; Diallo & Dossou-Yovo, 2024) ^[2, 4, 9].

References

1. Zhao J, Ramli NN, Nawi NM, Seng KWK, Sharifuddin J. Bridging the gap between natural and social sciences: a bibliometric review of climate-smart agriculture challenges and opportunities. *Environment, Development and Sustainability*. 2025. DOI:10.1007/s10668-025-06782-4.
2. Diallo A, Dossou-Yovo ER. A gendered analysis of farmers' access to and willingness to pay for climate information services: evidence from rice farmers in Mali. *Climate Services*. 2024;35:100507-100507. DOI:10.1016/j.cliser.2024.100507.
3. Roy M, Medhekar A. Transforming smart farming for sustainability through agri-tech innovations: insights from the Australian agricultural landscape. *Farming System*. 2025;3(4):100165-100165. DOI:10.1016/j.farsys.2025.100165.
4. Ngo VM, Nguyen LH, Nguyen HH, Chen XH. Climate finance adoption in emerging markets: key enablers from a multi-stakeholder perspective. *Studies in Economics and Finance*. 2025. DOI:10.1108/SEF-09-2024-0617.
5. Wang S, *et al.* Towards digital transformation of agriculture for sustainable development in China: experience and lessons learned. *Sustainability*. 2025;17(8):3756-3756. DOI:10.3390/su17083756.
6. Datta D. Building resilient food systems in Somalia: integrated approaches for conflict and climate challenges. *Outlook on Agriculture*. 2025;54(4):346-357. DOI:10.1177/00307270251364907.
7. Vuppapapati C, Ilapakurti A, Vuppapapati S, Rajasri K, Kedari S, Vuppapapati J. Toward an environmental, social, and governance (ESG)-centric edge AI architecture for smallholder farmers. In: *Applied*

- Human Factors and Ergonomics International. 2025;199:1166-1181. DOI:10.54941/ahfe1006928.
8. Ho YS, Lwesya F. Research focuses and trends in food security: bibliometric analysis. Sustainable Development. 2026;34(S1):297-317. DOI:10.1002/sd.70171.
 9. Ahmed M, Raza MY, Malik NA. Farming the future: a transformative shift from climate-smart to climate-resilient agriculture. In: Advances in Global Change Research. 2025;79:459-481. DOI:10.1007/978-3-032-00190-0_18.
 10. Tesfahun T, Abegaz A, Abate E. Adoption, impacts, and policy challenges of watershed management practices in Ethiopia (2015-2025): a systematic review. European Journal of Sustainable Development Research. 2026;10(2):em0376-em0376. DOI:10.29333/ejosdr/17947.
 11. ElZein Z, Negm A. Overview of sustainable architecture and urban practices in cities and communities. In: Urban Sustainability. 2025:3-24. DOI:10.1007/978-981-95-1645-2_1.
 12. Benjaafar H, Berrichi A, El Jai F, Arabi M. New generation agricultural cooperatives: towards a sustainable model serving ecology and environmental preservation. E3S Web of Conferences. 2025;632:03001-03001. DOI:10.1051/e3sconf/202563203001.
 13. Beuchelt TD, Badstue L. Gender, nutrition- and climate-smart food production: opportunities and trade-offs. Food Security. 2013;5(5):709-721. DOI:10.1007/s12571-013-0290-8.
 14. Omotayo AO, Adediran SA, Omotoso AB, Olagunju KO, Omotayo OP. Artificial intelligence in agriculture: ethics, impact possibilities, and pathways for policy. Computers and Electronics in Agriculture. 2025;239:110927-110927. DOI:10.1016/j.compag.2025.110927.
 15. Morkunas M, Volkov A. The progress of the development of climate-smart agriculture in Europe: is there cohesion in the European Union? Environmental Management. 2023. DOI:10.1007/s00267-022-01782-w.
 16. Wijesekara N. Pathways to resilience aligning health, climate, and communities in the Asia-Pacific. In: Climate Change, Public Health, and Regional Security in the Indo-Pacific: From Mitigation to Adaptation. 2026:71-87. DOI:10.1016/B978-0-443-40368-2.00036-2.
 17. Alonso-Fradejas A. The third standpoint: the politics of accommodating to green agrarian extractivism. Third World Quarterly. 2026. doi:10.1080/01436597.2025.2607646.
 18. Koblianska I. Carbon economy and governance: a comprehensive study. In: Agroforestry for Monetising Carbon Credits. 2025:369-393. doi:10.1007/978-3-031-97151-8_14.
 19. Luo XS, *et al.* Inclusive development and agricultural adaptation to climate change. Current Opinion in Environmental Sustainability. 2017;24:78-83. DOI:10.1016/j.cosust.2017.02.004.
 20. Shukla S, Chaudhary K, Aahana, Phutela S, Bhutani R, Shukla SK. Smart crop varieties and precision agriculture: a way ahead for climate-resilient sustainable agriculture. In: Climate Change and Agricultural Ecosystems: Current Challenges and Adaptation. 2025:435-466. DOI:10.1016/B978-0-443-26520-4.00027-5.
 21. Ozor N, *et al.* An integrated approach to gender equality, diversity, and inclusion in the development of artificial intelligence tools in agriculture and food systems in Africa. AI and Society. 2025. DOI:10.1007/s00146-025-02722-y.
 22. Teck V, *et al.* Land use and land cover change implications on agriculture and natural resource management of Koah Nheaeak, Monduliri province, Cambodia. Remote Sensing Applications: Society and Environment. 2023;29:100895-100895. DOI:10.1016/j.rsase.2022.100895.
 23. Gartaula HN, *et al.* Food system transformation for achieving gender equality and contributing to sustainable development goals. In: The Elgar Companion to Food System Transformation for Sustainable Development. 2026:72-87. DOI:10.4337/9781035332854.00010.
 24. Kamau JN, Magutu J, Amadi H. Policy interventions for inclusive sustainable development and climate change management. In: Climate Change Management. 2025:51-68. DOI:10.1007/978-3-031-85217-6_4.
 25. Yoshizumi M, Miyaguchi T. Conclusion. In: Navigating Local Sustainability in Food, Community, and Innovation: From Grassroots to Global. 2025:231-234. DOI:10.1007/978-981-96-8963-7_14.
 26. Khoza S, de Beer LT, van Niekerk D, Nemakonde L. A gender-differentiated analysis of climate-smart agriculture adoption by smallholder farmers: application of the extended technology acceptance model. Gender, Technology and Development. 2021;25(1):1-21. DOI:10.1080/09718524.2020.1830338.
 27. Aura CM, Awandu H, Musa S, Ntiba MJ. An approach for the assessment of climate smart technologies for fisheries and aquaculture in an Afrotropical system. Aquaculture, Fish and Fisheries. 2026;6(2):e70199-e70199. DOI:10.1002/aff2.70199.
 28. Shanzuwa S, *et al.* Effects of climate-induced drought on livestock production and market dynamics in Mazabuka district of Zambia. Frontiers in Sustainable Food Systems. 2026;10:1776530-1776530. DOI:10.3389/fsufs.2026.1776530.
 29. Poornima J, *et al.* Artificial intelligence for sustainable future leveraging technology for a better world. In: Studies in Systems, Decision and Control. 2026;645:931-941. DOI:10.1007/978-3-032-10016-0_74.
 30. Diwakar V, Shepherd A. Sustaining escapes from poverty. World Development. 2022;151:105611-105611. DOI:10.1016/j.worlddev.2021.105611.
 31. Aina YA, *et al.* Trajectories of circular economy in cities: key patterns and emerging pathways. Cities. 2026;172:106852-106852. DOI:10.1016/j.cities.2026.106852.