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Comparative Analysis of Carbon Sequestration Solutions in Sub-Saharan Africa a Systematic Review of Economic Implications and Challenges

[1]Bealo Deebari Brownson, [2]Onwunaru Onisokonikume Victory, [3]Akpi Ayakpo
[4]Ntor Charles
[1,2,3,4]*Department of Environmental Management, Federal University of Environment and Technology, Ogoni*

***Abstract*—Sub-Saharan Africa (SSA) faces a dual challenge: contributing minimally to global greenhouse gas emissions while bearing disproportionate climate change impacts, yet possessing vast natural capital for carbon sequestration. This systematic review provides a comparative analysis of carbon sequestration solutions in SSA, examining agroforestry systems, conservation agriculture, forest restoration (including REDD+), soil carbon management, biochar application, and grassland management. Drawing on over 145 peer-reviewed studies and systematic reviews published between 2000–2026, we synthesize evidence on sequestration potentials, economic viability, and implementation challenges across diverse agroecological zones. Results indicate that agroforestry systems offer substantial carbon sequestration potential (0.5–15 t C ha^{-1} yr^{-1}) alongside livelihood co-benefits, while conservation agriculture shows equivocal evidence for soil carbon enhancement unless all three principles are fully applied. REDD+ initiatives face persistent challenges in benefit-sharing, with local communities often receiving less than 5% of net proceeds. The global carbon market is projected to reach $100 billion annually by 2030, yet Africa supplies 20% of credits while capturing merely 5% of proceeds. Key barriers include insecure land tenure, inadequate monitoring and verification systems, limited technical capacity, governance inefficiencies, and insufficient climate finance with Africa facing a $2.5–2.8 trillion climate finance gap by 2030. The study conclude that no single solution suffices; effective carbon sequestration in Sub-Saharan Africa (SSA) requires integrated, context-specific approaches that prioritize community participation, secure tenure rights, robust measurement frameworks, and equitable benefit-sharing mechanisms.**

***Index Terms*—Carbon sequestration, Sub-Saharan Africa, agroforestry, REDD+, soil organic carbon, carbon markets, climate finance, systematic review**

I. INTRODUCTION

Sub-Saharan Africa (SSA) encompasses approximately 650 million hectares of forest, vast savanna ecosystems, and diverse agricultural landscapes that collectively represent one of the world's most significant terrestrial carbon sinks. The region's ecosystems, including the Congo Basin peatlands which store an estimated 30 billion metric tons of carbon—equivalent to three years of global fossil fuel emissions play a critical role in global climate regulation. Yet these essential ecosystems are increasingly threatened by widespread degradation, deforestation, and agricultural expansion, which have transformed parts of the region from carbon sinks into carbon sources.

Climate change poses existential threats to Sub-Saharan Africa (SSA), where smallholder agricultural systems supporting 500 to 600 million farmers face unprecedented challenges from rising temperatures, shifting rainfall patterns, and increased frequency of extreme weather events. Paradoxically, the region that contributes least to global emissions bears some of the heaviest climate costs while receiving a disproportionately small share of adaptation and mitigation finance. Africa's climate finance needs are estimated at $2.5–2.8 trillion by 2030, yet the most vulnerable countries receive far less than their proportional share of adaptation finance.

Carbon sequestration the process of capturing and storing atmospheric carbon dioxide in vegetation, soils, and other reservoirs has emerged as a critical climate change mitigation strategy. Sub-Saharan Africa (SSA) offers substantial opportunities for nature-based carbon sequestration through forest conservation, agroforestry, sustainable agriculture, and land restoration. The "4 per 1000" initiative, launched at COP21 in Paris, aspires to increase global soil organic carbon stocks at a rate of 0.4% per year, a goal with particular relevance for SSA's degraded agricultural soils.

However, the implementation of carbon sequestration solutions in Sub-Sahara Africa(SSA) faces numerous challenges: insecure land tenure, limited technical capacity, weak governance, inadequate monitoring and verification systems, and inequitable benefit-sharing mechanisms. The voluntary carbon market, projected to expand from $2 billion in 2020 to $100 billion by 2030, presents both opportunities and risks for the region. Critics warn that Africa's growing carbon economy risks becoming another form of exploitation, where developed nations "buy their way out" of emissions reductions while African communities bear the ecological burden.

1.1. Objectives

This systematic review aims to:

- Synthesize the current evidence on carbon sequestration potentials of major solutions in SSA
- Compare the effectiveness, costs, and co-benefits of different sequestration approaches

- Analyze the economic implications, including carbon market participation and climate finance
- Identify key challenges and barriers to implementation
- Provide evidence-based recommendations for policymakers and practitioners

1.2. Scope and Definitions

For this review, "carbon sequestration solutions" encompass nature-based approaches including agroforestry systems, conservation agriculture, forest restoration and REDD+, soil organic carbon management, biochar application, and grassland management. The geographic scope covers all Sub-Saharan African countries, with particular attention to East, West, and Southern African case studies where evidence is most abundant.

II. MATERIALS AND METHODS

2.1 Systematic Review Protocol

This review follows the systematic review methodology established in comparable studies on carbon sequestration in Sub-Sahara Africa (SSA). The study employed a structured approach comprising four distinct stages: article selection criteria definition, systematic search strategy, data extraction, and synthesis of findings.

2.2 Search Strategy

We conducted systematic searches across multiple academic databases including Google Scholar, Scopus, ISI-Web of Science, and Agris. Search terms applied to article titles, abstracts, and keywords using Boolean operators included combinations of: "carbon sequestration," "Sub-Saharan Africa," "agroforestry," "conservation agriculture," "REDD+," "soil organic carbon," "carbon markets," "climate finance," "economic implications," and "challenges." The search was supplemented by reference mining of identified review articles and key publications.

2.3 Inclusion and Exclusion Criteria

Studies were included if they met the following criteria: (a) peer-reviewed articles, systematic reviews, or authoritative reports published between 2000 and 2026; (b) focused on carbon sequestration in Sub-Saharan African contexts; (c) provided quantitative data on sequestration potential, economic implications, or implementation challenges; (d) written in English or with English abstracts. Exclusion criteria included: (a) studies without relevance to Sub-Sahara Africa(SSA); (b) purely theoretical or modeling studies without empirical grounding; (c) opinion pieces without systematic evidence; (d) duplicate publications.

The initial search yielded 1,067 results. Following screening for relevance and quality, 145 publications were included for full review, consistent with comparable systematic reviews in this field.

2.4 Data Extraction and Synthesis

Data were extracted using a standardized template capturing: (a) study location and agroecological zone; (b) sequestration solution type; (c) reported sequestration rates (t C ha^{-1} yr^{-1} or equivalent); (d) economic costs and benefits; (e) implementation challenges; (f) policy and institutional context. Given the heterogeneity in methodologies including differences in measurement approaches, soil sampling depths, and experimental durations. The study was adopted a narrative synthesis approach, complemented by quantitative summaries where sufficient comparable data existed.

III. RESULTS

3.1 Overview of Carbon Sequestration Solutions in Sub-Sahara Africa(SSA).

3.1.1 Agroforestry Systems

Agroforestry the integration of trees into agricultural landscapes emerges as the most extensively studied and promising carbon sequestration solution in SSA. A systematic review of 145 publications found that agroforestry systems substantially enhance soil fertility, provide viable climate adaptation and mitigation strategies, and diversify rural livelihoods. Another review of 218 peer-reviewed studies (2000–2024) synthesized evidence on agroforestry's role as a climate-smart economic strategy across Africa, Asia, and Latin America. A further systematic review of 201 selected articles across 22 African countries confirmed the growing body of literature on agroforestry, particularly over the last two decades.

Sequestration Potential: Agroforestry systems demonstrate substantial carbon sequestration capacity in both aboveground biomass and soil. In Tanzania, agroforestry systems have been reported to sequester up to 15 tons of carbon per hectare per year. In Sahelian countries (Senegal, Mali, Burkina Faso, Niger), trees were found to improve soil organic carbon stocks by 1- to 1.5-fold, with Faidherbia albida and Piliostigma reticulatum performing better than other species. Modeling studies in Senegal's old peanut basin predicted SOC stock gains at rates of +0.22 and +0.12 Mg C ha^{-1} yr^{-1} over 25 and 50 years, respectively, using tree legumes F. albida and Leucaena leucocephala.

Economic Implications: Agroforestry offers multiple economic co-benefits beyond carbon sequestration, including improved soil fertility, enhanced crop productivity, diversified income sources, and strengthened resilience against climate perturbations. However, adoption is limited by financial constraints, limited access to credit, and socio-economic disparities among farmers. Key barriers include land tenure insecurity, limited access to resources, and the need for context-specific research.

3.1.2 Conservation Agriculture

Conservation agriculture (CA) based on three principles: no- or minimum tillage, crop residue retention, and intercropping or rotation—aims to concurrently promote agricultural productivity, climate resilience, and environmental sustainability.

Sequestration Potential: Evidence on CA's potential to enhance soil carbon sequestration remains equivocal. A systematic review of 33 cases of conservation agriculture in SSA found that SOC storage rates were only significantly higher than the 4‰ yr^{-1} target when all three principles were fully applied. The data showed very large variability in SOC storage rates influenced by previous land-use history, soil type, sampling depth, crop types and management, and experimental duration. SOC storage rates significantly decreased with time in agroforestry systems, and no significant relationships between SOC storage rates and site variables were found for conservation agriculture.

Economic Implications: Adoption of CA among smallholder farmers faces significant barriers, including financial constraints, limited access to credit, and the need for upfront investments in equipment and training. The evidence is equivocal on whether CA delivers the promised climate and productivity benefits in SSA's diverse smallholder contexts.

3.1.3 Forest Restoration and REDD+

Forest restoration initiatives, including ecological restoration, forest landscape restoration, and REDD+ (Reducing Emissions from Deforestation and Forest Degradation), represent major carbon sequestration strategies in SSA's forested areas.

Sequestration Potential: A systematic review of 22 studies across SSA forested areas found that ecological forest restoration positively influences soil carbon stocks, particularly in enhancing ecosystem resilience and promoting sustainable land use. Miombo ecosystems—Southern Africa's extensive woodlands—sequester 0.5–1.2 t ha^{-1} yr^{-1} of carbon, with variability driven by rainfall, soil fertility, and disturbance history. Sustainable management could secure 6–10 Pg of carbon globally.

Economic Implications: REDD+ initiatives face persistent challenges in benefit-sharing. In the Democratic Republic of Congo, a benefit-sharing plan allocated only 4% of net REDD+ funds to Indigenous Peoples and local communities. In Cameroon, weak institutions have led to conflicts as a few elites captured REDD+ benefit-sharing decisions, disfavoring local communities. Studies revealed that most REDD+ schemes had overstated their climate impacts by up to 400%. A critical analysis of 22 REDD+ projects in SSA found that these projects increased the likelihood of both violent and non-violent conflict, with significant spillover effects beyond project boundaries.

3.1.4 Soil Organic Carbon Management

Soil organic carbon (SOC) management encompasses various practices including improved fallows, integrated soil fertility management, and sustainable land management practices.

Sequestration Potential: Natural and improved fallows have been identified as holding the largest potential for increasing SOC stocks in SSA. In semi-arid agroecological areas (Sahel), SOC concentrations are low (1–4.4 g kg^{-1}), constituting one of the main limitations to biomass production and carbon sequestration. Efficient management of crop residues and water is crucial to enhance SOC stocks. For agroforestry systems, SOC storage rates were significantly higher than 4‰ yr^{-1} in fallows and multistrata systems ($P = 0.0001$ and 0.0178, respectively).

Economic Implications: Low SOC levels in SSA are to a great extent the result of limited resources among smallholder farmers. The cost of labor may be a consideration, with one study in Senegal finding that cheap labor increases the probability of adopting soil carbon-enhancing practices. Practices such as agroforestry and conservation agriculture can restore SOC, but the 4‰ initiative should be implemented based on positive impacts on crop productivity rather than solely on climate change mitigation.

3.1.5 Biochar Application

Biochar—a carbon-rich product of biomass pyrolysis—has emerged as a promising amendment for soil carbon sequestration and agricultural productivity enhancement.

Sequestration Potential: A single ton of biochar can sequester between 0.5 and 3 tons of CO_2-equivalent, converting farmland into carbon-retaining zones. Biochar improves nutrient supply, water retention, and carbon storage, with particular relevance for dryland ecosystems. However, research gaps persist in SSA, highlighting the need for further investigation.

Economic Implications: Biochar production requires investment in pyrolysis technology and biomass feedstocks, which may be challenging for resource-constrained smallholders. The ability of biochar to sequester carbon while improving soil properties presents opportunities for integrated soil nutrient management and climate change mitigation.

3.1.6 Grassland Management

Grasslands across East Africa represent significant carbon sequestration potential, with studies synthesizing evidence from six countries (Burundi, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda).

Sequestration Potential: Integrating agroforestry practices with forage crops has enhanced carbon sequestration, with synergistic effects of combining trees and forage crops in agricultural landscapes. In Kenya, forage grasses such as Pennisetum purpureum and Cynodon species contribute to above-ground carbon sequestration.

Economic Implications: Grassland management offers co-benefits including improved livestock productivity, enhanced soil health, and diversified livelihood options, though adoption barriers similar to other agricultural practices persist.

3.1.7 Carbon capture technologies

Carbon capture technologies and methods are broadly categorized into Point-Source Technological Capture, Direct Atmospheric / Carbon Dioxide Removal (CDR), Biological & Nature-Based Solutions, and Geochemical / Marine Solutions.

1. Point-Source Technological Capture

Captured directly at high-emission industrial sites (e.g., power plants, cement, steel, and chemical facilities) before entering the atmosphere.

- Post-Combustion Capture: Separates CO_2 from flue gas after fossil fuels or biomass are burned.
  - Chemical Absorption: Uses liquid solvents (e.g., liquid amines) that bind to CO_2 when cooled and release it when heated.

- Solid Adsorption: Uses porous solid materials (metal-organic frameworks, zeolites, activated carbon) to trap CO_2
- Membrane Separation: Uses thin polymeric or ceramic filters that selectively allow CO_2 to pass through while blocking other gases.
- Cryogenic Separation: Cools flue gas to extremely low temperatures so CO_2 condenses or freezes into a solid, separating it from nitrogen and oxygen.

- Pre-Combustion Capture: Converts fossil fuel or biomass into a synthesis gas (syngas) of hydrogen H_2 and carbon monoxide CO via gasification or reforming. The CO is reacted with water to yield CO_2 and additional H_2, allowing the concentrated CO_2 to be stripped out before the hydrogen is burned for power.
- Oxy-Fuel Combustion: Fuel is burned in pure oxygen mixed with recycled flue gas (instead of air). This produces a flue gas composed almost entirely of water vapor and high-purity CO_2, making capture via condensation straightforward.

2. Direct Atmospheric & Engineered Removal (CDR)

Captures CO_2 directly from ambient air rather than industrial point sources.

- Direct Air Capture (DAC): Uses large industrial fan arrays to draw ambient air over solid sorbents or liquid solvents that chemically bind to dilute atmospheric CO_2 (approx 0.04%), releasing it under heat or pressure for permanent storage.
- Bioenergy with Carbon Capture and Storage (BECCS): Biomass (trees, agricultural residues, dedicated crops) absorbs atmospheric CO_2 through photosynthesis. The biomass is burned for electricity or processed into biofuel, and the resulting point-source CO_2 emissions are captured and geologically stored, resulting in net-negative atmospheric emissions.

3. Biological & Nature-Based Solutions

Leverages natural ecosystem processes (photosynthesis and soil organic carbon accumulation) to capture and store carbon.

- Afforestation & Reforestation: Planting trees on historically non-forested land or restoring lost forest biomes to store carbon in above-ground biomass, root systems, and forest soils.
- Agroforestry: Integrating woody perennial trees with crops (alley cropping) or livestock grazing systems (silvopastoral) to increase biomass carbon density on agricultural lands.
- Blue Carbon Ecosystem Restoration: Protecting and restoring coastal and marine wetlands specifically mangroves, tidal salt marshes, and seagrass meadows which store organic carbon in anaerobic, waterlogged soils for centuries.
- Soil Carbon Sequestration (Regenerative Agriculture): Farming and land management practices (no-till farming, cover cropping, compost application, rotational grazing) designed to build soil organic matter and fix carbon underground.

4. Geochemical & Marine Capture Solutions

Accelerates natural chemical weathering and mineral reactions to bind carbon into stable mineral compounds or ocean chemistry.

- Enhanced Rock Weathering (ERW): Spreading finely ground silicate minerals (such as basalt or olivine) over agricultural fields or land surfaces. As rainfall reacts with the rock dust, it chemically transforms atmospheric CO_2 into dissolved bicarbonate ions, which eventually flow into oceans or form carbonate minerals.
- Carbon Mineralization (Ex-situ & In-situ): Reacting captured CO2 with alkaline industrial wastes (e.g., slag, fly ash) or injecting it deep into reactive basaltic rock formations underground, where it chemically reacts to permanently turn into solid stone (e.g., calcite).
- Biochar Production: Pyrolyzing (heating in the absence of oxygen) agricultural waste or biomass into stable, solid charcoal. Applied to agricultural soils, biochar locks away carbon for centuries while improving soil moisture retention.
- Direct Ocean Capture & Alkalinity Enhancement: Adding alkaline materials (e.g., lime) to ocean surface waters or using electrochemical processes to strip CO_2 directly from seawater. This increases the ocean's capacity to absorb additional CO_2 from the atmosphere without raising ocean acidity.

Summary of Primary Capture Mechanisms

Category	Primary Capture Mechanism	Scale & Focus	Levelized Cost Range
Point-Source Capture	Solvents, Adsorbents, Membranes, Oxy-fuel	Industrial emissions mitigation	Low–Medium ($3- $100/$tCO_2$)
Direct Air Capture (DAC)	Liquid/Solid chemical sorbents	Direct atmospheric removal	VeryHigh ($400- $800/$tCO_2$)
Biological Systems	Photosynthesis & organic storage	Forest, agricultural, and coastal sinks	Low ($10-$50/tCO_2)
Geochemical & Marine	Weathering, mineralization, pyrolysis	Mineral and ocean carbon locking	Medium–High ($50-$200/tCO_2)

3.2 Comparative Analysis of Sequestration Solutions

Table 1: Comparative Summary of Carbon Sequestration Solutions in Sub-Saharan Africa

Solution	Sequestration Rate (t C ha^{-1} yr^{-1})	Primary Mechanism	Key Co-benefits	Major Challenges
Agroforestry	0.5–15 (highly variable)	Aboveground biomass + soil	Soil fertility, livelihoods, biodiversity	Land tenure, resource access, context-specificity

Solution	Sequestration Rate (t C ha^{-1} yr^{-1})	Primary Mechanism	Key Co-benefits	Major Challenges
Conservation Agriculture	Variable (equivocal)	Soil organic carbon	Soil health, erosion control	Adoption costs, credit access, equivocal evidence
Forest Restoration/REDD+	0.5–1.2 (miombo)	Forest biomass + soil	Biodiversity, watershed services	Benefit-sharing, governance, MRV gaps
SOC Management	Variable (site-dependent)	Soil organic matter	Crop productivity, soil health	Resource constraints, labor costs
Biochar	0.5–3 t CO_2-eq t^{-1}	Soil carbon stabilization	Soil fertility, water retention	Technology costs, knowledge gaps
Grassland Management	Under investigation	Soil + aboveground biomass	Livestock productivity	Adoption barriers, knowledge gaps

Comparative Sequestration Potential and Techno-Economics

Mitigation pathways display variations across biological potential, technological maturity, capital requirements, and abatement costs.

Solution Pathway	Mitigation Category	Carbon Storage Capacity (Mg C ha−1)	Annual Sequestration (tCO2 e ha−1yr−1)	Levelized Abatement Cost ($/tCO2 e)	Technology Readiness Level (TRL)	Primary Constraints
Agroforestry (Silvopastoral / Alley)	Biological	45.2 ± 6.8	4.2±1.1	$12 - $28	8 - 9	High transaction costs with smallholder

						s
Monoculture Afforestation	Biological	112.0 ± 14.5	8.5 ±2.0	$8 - $22	9	Biodiversity reduction, fire risk
Mangrove Restoration (Blue Carbon)	Coastal / Ecological	382.4 ±24.5	18.5 ±4.2	$15 - $35	7- 8	Coastal development, salinity shifts
Biochar Soil Amendment	Geochemical	65.0 ±8.2	3.1 ±0.8	$45 - $90	6- 7	Feedstock transport logistics
Direct Air Capture (DACCS)	Technological	N/A(Point Facility)	> 100,000 t/yr/plant}	$450 - $680	4- 5	High energy demands, high CAPEX
BECCS	Bio-Industrial	N/A(Point Facility)	Variable	$120 - $240	5 - 6	Competition with food production

3.3 Economic Implications

3.3.1 Carbon Markets and Pricing

The global voluntary carbon market is projected to expand significantly, with estimates suggesting growth from $2 billion in 2020 to $100 billion by 2030. However, Africa's participation remains limited the continent supplies approximately 20% of global carbon credits but captures merely 5% of proceeds. This disparity reflects structural inequalities in carbon market design and operation.

South Africa operates Africa's first national carbon tax, generating funds for energy transition. Kenya is piloting voluntary carbon market frameworks to boost nature-based credits, while Nigeria launched a domestic carbon market initiative in 2022. The African Continental Free Trade Area (AfCFTA) presents opportunities for continental coordination in establishing carbon markets, with simulations indicating that combining AfCFTA implementation with climate policies could reduce Africa's GHG emissions by 12%–23% by 2045.

3.3.2 Climate Finance Gap

Africa faces a climate finance gap of $2.5–2.8 trillion by 2030. The annual shortfall in adaptation finance alone is estimated at $51 billion. International climate finance commitments have been delayed or delivered largely through debt-creating instruments, limiting the effectiveness of climate action. Some experts argue that given Africa's role in global carbon storage, particularly its forests, the continent is owed double its adaptation finance needs.

3.3.3 Benefit-Sharing Inequities

Benefit-sharing remains a critical challenge across carbon sequestration initiatives. In REDD+ projects, local communities often receive disproportionately small shares of revenues. In the Democratic Republic of Congo, despite a national framework mandating that 25% of REDD+ revenues flow to locals, actual benefit-sharing falls far short. The benefit-sharing mechanism for one major project allocated only 45% of net proceeds to Community Forest Management Groups, with the project proponent failing to comply with legal requirements that benefit-sharing be derived from gross revenue.

3.3.4 Economic Costs and Trade-offs

Carbon sequestration projects entail significant economic costs and trade-offs. For the 500–600 million smallholder farmers in Africa, the societal benefits of carbon farming practices are clear, but the costs for individual farmers can be high. Monoculture plantations, commonly used in some offset schemes, can have negative ecological and social consequences: water tables fall, local livelihoods tied to wild-foraged resources collapse, and biodiversity declines.

3.4 Implementation Challenges

3.4.1 Land Tenure and Carbon Rights

Insecure land tenure represents one of the most pervasive barriers to carbon sequestration in SSA. Weak land tenure arrangements and the absence of carbon rights frameworks create fundamental challenges. Communities report that projects have restricted access to traditional lands and livelihoods. The commodification of African natural resources risks enabling land dispossession and elite capture.

3.4.2 Governance and Institutional Weaknesses

Governance inefficiencies, weak policy enforcement, and inadequate funding pose significant challenges. In Cameroon, weak institutions have led to conflicts as elites captured benefit-sharing decisions. Staffing cycles have caused REDD+ projects in Uganda to lose institutional memory and local knowledge. Political risk is increasingly pricing African carbon credits, with policy shifts, CORSIA eligibility, and forest finance shaping bankable deals.

3.4.3 Monitoring, Reporting, and Verification (MRV)

Accurate measurement and reporting of carbon sequestration remains challenging. Without robust MRV systems, access to results-based payments is limited. The lack of monitoring capacity undermines both the credibility of carbon credits and the potential for equitable benefit-sharing. The global carbon market crisis is partly attributed to overstated climate impacts, with studies revealing that most REDD+ schemes had overstated their impacts by up to 400%.

3.4.4 Technical Capacity and Knowledge Gaps

Limited technical capacity in potential applicant institutions constrains project development. Uneven technical capacity across countries and institutions shapes carbon market participation.

Research gaps persist in understanding belowground carbon dynamics, greenhouse gas fluxes, and context-specific sequestration potentials.

3.4.5 Social and Equity Concerns

Carbon sequestration projects raise significant social and equity concerns. Communities report that promised "win-win" benefits prove elusive, with many being left with empty promises and restricted access to ancestral lands. Most financial benefits flow to investors and intermediaries abroad. Critics warn that Africa's growing carbon economy risks becoming another form of exploitation.

Table 2: Summary of Key Implementation Challenges

Challenge Category	Specific Issues	Affected Solutions
Land Tenure	Insecure rights, absence of carbon rights frameworks	All land-based solutions
Governance	Weak institutions, elite capture, policy enforcement gaps	REDD+, forest restoration
MRV Capacity	Inadequate measurement systems, data gaps	All solutions
Technical Capacity	Limited expertise, institutional constraints	All solutions
Finance	High upfront costs, limited credit access	Agroforestry, CA, biochar
Social Equity	Benefit-sharing inequities, community displacement	REDD+, carbon markets

IV. DISCUSSION

4.1 Synthesis of Findings

This systematic review reveals that no single carbon sequestration solution adequately addresses the diverse ecological, economic, and social contexts of Sub-Saharan Africa. Agroforestry emerges as the most promising and extensively studied approach, offering substantial carbon sequestration potential alongside multiple co-benefits for soil fertility, livelihoods, and biodiversity. However, its effectiveness varies significantly across contexts, and adoption barriers particularly land tenure insecurity and limited resource access remain formidable.

The equivocal evidence for conservation agriculture highlights the importance of context-specific implementation and the need for rigorous, long-term research. Simply promoting CA as

a universal solution risks disappointment and may divert resources from more effective approaches. The finding that SOC storage rates under conservation agriculture are only significant when all three principles are fully applied underscores the challenges of implementing complex management systems among resource-constrained smallholders.

Forest restoration and REDD+ initiatives demonstrate significant carbon sequestration potential but face persistent governance and equity challenges. The documented conflicts, benefit-sharing inequities, and overstated climate impacts suggest that current REDD+ implementation models require fundamental reform. The finding that only 4% of net REDD+ funds reach Indigenous Peoples and local communities in some projects represents a profound failure of the stated goals of inclusive, equitable climate action.

4.2 Economic Implications in Context

The economic analysis reveals a stark paradox: Africa possesses vast natural carbon capital yet captures a disproportionately small share of carbon market revenues. The continent supplies approximately 20% of global carbon credits but receives merely 5% of proceeds. This disparity reflects deeper structural inequalities in global carbon market governance, where African countries remain price-takers rather than agenda-setters.

The projected expansion of voluntary carbon markets from $2 billion to $100 billion by 2030 presents both opportunity and risk. If managed equitably, carbon markets could channel significant finance to sustainable land management, community development, and climate adaptation. However, without stronger regulatory frameworks, transparent MRV systems, and inclusive benefit-sharing arrangements, carbon markets risk perpetuating the very inequalities they purport to address.

The climate finance gap of $2.5–2.8 trillion by 2030 underscores the inadequacy of current international climate finance mechanisms. The reliance on debt-creating instruments for climate finance is particularly problematic for Sub-Sahara Africa(SSA) countries already facing sovereign debt crises. As some experts argue, given Africa's role in global carbon storage, the continent is owed far more than it receives in adaptation finance.

4.3 The Challenge of Scale

A critical finding of this review is the persistent gap between demonstrated potential and actual implementation at scale. While numerous studies demonstrate the technical feasibility of carbon sequestration in SSA, adoption remains limited, particularly among the 500–600 million smallholder farmers who manage much of the region's agricultural land. The mismatch between societal benefits and individual costs represents a fundamental challenge requiring innovative policy and financing mechanisms.

The scarcity of good quality data on SOC stocks in Sub-Sahara Africa SSA and the high variability in reported sequestration rates complicate evidence-based policy making. Methodological heterogeneity including differences in measurement approaches, soil sampling depths, and experimental durations limits direct comparisons and meta-analyses. Future research

should prioritize standardized methodologies, long-term monitoring, and geographically comprehensive data collection.

4.4 Policy and Institutional Implications

The challenges identified in this review point to several policy and institutional priorities:

Land tenure reform is essential. Without secure tenure rights and clear carbon rights frameworks, smallholders cannot access carbon markets or invest in long-term sequestration practices.

Governance strengthening is critical. Weak institutions enable elite capture, benefit-sharing inequities, and project failures. Stronger national and regional regulatory frameworks, transparent MRV systems, and fair pricing benchmarks are essential.

Benefit-sharing mechanisms must be reformed to ensure that local communities who bear the costs and risks of carbon sequestration receive equitable shares of revenues. The current practice of allocating minimal shares to communities while investors and intermediaries capture most benefits is both unjust and unsustainable.

Capacity building at all levels from local communities to national institutions is necessary to enable effective participation in carbon markets and sequestration initiatives.

4.5 Limitations of This Review

This systematic review has several limitations geographic distribution of evidence is uneven, with East and Southern Africa better represented than Central and West Africa. Language bias focusing on English-language publications may exclude relevant research published in French, Portuguese, or other languages. Also, the heterogeneity of methodologies across studies limits quantitative synthesis. Fourth, publication bias may favor positive results, potentially overstating sequestration potentials. Finally, the rapidly evolving policy and market landscape means that some findings may become outdated quickly.

V. CONCLUSION

This systematic review provides a comprehensive comparative analysis of carbon sequestration solutions in Sub-Saharan Africa, synthesizing evidence from 145 studies on agroforestry, conservation agriculture, forest restoration, soil carbon management, biochar, and grassland management. Several key conclusions emerge:

Agroforestry represents the most promising and extensively evidenced carbon sequestration solution for SSA, offering substantial carbon storage (0.5–15 t C ha^{-1} yr^{-1}) alongside multiple co-benefits for soil fertility, livelihoods, and biodiversity. However, adoption barriers particularly land tenure insecurity and limited resource access must be addressed through targeted policy support.

The evidence for conservation agriculture as a carbon sequestration solution is equivocal. SOC storage is only significantly enhanced when all three CA principles are fully applied, and results show high variability across contexts. Context-specific implementation and realistic expectations are essential.

Forest restoration and REDD+ initiatives demonstrate significant potential but face persistent governance and equity challenges. The documented conflicts, benefit-sharing inequities (with local communities receiving as little as 4% of net proceeds), and overstated climate impacts demand fundamental reform.

Africa's participation in carbon markets reflects deep structural inequalities: the continent supplies 20% of global credits but captures only 5% of proceeds. Addressing this disparity requires stronger regulatory frameworks, transparent MRV systems, and inclusive governance.

The climate finance gap of $2.5–2.8 trillion by 2030 far exceeds current flows, highlighting the inadequacy of international climate finance mechanisms and the need for innovative financing approaches.

Finally, no single solution suffices. Effective carbon sequestration in SSA requires integrated, context-specific approaches that prioritize community participation, secure tenure rights, robust measurement frameworks, and equitable benefit-sharing. The choice of solutions must be guided by local ecological conditions, socioeconomic contexts, and the preferences and capacities of local communities.

VI. RECOMMENDATIONS

Based on the findings of this systematic review, we offer the following recommendations for policymakers, practitioners, and researchers:

6.1 For Policymakers

Reform land tenure and carbon rights frameworks: Establish clear, secure tenure rights and carbon rights frameworks that enable smallholders to participate in carbon markets and invest in long-term sequestration practices.

Strengthen governance institutions: Build capacity for transparent MRV systems, fair pricing benchmarks, and inclusive benefit-sharing arrangements. Address governance weaknesses that enable elite capture and benefit-sharing inequities.

Develop national and regional carbon market frameworks: Create regulatory environments that enable equitable participation in carbon markets, moving from being price-takers to active agenda-setters.

Prioritize climate finance for adaptation and mitigation: Address the $2.5–2.8 trillion climate finance gap through innovative financing mechanisms that do not increase debt burdens.

Integrate carbon sequestration into national development planning: Align carbon sequestration initiatives with agricultural development, food security, and poverty reduction goals.

6.2 For Practitioners and Project Developers

Adopt context-specific approaches: Recognize that no single solution fits all contexts. Design interventions based on local ecological conditions, socioeconomic realities, and community preferences.

Ensure meaningful community participation: Engage local communities as partners rather than beneficiaries. Ensure that benefit-sharing mechanisms are transparent, equitable, and responsive to community needs.

Invest in robust MRV systems: Develop and implement rigorous monitoring, reporting, and verification systems to ensure the credibility of carbon credits and enable access to results-based payments.

Prioritize agroforestry and integrated approaches: Given the strong evidence for agroforestry's multiple benefits, prioritize agroforestry as a core strategy, complemented by other approaches where appropriate.

Address adoption barriers: Provide financial and technical support to overcome barriers including high upfront costs, limited credit access, and knowledge gaps.

6.3 For Researchers

Standardize methodologies: Develop and adopt standardized protocols for measuring and reporting carbon sequestration to enable meaningful comparisons and meta-analyses.

Expand geographic coverage: Prioritize research in understudied regions, particularly Central and West Africa, to address geographic biases in the evidence base.

Conduct long-term monitoring: Establish long-term monitoring sites to track carbon dynamics over time, addressing the limitation that SOC storage rates decrease with time in some systems.

Investigate belowground carbon dynamics: Address knowledge gaps in belowground carbon dynamics and greenhouse gas fluxes.

Examine social and economic dimensions: Strengthen research on the social and economic dimensions of carbon sequestration, including benefit-sharing, equity, and livelihood impacts.

6.4 For International Partners

Honor climate finance commitments: Fulfill and exceed commitments to provide adequate, accessible climate finance that does not increase debt burdens.

Support capacity building: Invest in technical and institutional capacity building at all levels to enable effective participation in carbon markets and sequestration initiatives.

Promote equitable carbon market governance: Advocate for reforms that ensure equitable participation, transparent pricing, and fair benefit-sharing in global carbon markets.

Recognize Africa's contributions: Acknowledge and compensate Africa's role in global carbon storage through appropriate financial and technical support.

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