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Climate-Smart Agricultural Finance (CSAF): A model for sustainable investments in agriculture

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Abstract

Climate-Smart Agricultural Finance (CSAF) integrates environmental risk assessments into agricultural lending models to promote sustainability and climate resilience. This paper explores the significance of CSAF in mitigating climate-related risks, improving farm productivity, and enhancing long-term economic stability for both farmers and investors. It outlines the mechanisms through which CSAF promotes sustainable agriculture, such as the use of green bonds, sustainability-linked loans, and carbon credit financing. Additionally, it analyzes the benefits of CSAF, including improved climate resilience, risk mitigation, and financial returns for investors. The paper concludes with recommendations for improving CSAF models, emphasizing financial inclusion, enhanced data collection, and public-private partnerships to promote wider adoption. CSAF offers a promising path toward building a more sustainable and resilient agricultural sector in the face of climate change.

Keywords: Climate-Smart Agricultural Finance; Sustainability; Climate Resilience; Environmental Risk Assessment; Sustainable Agriculture; Agricultural Lending

1. Introduction

1.1. Defining Climate-Smart Agricultural Finance (CSAF)

Climate-Smart Agricultural Finance (CSAF) is defined as a financial model that explicitly integrates environmental and climate risk assessments into agricultural lending and investment decisions (Lalande, 2024). Unlike traditional agricultural finance, which may prioritize short-term profitability, CSAF aims to ensure that lending supports long-term sustainability and resilience to climate change. It encourages both financial institutions and farmers to consider the environmental impact of their decisions, creating a framework in which economic activities are aligned with climate-smart outcomes (Benami, Bell, Messer, Zhang, & Cecil, 2024).

One of the key features of CSAF is its dual focus on mitigation and adaptation. Mitigation refers to reducing agriculture's contribution to climate change by promoting practices that lower greenhouse gas emissions, such as sustainable land management, agroforestry, and organic farming. On the other hand, adaptation involves adjusting agricultural practices to better cope with the changing climate, such as improving water management systems or planting drought-resistant crops. By incorporating mitigation and adaptation strategies, CSAF ensures that agricultural investments are profitable and resilient in the face of climate risks (Havemann, Negra, & Werneck, 2022).

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CSAF also involves the use of environmental risk assessments as part of the decision-making process. These assessments evaluate how vulnerable a particular agricultural project is to climate-related risks. For example, suppose a farm is located in a region prone to drought. In that case, the lender may recommend investments in irrigation systems or drought-tolerant crops. This proactive approach helps farmers reduce their exposure to climate risks while ensuring that the loan is less likely to default due to environmental factors (Aslam et al., 2021).

The integration of CSAF into agricultural finance is critical for promoting sustainable agricultural practices. Traditional agricultural finance often focuses on maximizing immediate returns, sometimes at the expense of long-term environmental sustainability. Practices such as over-reliance on chemical fertilizers, monoculture, and deforestation can provide short-term gains but lead to long-term environmental degradation, making farming systems more vulnerable to climate change. CSAF shifts the focus toward practices that are economically viable and environmentally sustainable (Advisors, 2022).

CSAF promotes practices such as regenerative agriculture, agroecology, and sustainable intensification, all of which are designed to enhance productivity while improving environmental outcomes. These practices help restore soil health, improve biodiversity, and reduce the carbon footprint of farming activities. For instance, regenerative agriculture focuses on restoring the health of degraded soils through techniques like cover cropping and crop rotation, which can sequester carbon and improve water retention. Agroecology, on the other hand, promotes biodiversity and ecosystem services as a means of improving resilience to climate shocks (Ntawuruhunga, Ngowi, Mangi, Salanga, & Shikuku, 2023).

By incentivizing such practices, CSAF helps shift agricultural systems from unsustainable, extractive models to more regenerative ones. This transition reduces the environmental impact of farming and makes agricultural systems more resilient to the impacts of climate change, such as extreme weather events, shifting growing seasons, and pests.

1.2. The Role of CSAF in Integrating Environmental Risk Assessments

One of the most innovative aspects of CSAF is its incorporation of environmental risk assessments into the lending process. Traditional agricultural lending models often overlook environmental risks, focusing instead on economic factors like projected yield, market demand, and credit history. However, as climate change becomes a more pressing concern, these factors are no longer sufficient for evaluating the long-term viability of agricultural projects. CSAF addresses this gap by requiring lenders to assess environmental risks alongside economic ones (Zebisch et al., 2021).

Environmental risk assessments involve evaluating a range of climate-related factors that could affect the success of a farming operation. These factors include climate variability, such as the likelihood of droughts, floods, or other extreme weather events, as well as long-term trends like rising temperatures and changing rainfall patterns. By considering these risks, lenders can make more informed decisions about which projects to fund and under what conditions (Tanir, Yildirim, Ferreira, & Demir, 2024). For example, a CSAF model might lower interest rates for farmers who invest in sustainable practices, such as water-efficient irrigation systems or solar-powered equipment. Alternatively, lenders might require borrowers to implement specific climate adaptation measures as a condition for receiving a loan. This approach protects the lender's investment and encourages farmers to adopt practices that improve their resilience to climate change.

CSAF also benefits financial institutions by reducing the risk of loan defaults caused by climate-related disasters. When environmental risks are not adequately considered, agricultural investments are more likely to fail in the face of extreme weather events or long-term climate shifts. By integrating environmental risk assessments into the lending process, CSAF helps mitigate these risks, ensuring that both farmers and financial institutions are better prepared for the impacts of climate change (Talari, Cummins, McNamara, & O'Brien, 2022). Finally, CSAF is critical in addressing climate change and fostering resilience in agricultural systems. Agriculture is both a contributor to and a victim of climate change, accounting for roughly 10-12% of global greenhouse gas emissions. At the same time, farmers are on the front lines of climate impacts, experiencing the effects of changing weather patterns, soil degradation, and water scarcity (Chataut, Bhatta, Joshi, Subedi, & Kafle, 2023).

2. Environmental Risk Assessments in Agricultural Lending

2.1. Identifying Environmental Risks in Agricultural Lending

The first step in addressing environmental risks in agricultural lending under the CSAF framework is to accurately identify the types of risks that could impact agricultural projects. Environmental risks are broadly categorized into acute risks and chronic risks. Acute risks refer to sudden, extreme events such as droughts, floods, hurricanes, or heatwaves,

which can immediately disrupt farming operations and reduce crop yields. Chronic risks, on the other hand, are long-term, gradual changes in environmental conditions, such as rising temperatures, changing rainfall patterns, or soil degradation. These slow-onset risks can erode the productive capacity of farms over time, leading to declining yields and reduced profitability (Raymond et al., 2020).

Climate change exacerbates both acute and chronic risks in agriculture. For example, regions that were once suitable for certain crops may no longer have the necessary climatic conditions for optimal growth, forcing farmers to shift their production methods or locations. Similarly, increased frequency and intensity of extreme weather events can cause significant damage to crops, livestock, and infrastructure. These risks directly threaten the economic viability of agricultural projects, making it essential for lenders to consider them when making financing decisions (Nhemachena et al., 2020).

Under the CSAF framework, identifying these risks involves using climate models and environmental data to predict how future climate conditions may impact specific agricultural projects. Climate models provide insights into the potential frequency and severity of extreme weather events, while environmental data—such as soil quality, water availability, and temperature trends—help assess the long-term sustainability of farming operations in different regions. By leveraging these tools, financial institutions can better understand the environmental context in which a farm operates, allowing them to make more informed lending decisions (Aragón, Oteiza, & Rud, 2021).

2.2. Evaluating Environmental Risks in Agricultural Lending

Once environmental risks have been identified, the next step is to evaluate their potential impact on the agricultural project and determine the level of risk exposure. This evaluation process is critical because it influences whether a loan is approved and under what conditions. Financial institutions evaluate environmental risks by considering several key factors, including the farming operation's vulnerability, the farmer's adaptive capacity, and the likelihood of climate-related events affecting the project (Wu, Li, Liu, & Tong, 2021).

Vulnerability assessment focuses on determining how susceptible a farming operation is to environmental risks. For instance, farms located in low-lying areas may be more vulnerable to flooding, while those in arid regions may face higher risks from drought. The type of crop or livestock being produced also plays a role in determining vulnerability; certain crops are more sensitive to temperature changes or water availability than others. By understanding the specific vulnerabilities of a farm, lenders can assess the potential for financial loss due to environmental factors (Ho, Kuwornu, Tsusaka, Nguyen, & Datta, 2021).

In addition to vulnerability, the adaptive capacity of the farmer is another crucial consideration. Adaptive capacity refers to the ability of the farmer to adjust their practices in response to environmental risks. This can include adopting new technologies, such as drought-resistant seeds or precision irrigation systems, as well as improving farm management practices, such as diversifying crops or improving soil health. Farmers with higher adaptive capacity are better positioned to manage environmental risks, reducing the likelihood of financial losses and improving the project's overall sustainability (Chepkoech, Mungai, Stöber, & Lotze-Campen, 2020).

Lenders also evaluate the likelihood of climate-related events affecting the farming operation. This involves assessing the probability of extreme weather events or long-term climate shifts occurring in the region where the farm is located. For example, suppose climate models predict a high likelihood of increased drought in a particular region. In that case, lenders may view this as a significant risk factor. However, suppose the farmer has invested in irrigation infrastructure or other adaptive measures. In that case, the lender may deem the risk to be manageable (Brunetti et al., 2022).

2.3. Tools for Assessing Environmental Risks

Various tools and methodologies are available for assessing environmental risks within the CSAF framework. These tools help financial institutions gather and analyze the data needed to make informed decisions about lending to agricultural projects. Key tools include geospatial analysis, climate risk indices, and scenario planning. Geospatial analysis uses satellite imagery and geographic information systems (GIS) to evaluate environmental conditions in specific areas (Pomortseva, Kobzan, Yevdokimov, & Kukhar, 2020). For example, satellite data can be used to monitor soil moisture levels, crop health, and water availability. This data helps lenders assess the environmental conditions of a farm in real-time, allowing them to identify potential risks before they escalate into financial losses. Geospatial analysis is particularly useful for monitoring large-scale agricultural projects or farms located in remote areas, where traditional methods of data collection may be difficult (Tsatsaris et al., 2021).

Another tool commonly used in CSAF is the climate risk index. This index quantitatively assesses a farm's exposure to climate-related risks. It takes into account factors such as the frequency of extreme weather events, long-term temperature trends, and the availability of natural resources like water. By providing a numerical score, the climate risk index allows lenders to easily compare the risk levels of different projects and make more objective decisions about which ones to fund (Gerlak et al., 2021).

Scenario planning is another tool that plays an essential role in environmental risk assessments. Scenario planning involves creating multiple hypothetical future scenarios based on different climate change projections. For example, one scenario might assume moderate climate change impacts, while another assumes more severe impacts. By exploring how a farming operation might perform under different scenarios, lenders can better understand the range of possible outcomes and make more resilient financing decisions (Lumeng & Jianguo, 2022).

2.4. Influence of Environmental Risk Assessments on Lending Decisions

Environmental risk assessments significantly influence lending decisions in the context of CSAF. Once risks are identified and evaluated, financial institutions use this information to determine the terms and conditions of loans. For instance, a project with high environmental risk might receive a loan with higher interest rates to compensate for the increased likelihood of default. Alternatively, the lender might require the farmer to implement specific risk mitigation measures—such as installing irrigation systems or switching to more climate-resilient crops—before the loan is approved (Van Greuning & Bratanovic, 2020).

In some cases, environmental risk assessments might lead to the outright rejection of a loan application if the risks are deemed too high. For example, suppose a farm is located in a highly vulnerable region to frequent droughts, and the farmer lacks the resources or capacity to adapt. In that case, the lender may decide the project is not financially viable. This ensures that financial institutions are not investing in projects likely to fail due to environmental factors, protecting both the lender's capital and the farmer's livelihood (Belova, Posadneva, Plaksa, Tesalovsky, & Volkodavova, 2023). On the other hand, projects with lower environmental risk or higher adaptive capacity may receive more favorable loan terms. For example, a farm invested in renewable energy or water-efficient technologies might be rewarded with lower interest rates or longer repayment periods. This reduces the farmer's financial burden and incentivizes the adoption of sustainable practices that enhance the farm's resilience to climate change (Huang, Kerstein, Wang, & Wu, 2022).

3. Mechanisms for Promoting Sustainability through CSAF

3.1. Green Bonds in Agricultural Finance

Green bonds are among the most innovative financial instruments used within the CSAF framework. Green bonds are fixed-income security designed to raise capital for projects with a positive environmental impact. Green bonds can finance a wide range of sustainable practices in agriculture, including renewable energy installations, water conservation systems, and organic farming initiatives. By issuing green bonds, financial institutions can direct funds specifically toward projects that contribute to environmental sustainability while providing a return on investment for bondholders (Zhao et al., 2022).

Green bonds play a crucial role in promoting environmentally responsible farming practices. For example, a farm might issue green bonds to finance the installation of solar panels, reducing its reliance on fossil fuels and lowering its carbon footprint. Alternatively, green bonds might be used to fund the development of more efficient irrigation systems, helping farmers conserve water in regions affected by drought. These investments improve the farm's sustainability and make it more resilient to the impacts of climate change (Versal & Sholoiko, 2022).

One of the advantages of green bonds is that they can attract a wide range of investors, including institutional investors and individuals who are interested in supporting sustainable development. This influx of capital helps to scale up investments in sustainable agricultural practices, allowing more farmers to adopt technologies and methods that reduce environmental degradation. Moreover, because green bonds are tied to specific environmental outcomes, they provide a clear and measurable way for investors to track the impact of their investments, making them an attractive option for those looking to contribute to climate-smart agriculture (Environment & Secretariat, 2023).

3.2. Sustainability-Linked Loans

Sustainability-linked loans (SLLs) are another important financial instrument within the CSAF framework. Unlike traditional loans, which are typically based solely on the borrower's creditworthiness, SLLs tie the interest rates and loan terms to the borrower's ability to meet specific sustainability targets. These targets can include reducing

greenhouse gas emissions, improving water efficiency, or adopting regenerative farming practices. Suppose the borrower meets or exceeds these sustainability goals. In that case, they may benefit from lower interest rates or more favorable loan terms. Conversely, failure to meet these targets can result in higher interest rates or other financial penalties (Pohl, Schüler, & Schiereck, 2023).

SLLs provide a powerful incentive for farmers to adopt sustainable farming practices. By tying financial benefits to environmental outcomes, SLLs encourage farmers to proactively reduce their environmental impact. For example, a farmer who commits to reducing their farm's carbon emissions by a certain percentage might receive a lower interest rate on their loan, making investing in energy-efficient equipment or switching to renewable energy sources more affordable. This helps the farmer save money and contributes to broader efforts to mitigate climate change (Du, Harford, & Shin, 2023).

One of the key strengths of SLLs is their flexibility. Unlike green bonds, which are typically used to fund specific projects, SLLs allow farmers to use the loan for general purposes, provided they meet their sustainability targets. This flexibility makes SLLs particularly appealing to farmers who may need financial support for a variety of operational needs while also working toward sustainability goals. Additionally, because the financial benefits of SLLs are directly tied to environmental performance, they encourage continuous improvement, pushing farmers to adopt more sustainable practices over time (Chan, 2021).

3.3. Carbon Credit Financing

Carbon credit financing is another mechanism within CSAF that promotes sustainable agriculture by creating financial incentives for reducing greenhouse gas emissions. Under this system, farmers who adopt practices that sequester carbon or reduce emissions—such as reforestation, soil carbon sequestration, or methane reduction—can earn carbon credits. These credits can then be sold on carbon markets, providing an additional source of income for the farmer. Carbon credit financing encourages farmers to adopt more sustainable practices and helps offset the carbon emissions of other sectors, contributing to global efforts to combat climate change (Lokuge & Anders, 2022).

For instance, a farmer who practices conservation tillage—a method that minimizes soil disturbance and promotes carbon sequestration—can earn carbon credits based on the amount of carbon captured by the soil. These credits can then be sold to companies or individuals looking to offset their own carbon emissions. This creates a win-win situation in which the farmer benefits financially from sustainable practices while contributing to climate mitigation efforts (Khatri-Chhetri et al., 2021).

Carbon credit financing also helps to bridge the gap between environmental sustainability and economic viability. Many farmers are hesitant to adopt sustainable practices because of the upfront costs involved, such as purchasing new equipment or altering their farming techniques. However, by generating additional income through the sale of carbon credits, farmers can offset these costs and make sustainability more financially feasible. This creates a positive feedback loop in which sustainable practices lead to increased financial returns, encouraging further investment in sustainability (Agrawal et al., 2024).

In addition to carbon credit markets, some governments and international organizations offer carbon offset programs that provide financial incentives for farmers to reduce their emissions. These programs often provide technical assistance and funding to help farmers implement climate-smart practices, further encouraging the adoption of sustainable agriculture. By participating in these programs, farmers contribute to global climate goals and improve the long-term sustainability of their operations (Batra, 2023).

3.4. Policy Support for CSAF Mechanisms

While financial instruments like green bonds, SLLs, and carbon credit financing are essential for promoting sustainability within the CSAF framework, they are most effective when supported by government policies and regulatory frameworks. Governments can play a critical role in encouraging sustainable agriculture by providing financial incentives, setting regulatory standards, and offering technical assistance to farmers. For example, governments can offer tax credits or subsidies for farmers who invest in renewable energy or water conservation systems. These incentives help to lower the financial barriers to adopting sustainable practices, making it more attractive for farmers to participate in CSAF programs (Branca, Cacchiarelli, Haug, & Sorrentino, 2022).

In addition to financial incentives, regulatory policies can help ensure that agricultural activities are aligned with environmental goals. For instance, governments can implement regulations that limit the use of harmful chemicals, promote soil conservation, or encourage the use of renewable energy in agriculture. By creating a regulatory

environment that prioritizes sustainability, governments can support the widespread adoption of CSAF mechanisms and ensure that the agricultural sector contributes to national and international climate goals (Piñeiro et al., 2020).

Furthermore, governments can collaborate with international organizations, financial institutions, and private sector actors to develop public-private partnerships that promote CSAF. These partnerships can provide farmers with access to the technical expertise, financial resources, and market opportunities they need to transition to more sustainable practices. For example, a partnership between a government agency and a financial institution might provide low-interest loans to farmers who adopt climate-smart technologies while offering technical assistance to help them implement these practices effectively (Szebini, Anyango, Orora, & Agwe, 2021).

The financial instruments and policies within the CSAF framework—such as green bonds, SLLs, and carbon credit financing—play a vital role in encouraging environmentally responsible farming practices. By providing farmers with financial incentives to adopt sustainable practices, these mechanisms help to align economic interests with environmental goals. This is particularly important in agriculture, where the upfront costs of adopting sustainable practices can be high, and the financial benefits may take time to materialize (Diop, Chirinda, Beniaich, El Gharous, & El Mejahed, 2022).

Through CSAF mechanisms, farmers are encouraged to invest in renewable energy, water conservation, soil health, and other sustainable practices that reduce their environmental impact. These investments help mitigate climate change and improve the long-term viability of farming operations, making them more resilient to environmental risks. At the same time, CSAF mechanisms help to create a more sustainable and equitable agricultural system, where farmers are rewarded for their efforts to protect the environment and contribute to global sustainability goals (Wijerathna-Yapa & Pathirana, 2022).

4. Climate Resilience and CSAF

4.1. Long-Term Sustainability for Farmers

One of the primary advantages of CSAF for farmers is its focus on long-term sustainability. Traditional agricultural finance models have often prioritized short-term gains over the long-term health of farming systems. In contrast, CSAF encourages farmers to adopt practices that preserve natural resources, reduce environmental degradation, and promote sustainability over the long term. This shift in focus benefits farmers by helping them build farming systems that are resilient to climate change and can continue to produce high-quality crops for years to come (Majeed et al., 2023).

For example, farmers who adopt conservation agriculture—a set of practices that reduce soil erosion, improve water retention, and enhance soil fertility—are better equipped to withstand the impacts of extreme weather events such as droughts or floods. By preserving the health of their soil, these farmers can maintain higher yields even in the face of climate variability, ensuring the long-term sustainability of their operations. CSAF provides financial incentives to help farmers implement these practices, making investing in the technologies and methods needed to build resilient farming systems easier (Elahi, Khalid, & Zhang, 2022).

In addition, CSAF promotes the adoption of renewable energy and energy-efficient technologies in agriculture, reducing the sector's reliance on fossil fuels and lowering greenhouse gas emissions. This not only helps to mitigate climate change but also reduces farmers' energy costs, contributing to the economic sustainability of their operations. For example, a farmer investing in solar panels to power irrigation systems can reduce their dependence on expensive and environmentally harmful diesel generators, lowering their energy bills and carbon footprint (Guno & Agaton, 2022).

4.2. Improved Resilience to Climate Change

Another critical benefit of CSAF is its role in improving farmers' resilience to climate change. Climate change is already having significant impacts on agricultural production, with rising temperatures, changing precipitation patterns, and more frequent extreme weather events all threatening the livelihoods of farmers around the world. CSAF helps farmers to adapt to these challenges by providing the financial resources and technical support they need to implement climate-smart practices that reduce their vulnerability to climate-related risks (A. O. Adewusi et al.).

One of the ways CSAF improves resilience is by encouraging farmers to adopt diversified farming systems. Rather than relying on a single crop, which can be particularly vulnerable to climate-related risks such as drought or pests, farmers are encouraged to plant a variety of crops or integrate livestock into their operations. This diversification not only helps

to spread risk but also improves the overall health and productivity of the farm. For example, integrating livestock into a crop-based farming system can provide additional income streams, reduce the need for synthetic fertilizers, and improve soil health through the recycling of nutrients (Mir et al., 2022).

CSAF also supports the use of climate-resilient crop varieties that can withstand climate change's impacts. For instance, farmers may be encouraged to plant drought-resistant crops in regions where water scarcity is a growing concern. These crops require less water to grow, making them more resilient to dry conditions and helping to ensure stable food production even during periods of drought. Similarly, farmers in flood-prone areas may be encouraged to plant flood-tolerant varieties, reducing the risk of crop losses due to flooding (Carr, Goble, Rosko, Vaughan, & Hansen, 2020).

In addition to supporting resilient farming practices, CSAF helps farmers access early warning systems and climate information services that provide timely data on weather patterns, pest outbreaks, and other climate-related risks. By having access to accurate and up-to-date information, farmers can make better-informed decisions about when to plant, irrigate, and harvest their crops, reducing their vulnerability to climate shocks (Kom, 2020).

4.3. Economic Stability and Productivity for Farmers

CSAF also offers significant economic benefits for farmers by enhancing their productivity and contributing to the economic stability of their operations. By promoting adopting climate-smart practices, CSAF helps farmers increase their yields and reduce input costs, improving their overall profitability. For example, a farmer who adopts precision agriculture technologies—such as GPS-guided tractors or remote sensing tools—can reduce the amount of water, fertilizer, and pesticides they use, lowering their input costs while maintaining or even increasing their yields (A.O. Adewusi, N.R. Chiekezie, & N.L. Eyo-Udo, 2022).

Moreover, CSAF mechanisms such as sustainability-linked loans and carbon credit financing provide additional income streams for farmers, further contributing to their economic stability. Farmers who adopt practices that sequester carbon or reduce emissions by participating in carbon markets can earn carbon credits that can be sold to companies looking to offset their own carbon footprints. This provides farmers with an additional source of income and helps make climate-smart practices more financially viable (Everhart, 2023).

By improving the environmental sustainability and economic viability of farming operations, CSAF helps farmers build more stable and resilient businesses. This stability is particularly important in the face of climate change, which can potentially disrupt agricultural production and threaten the livelihoods of millions of farmers worldwide. By providing farmers with the tools and resources they need to adapt to these challenges, CSAF helps to ensure that they can continue to produce food and support their families, even in the face of an uncertain climate future (Abobatta, 2021).

4.4. Benefits for Investors: Mitigating Risks and Maximizing Returns

While CSAF provides clear benefits for farmers, it also offers significant advantages for investors. One of the main benefits of CSAF for investors is its ability to mitigate risks. Agriculture is inherently risky, with farmers exposed to a wide range of environmental, economic, and social risks that can impact their ability to repay loans or generate returns on investment. However, by integrating environmental risk assessments into lending models, CSAF helps to reduce these risks and improve the long-term viability of agricultural investments. For example, investors can reduce the risk of crop failures or livestock losses due to extreme weather events by financing farmers who adopt climate-smart practices. Farmers who use drought-resistant crops, implement efficient irrigation systems, or diversify their farming systems are less likely to suffer significant losses during periods of drought or other climate-related disruptions. This, in turn, reduces the likelihood of loan defaults and improves the overall stability of agricultural investments (Aiguobarueghian, Adanma, Ogunbiyi, & Solomon, 2024; Kupa, Adanma, Ogunbiyi, & Solomon, 2024).

In addition to mitigating risks, CSAF offers investors the opportunity to earn competitive returns while supporting sustainable development goals. As the demand for sustainable and responsible investments grows, CSAF provides a way for investors to align their portfolios with their values while still generating financial returns (Ejairu et al., 2024; Uwaga & Nzegbule).. For example, green bonds and sustainability-linked loans give investors a return on investment while ensuring their capital is used to support environmentally responsible projects. This not only helps to attract more investors to the agricultural sector but also contributes to the broader goal of promoting sustainability in global food systems. Moreover, CSAF can help investors diversify their portfolios by providing access to various agricultural projects and markets. By investing in climate-smart agriculture, investors can gain exposure to a growing sector that is critical to the future of global food security and climate resilience. This diversification can help to reduce overall portfolio risk and provide investors with new opportunities for growth.

The cumulative benefits of CSAF for both farmers and investors contribute to enhanced agricultural productivity and global food security. As farmers adopt climate-smart practices, they are able to produce more food using fewer resources, ensuring that agricultural production can keep pace with the growing global demand for food. At the same time, CSAF helps to make agriculture more resilient to climate change, reducing the risk of crop failures and ensuring stable food supplies even in the face of environmental challenges (A.O Adewusi, N.R Chiekezie, & N.L Eyo-Udo, 2022; Adebunmi Okechukwu Adewusi, Chikezie, & Eyo-Udo, 2023; Udegbe, Nwankwo, Igwama, & Olaboye).

5. Conclusion

Climate-Smart Agricultural Finance presents a transformative approach to ensuring sustainable agricultural development while addressing the pressing challenges of climate change. By integrating environmental risk assessments into lending models, CSAF provides farmers and investors with tools to promote long-term sustainability, mitigate climate-related risks, and enhance resilience in the agricultural sector. Throughout this discussion, key benefits of CSAF have been identified, including the adoption of climate-smart practices, improved farm productivity, economic stability, and diversified financial products such as green bonds and carbon credit financing.

CSAF's role in promoting sustainability cannot be overstated. By encouraging farmers to adopt renewable energy technologies, practice conservation agriculture, and diversify their farming systems, CSAF fosters long-term resilience. It provides a path for farmers to maintain stable food production in the face of climate change while ensuring responsible resource use. From an investment perspective, CSAF offers a compelling model for mitigating risks, ensuring that agriculture remains a viable and attractive sector for funding. By aligning financial incentives with climate resilience, CSAF allows investors to participate in the growing demand for sustainable development while also earning competitive returns.

Despite these benefits, there is room for improvement in CSAF models. One key recommendation is the expansion of financial inclusion for smallholder farmers, who often lack access to the capital required to invest in climate-smart technologies. To address this, governments and financial institutions should create subsidies and grant programs that help lower these farmers' financial barriers to entry. This can enhance CSAF's reach, enabling more farmers to benefit from sustainable finance.

Another recommendation is to improve data collection and analysis to refine environmental risk assessments. By leveraging advancements in satellite technology, remote sensing, and climate data analytics, CSAF can provide more accurate, real-time information to both lenders and farmers. This would improve decision-making and ensure that investments are better targeted toward areas with the highest climate risks and potential for sustainable growth. Finally, promoting public-private partnerships can help expand CSAF adoption. Governments, financial institutions, and international development organizations should collaborate to create awareness campaigns and incentive structures that encourage broader participation in CSAF initiatives. By aligning regulatory frameworks and financial products with sustainability goals, these partnerships can facilitate widespread adoption of CSAF, ensuring that agricultural finance plays a pivotal role in building a climate-resilient future.

Compliance with ethical standards

Disclosure of Conflict of interest

The authors declare that they do not have any conflict of interest.

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