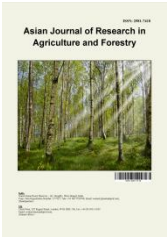

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The Sustainability of Carbon Markets for Climate-Smart Agriculture among Smallholder Farmers in Uganda

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study assesses the sustainability of Uganda's carbon markets in the context of climate-smart agricultural practices with the aim of aligning them with sustainable development goals. The research emphasizes integrating dimensions of sustainable development to proactively address food security and climate issues. Climate-smart agricultural practices that support the efficiency of small-scale farming enable farmers to generate income through the sale of carbon-related environmental services such as reduced greenhouse gas emissions and carbon sequestration. While these practices contribute to the resilience of smallholder farmers' livelihoods, challenges arise from large project volumes with low transaction costs, resulting in insufficient carbon revenues for local communities. Furthermore, limited methods and complex procedures hinder progress. The study recommends involving national or international organizations to bridge the gap between

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farmer groups and the carbon market, with a focus on government policy and private sector collaboration to incentivize environmental services. In summary, establishing sustainable, climate-smart agricultural links to the carbon market can bring co-benefits including income diversification, poverty reduction and biodiversity conservation.

Keywords: Climate-smart agriculture; carbon markets; carbon prices; smallholder farmers.

1. INTRODUCTION

The United Nations Food and Agriculture Organization (FAO) noted at the 2010 Hague Conference on Agriculture, Food Security and Climate Change (FSCC), Climate-Smart Agriculture (CSA) is critical to achieving sustainable development goals worldwide. Through simultaneously addressing food security and climate-related difficulties, this method successfully integrates economic, social and environmental elements [1]. Following a three-pronged model, CSA prioritizes sustainably increasing agricultural incomes and productivity, promoting climate change adaptation and resilience, and reducing or eliminating greenhouse gas emissions wherever possible.

CSA helps to concretize the goals of sustainable development. The three dimensions of sustainable development take food security and climate concerns into account in a forward-looking perspective [2]. CSA is guided by principles that aim to increase resource efficiency and resilience in agriculture. The importance of CSA in achieving sustainable development goals is widely recognized. However, there is a clear knowledge gap regarding the real barriers that smallholder farmers face when implementing CSA methods. Therefore, a thorough investigation of the sustainability of carbon markets for CSA among smallholder farmers is needed [3].

Many agricultural, agricultural and forestry management systems and practices, such as sustainable land management, integrated food-energy systems and agroforestry, are climate-smart [4]. Some of the adopted CSA technologies or practices increase soil and aboveground biomass carbon content and improve productivity and resilience [5]. The side effect of climate mitigation and adaptation can be improved through integrated landscape management by exploiting the climate mitigation opportunities of a particular landscape through increased biomass production. CSA is neither a new agricultural system nor a set of practices. It is a new approach, a way to drive the necessary changes in agricultural systems given the need to jointly address food security and climate change. CSA shares the goals and guiding principles of sustainable development and the green economy. The aim is to increase food security and contribute to the conservation of natural resources [6]. In addition, there is a close connection with the concept of sustainable intensification, developed entirely for crop production by the FAO and now being extended to other sectors and a food chain approach.

The four essential components of food safety availability, accessibility, use and stability are considered by CSA. However, there is a clear knowledge gap about the complex interactions between production-focused CSA, farmer-focused policies and highlighted food security issues. Although the main goals of CSA are to increase incomes, stabilize the economy, and increase productivity, the methods and tactics used to achieve these goals are not as well understood [7]. To close this gap, a more in-depth study of the realistic pathways and difficulties associated with integrating CSA concepts into smallholder farms is required. Furthermore, there may be synergies between CSA and sustainable crop production intensification (SCPI), although further research is needed to determine the precise connections and complementary characteristics of the two ideas.

Within the CSA paradigm, Carbon Market (CM) intervention is an example of a proactive tactic that aims to stimulate immediate action in support of a transformation process that will eventually take place. The CSA approach addresses the urgent question: “What steps can be taken now to achieve a more sustainable future in agriculture in the face of climate change?” as opposed to imagining an idealized future system of sustainability [8]. The focus is on realistic measures adapted to the current agroecological, socio-economic and political situation, and not just on imagining future aspects. This method involves developing transition plans that identify significant opportunities to begin the process while

realistically considering current constraints [9]. Nevertheless, in many situations there is a significant knowledge gap regarding the reproducibility and scalability of effective transition tactics. To address this gap, contextual factors that influence the effectiveness of CSA interventions and facilitate the development of adaptive and widely applicable strategies for sustainable agriculture under changing climate conditions need to be comprehensively investigated (10).

The CM policy was initiated under the CDM systems and established under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) to combat climate change. Reduced Degradation and Desertification (REDD+) was a collaborative project between three UN agencies, the FAO, the United Nations Environment Program (UNEP) and the United Nations Development Program (UNDP), to pay countries to keep rainforests pristine. UNFCCC, which was initially not interested in considering REDD+, actually did so under pressure from other UN agencies. However, Uganda has developed a strategy to access carbon funds from various programs. In 2006, the Uganda Carbon Bureau, the only full-service carbon company, was registered. Among other things, it provides carbon credits, provides information on climate change and carbon markets, and maintains close relationships with Uganda's major donors and international NGOs working on the dynamics of climate change and carbon finance.

CSA programs serve two purposes: they mitigate the impacts of climate change and provide critical adaptation strategies. These methods can be easily integrated into the broader agricultural development agenda [11], which, in addition to financial incentives, is based on the fundamental goal of improving the efficiency and sustainability of small-scale agriculture. Regardless of external incentives, the implementation of CSA practices has the potential to significantly increase the resilience of smallholder farmers and diversify their income sources [12]. The growth of the carbon market and the dynamics of future demand and pricing for environmental credits will play a critical role in achieving these benefits. It is critical to create payment for environmental services (PES) programs that engage stakeholders at national and regional levels and establish strong connections between local actions within farmers and community organizations to ensure the sustainability of such projects. Farmers combine their efforts on small farms to create quantities sufficient for market transactions and act as sellers who generate carbon [13]. Conversely, national and regional stakeholders including businesses, governments and non-governmental organizations (NGOs) play a critical role in supporting the viability and scalability of climate-smart agricultural practices, either by financing carbon credits or controlling carbon trading. However, there is a research gap in understanding the long-term sustainability and equity impacts of these market-driven mechanisms, which warrants further investigation into their socioeconomic and environmental impacts. Closing this gap will help refine and optimize the design of payment systems and ensure their effectiveness in supporting smallholder systems, while aligning with broader climate and sustainability goals.

CSA aims to increase soil organic carbon through improved efficiency and resilience of the carbon market. The carbon improves nutrient and water uptake by plants, which increases yields and resource efficiency of land, nutrients and water. It also reduces soil erosion and increases water retention in conservation agriculture [14]. This combination makes the system more resilient to fluctuations in precipitation and extreme events. Increasing carbon sinks in soils also sequester carbon, helping to mitigate climate change. For all these reasons, restoring degraded land and increasing organic carbon content in soils is a priority action. All of this will increase the content of carbon sinks, thereby increasing the size of carbon markets.

The fact that programs led by carbon buyers and brokers often produce large volumes with low transaction costs and less uncertainty represents one of the biggest challenges for CSA. But the more farms that participate, the more complicated it is to aggregate the sequestered carbon drives up transaction costs and increases uncertainty. As a result, the amount of carbon revenue paid to surrounding cities or farmers is typically insufficient. Insufficient capacity also leads to problems in implementing, monitoring and reviewing projects. The complicated processes associated with carbon sequestration require consultation from trained specialists, which increases the overall cost. Further development of agricultural soil carbon sequestration programs is hampered by the limited number of approved methods and complex procedures [15]. Although projects use

both independent assessments and self-reports, the organization reviews the annual reports submitted to Plan Vivo through a review process and sporadic site visits, with independent third parties conducting the review [16]. The cost of Carbon stock is still relatively low, which is the prevailing concern despite the large co-benefits associated with it.

2. CONTRIBUTION OF CARBON PROJECTS TO SUSTAINABLE DEVELOPMENT IN UGANDA

In Uganda, Blum [17] notes that carbon initiatives are essential for sustainable development as they promote both economic empowerment and environmental protection. Initiatives that focus on reforestation, for example, improve biodiversity, protect watersheds and sequester carbon. Yet there are significant differences in the way local communities share the profits fairly. The economic and environmental benefits of carbon projects are often limited for marginalized communities because larger landowners or certain groups tend to receive more of these benefits. In order to close this inequality, inclusive methods must be implemented that ensure a fair distribution of benefits. This will improve the overall impact on sustainability by teaching climate-smart farming techniques to small-scale farmers. Carbon programs in the Ugandan agricultural sector support sustainable development. For example, initiatives that support agroforestry and sustainable land management techniques improve soil fertility and water retention, while also sequestering carbon. However, a significant shortcoming is that these programs rarely take gender-specific strategies into account. For the reason that they are heavily involved in agriculture, women often face obstacles when trying to participate in and benefit from carbon projects. Developing and implementing programs that specifically address the unique needs and difficulties of women farmers is necessary to close the gender gap while ensuring equal benefits and active participation [18].

Cooperative, community-led carbon offset activities under the CSA paradigm. Smallholder farmers actively participate in business-oriented activities in the voluntary carbon market [19]. Michaelowa et al. [18] praises these initiatives for their clever combination of improving rural life through carbon sequestration and small-scale, farmer-led forestry or agroforestry initiatives. This strategy promotes environmental and economic sustainability while reducing the strain on natural resources. By applying diverse land use practices, project participants improve food security, preserve biodiversity, sequester carbon and conserve watersheds. Suggested techniques include planting orchards and growing mixed forests with native or naturalized tree species. Interestingly, individual farmers own the carbon credits, but they choose to sell them collectively through group marketing campaigns. The International Small Group and Tree Planting Program (TIST) and Trees for Global Benefits (TGB) have evolved into self-financing mechanisms. These methods use the market to stimulate cash flow and increase the number of farmers participating in forestry initiatives by providing farmers with upfront funds to start such programs [20].

The carbon programs aim to increase the yields of rural agricultural communities while halting the unsustainable exploitation of forest resources and the degradation of ecosystem quality. This serves as a creative financial tool that motivates farmers to engage in ventures that generate long-term income. This improves the health of the ecosystem and partially reverses the destruction of the ecosystem. At the same time, funds are provided to recoup investments, increase engagement and promote diversity. Farmers who participate are typically paid to increase carbon stocks on their property. Due to the payment structure, farmers are able to use part of their property for asset development and consider it in terms of long-term investments [21,22]. These assets provide long-term benefits from trees in addition to immediate cash from annual crops.

The carbon programs work with existing community organizations to motivate farmers and provide ongoing monitoring of land management plans [23]. Farmers in the target communities participate in workshops and training to identify which forestry farms best meet their needs [24]. Small farmers register and then sign sales contracts specifying the terms and amounts. New regions that need financing, technical specifications and market prospects are found through farmer groups. Carbon projects and companies pool the credits of different farmer groups and negotiate prices directly or through brokers on behalf of the farmers [25]. This guarantees access to the market for small farmers who normally do not have such opportunities. By helping local institutions become more efficient, these companies also

help farmers diversify their sources of income and improve their ability to withstand the effects of climate change and achieve sustainable development through institutional financing and capacity, sector cooperation, management techniques, policy implementation Measures and legal actions to advance compliance in line with Turyasingura et al. [26].

2.1 Causes of Low Carbon Payments among Farmers Using CSA in Uganda

The limited availability of carbon markets is a key factor contributing to Ugandan farmers practicing CSA payments for low carbon emissions [27]. Many farmers, particularly smallholders, struggle to navigate complex carbon trading markets. Their inability to reap the benefits of carbon sequestration projects is complicated by their lack of knowledge and resources to participate in these markets. Farmers miss out on potential revenue streams when there is no clear way to link their green operations to carbon credits, resulting in lower carbon payments [28]. The lack of reliable procedures for monitoring and verifying CSA initiatives is another important factor [29]. Carbon sequestration or quantifiable and verifiable emissions reductions are often linked to carbon credits. In Uganda, uncertainty arises due to the lack of trustworthy tools and methods to accurately track and validate these results. Both buyers of carbon credits and investors need to be aware of the environmental impact of the projects they finance. The lack of reliable procedures for monitoring and verifying CSA initiatives is another important factor [29]. Carbon sequestration or quantifiable and verifiable emissions reductions are often linked to carbon credits. In Uganda, uncertainty arises due to the lack of trustworthy tools and methods to accurately track and validate these results. Both buyers of carbon credits and investors need to be aware of the environmental impact of the projects they finance. Lower carbon payments arise because without such mechanisms, farmers struggle to demonstrate the value of their climate-friendly actions.

Another challenge to receiving enough carbon payments in Uganda is the financial capacity of Ugandan farmers [2]. Implementing CSA methods often requires upfront investments in sustainable technologies, crop diversification and better land management. For many farmers, making these initial investments is difficult, especially for those with minimal resources. Adoption of climate-smart practices slows when adequate financial support or incentives are not in place, reducing the overall impact on carbon sequestration and ultimately reducing farmers' carbon payments [30].

The idea of pricing greenhouse gas emissions and establishing a market-based pricing mechanism through certificate trading offers a powerful climate financing instrument despite all the challenges associated with its implementation [14]. A significant portion of foreign funding for CSA initiatives could come through carbon markets. But for at least 20 years there has been an ongoing debate about whether or not carbon credits for reducing agricultural greenhouse gases should be included in compliance with carbon markets. The challenges of maintaining environmental integrity in terms of potential leaks, unclear durability, and the additionality of greenhouse gas reductions are some of the concerns. Another factor contributing to Ugandan farmers' participation in CSA low-carbon payments is the lack of regulatory frameworks and supportive policies. Creating a favorable environment for carbon trading can be hampered by a lack of government policies and incentives. Policies that recognize and provide incentives for farmers' sustainable efforts are needed. Without such frameworks, the carbon market is unpredictable, making it difficult for farmers to raise capital and negotiate advantageous terms for the carbon credits they produce.

Low carbon payments are the result of a lack of knowledge and education about the benefits of CSA and participation in carbon markets. Many farmers may be unaware of the potential financial benefits of implementing climate-smart techniques and participating in carbon trading [31]. Missed opportunities can result from ignorance of the value of carbon credits and how the market works. Improving carbon payments for Ugandan farmers requires educating them about the financial and environmental benefits of their practices and giving them the know-how to participate in carbon markets.

2.2 Strategies for Sustainable Carbon Markets for Small Scale Farmers Practicing CSA

In order for carbon markets to remain stable, institutional and corporate reforms of the agricultural and food system must be supported. In order for small farmers, fishermen and

pastoralists to increase their productivity, these changes require strong support from the public and commercial sectors. The importance of these changes is underlined by the resulting economic growth and job creation, particularly in rural areas and countries with a strong agricultural sector. The need for innovative methods, tools and services that small farmers, pastoralists, fishermen and foresters can access both financially and physically [32]. This accessibility creates opportunities for neighborhood businesses to meet farmers' needs when CSA techniques are implemented. Information about weather, temperature and agricultural opportunities is quickly shared by local organizations and institutions, which are essential to the dissemination of technical knowledge.

For carbon markets to thrive, financial services and market access must be considered. By providing credit, insurance, safety nets and incentives for environmental services, efficient microfinance channels are crucial to encourage farmers to adopt new technologies, practices and attitudes. Important elements include strengthening small farmers' market knowledge, linking them to national and international markets and stimulating local markets. The dynamics of international climate finance favor CSA and provide opportunities to convert public and private investments in agriculture into CSA investments. Integrating strategies and raising international finance for projects are necessary to overcome the obstacle of dispersed climate finance sources, particularly in the context of clean energy (CSA) [33]. The global climate problem is highlighted by the crucial role of agriculture in adapting to climate change and its contribution to greenhouse gas emissions.

Underdeveloped financial channels may provide limited support, although progress is being made, as demonstrated by the continued emphasis on CSA operations in public financing, such as the GEF-6 replenishment. This dynamic could impact the Green Climate Fund design process in the medium term and open the door to more CSA funding. Developing countries need to address prerequisites such as data quality, monitoring mechanisms, institutional capacity and policy frameworks to effectively utilize increased international CSA support [34]. A solid foundation can be built by bridging gaps in the agricultural sector, leveraging current knowledge and experience, and leveraging climate change prioritization and assessment. Developing countries should take the initiative to create the necessary framework to take advantage of new opportunities in carbon markets and gain a lead in clean energy.

3. CONCLUSION AND RECOMMENDA-TIONS

In conclusion, there is a great deal of promise for Both environmental and financial benefits from sustainability of carbon markets for CSA among Ugandan smallholder farmers. It is important that the Ugandan government, foreign organizations and local actors work together to provide comprehensive assistance and ensure its longevity and positive impact. It is imperative to strengthen institutional frameworks, improve access to financial services and promote knowledge sharing. In addition, specific capacity building initiatives need to be implemented to enable smallholders to play an active role in carbon markets. It will be crucial to have systems in place for ongoing monitoring and assessment to be able to change plans if necessary.

Integrating carbon projects into Uganda's sustainable development framework represents a viable approach to mitigating environmental challenges and promoting economic expansion. To optimize these benefits, coordinated efforts are needed to align carbon projects with broader sustainable development goals. To ensure successful project implementation, collaboration between government organizations, non-profit organizations and commercial companies is essential. Additionally, a transparent and inclusive strategy for distributing carbon payment revenue is essential, with a focus on equitably distributing benefits to surrounding communities. This not only increases the overall impact of carbon programs, but also supports Uganda's long-term sustainable development.

Identifying low-carbon payments among Ugandan farmers using CSA highlights key issues that need to be addressed for these programs to be successful. Stakeholders are recommended to thoroughly review current payment systems to ensure that they adequately compensate farmers for their actual environmental contributions in order to address this issue. Improving data collection and verification procedures and open and fair pricing structures can help address existing barriers. There is a need for increased emphasis on capacity building initiatives so that farmers understand the importance of their inputs and are

given the tools they need to interact more successfully with carbon markets.

Smallholder farmers pursuing CSA require a multi-pronged approach. It is imperative to develop and implement policies that consider the unique challenges faced by smallholder farmers and create an enabling environment for their participation. Governments, together with international organizations, should invest in building robust monitoring and verification systems to ensure the credibility of carbon credits. Additionally, incentivizing the adoption of CSA practices through targeted financial support and capacity building initiatives will contribute to the resilience and long-term success of carbon markets. Emphasizing community engagement and stakeholder collaboration will be instrumental in creating a sustainable ecosystem that benefits both farmers and the environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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