CLIMATE SMART AGRIBUSINESS FINANCING (CSAF) FORESTRY AND WASTE MANAGEMENT

GLOBAL ISSUES & LOCAL PERSPECTIVES

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Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It is eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous **Climate Smart Agribusiness Financing (CSAF) Forestry and Waste Management** issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which **Climate Smart Agribusiness Financing (CSAF) Forestry and Waste Management** issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue **Climate Smart Agribusiness Financing (CSAF) Forestry and Waste Management** necessary in policy making process that will stimulate increase in food production and environmental sustainability. **Climate Smart Agribusiness Financing (CSAF) Forestry and Waste Management :** *Global Issues & Local Perspectives* is organized in two parts. Part One deals with The Concept of **Climate Smart Agribusiness Financing (CSAF)**, Part Two is concerned with The Concept of **Forestry and Waste Management**

Eteyen Nyong; August 2026

Chapter Four

Resource-Efficient Waste Management and Financing in Climate-Smart Agribusiness

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1.0 Introduction

Agriculture is an important part of Nigeria's economy, providing food, jobs, industrial raw materials, and income for millions of people, especially in rural areas. However, farming and related activities also generate large amounts of waste, including crop residues, animal manure, agro-processing by-products, and market waste. Common examples are cassava peels, rice husks, maize stalks and cobs, yam peels, cocoa pods, oil palm residues, poultry droppings, cattle dung, and fish processing waste. Much of this waste is poorly managed through open burning, indiscriminate dumping, or discharge into water bodies, resulting in environmental pollution, greenhouse gas (GHG) emissions, soil and water contamination, and public health problems.

Despite its potential value, agricultural waste in Nigeria remains largely underutilized. Valuable materials that could be converted into organic fertilizer, livestock feed, renewable energy, biochar, and biomass briquettes are often lost. This creates both environmental challenges and missed economic opportunities for farmers and rural communities. The problem is worsened by limited awareness, inadequate technologies, weak extension services, poor infrastructure, and insufficient financing.

Growing concerns about climate change, environmental degradation, food insecurity, and resource scarcity have increased interest in sustainable agricultural waste management. Resource-efficient waste management promotes the reuse, recycling, recovery, and conversion of agricultural residues into useful products. For example, cassava peels can be processed into livestock feed, rice husks and maize cobs into biochar or biomass fuel, while poultry manure and cattle dung can be converted into organic fertilizer or biogas. These practices reduce waste, improve soil health, lower production costs, create income opportunities, and promote sustainable resource use.

The circular economy further supports this approach by encouraging the recovery, recycling, and reuse of resources. Despite its benefits, adoption remains limited by inadequate awareness, poor access to affordable technologies, weak extension services, and insufficient finance. Greater access to climate-smart financing, government incentives, cooperative credit, and public-private partnerships can support wider adoption. Resource-efficient agricultural waste management therefore contributes to climate-smart agribusiness, environmental sustainability, climate resilience, and long-term food security.

2.0 Sources and Types of Agricultural Waste

Agricultural waste refers to unwanted materials produced during crop farming, livestock production, harvesting, processing, storage, transportation, and marketing. These materials can be reused, recycled, or changed into useful products. In climate-smart agribusiness, agricultural waste is increasingly seen as a valuable resource rather than something to throw away. Through proper management, waste can be converted into compost, livestock feed, renewable energy, biochar, and other useful products that support environmental protection and economic development (Awasthi *et al.*, 2024). In Nigeria, the large amount of agricultural waste produced each year creates environmental problems but also provides opportunities for sustainable agribusiness.

Crop residues are a major source of agricultural waste. They include maize stalks and cobs, rice husks, cassava peels, yam peels, sorghum stalks, millet straw, groundnut shells, and plantain leaves. These materials are often burned or left to decay, but they can be used to produce livestock feed, biochar, biomass fuel, and organic fertilizer. This helps improve soil fertility and reduces the need for chemical fertilizers.

Livestock production also produces wastes such as poultry droppings, cattle dung, pig manure, goat and sheep manure, and animal urine. When poorly managed, these wastes can cause pollution and release harmful gases. However, they can be used to make compost, organic fertilizer, and biogas for energy production.

Agro-processing also generates wastes such as palm kernel shells, cocoa pod husks, sugarcane bagasse, coconut shells, groundnut shells, and rice bran. These materials can be used to produce biomass fuel, compost, animal feed, and other useful products. Market and vegetable wastes, including spoiled fruits, vegetables, and leaves, can also be composted, used as animal feed, or converted into biogas.

Overall, agricultural waste in Nigeria provides opportunities for resource-efficient management. Converting waste into useful products can improve soil fertility, create jobs, generate income, reduce production costs, provide renewable energy, and minimize environmental pollution. Effective waste management therefore supports climate-smart agribusiness, resource efficiency, climate resilience, and sustainable food production.

Table 1. Common Agricultural Wastes in Nigeria and Their Resource-Efficient Uses

Agricultural Waste	Major Sources	Resource-Efficient Uses
Maize Stalks and cobs	Maize farms	Compost, livestock feed, biochar, briquettes

Rice husks	Rice milling	Biochar, biomass fuel, briquettes, mushroom substrates
Cassava peels	Cassava processing	Processed livestock feed, compost, biogas production
Yam peels	Yam processing	Compost, livestock feed, biogas
Poultry droppings	Poultry farms	Organic fertilizer, compost, biogas
Cattle dung	Cattle farms	Compost, biogas, organic manure
Pig manure	Pig farms	Biogas production, compost, organic fertilizer
Palm kernel shells	Palm oil processing	Biomass fuel, activated carbon, briquettes
Cocoa pod husks	Cocoa processing	Compost, organic fertilizer, biochar
Sugarcane bagasse	Sugar processing	Bioenergy, paper production, biodegradable packaging
Vegetable waste	Farms and markets	Compost, livestock feed, biogas
Fruit waste	Markets and food processing	Compost animal feed, biogas

Source: Adapted from Awasthi *et al.* (2024); Kolawole *et al.* (2024); Zhao *et al.* (2023).

3.0 Resource-Efficient Agricultural Waste Management

Resource-efficient agricultural waste management involves sustainable ways of collecting, reusing, recycling, and converting farm waste and by-products into useful materials. Instead of treating agricultural waste as something to discard, this approach views it as a valuable resource that can produce useful products, reduce pollution, and create economic benefits. Agricultural wastes include crop residues such as maize stalks, rice husks, cassava peels, yam peels, and cocoa pod husks; livestock wastes such as animal manure; and agro-processing by-products. These materials can be converted into compost, organic fertilizer, livestock feed, biochar, biogas, biomass briquettes, renewable energy, and other useful products.

A major part of this approach is the waste-to-wealth concept, which involves converting waste into useful and marketable products. For example, crop residues can be processed into compost, biochar, animal feed, or biomass fuel. Animal manure can be used to produce organic fertilizer and biogas, while cassava peels and other agro-processing wastes can be processed into livestock feed. These practices reduce waste disposal problems and provide additional income for farmers, agribusinesses, and rural communities.

Resource-efficient waste management is also linked to the circular economy, which promotes the reuse and recycling of resources. In agriculture, waste from one production activity can become an input for another. Animal manure can improve soil fertility, crop residues can serve as livestock feed, and livestock waste can produce biogas and organic fertilizer. These practices reduce dependence on external inputs and improve resource use.

Resource-efficient waste management also provides environmental and economic benefits. It reduces pollution from open burning and uncontrolled dumping while improving soil fertility, nutrient availability, and water retention. The use of agricultural waste for renewable energy can also reduce dependence on fossil fuels. In Nigeria, waste valorisation provides opportunities for sustainable agriculture, renewable energy, and circular economy development (Echefu *et al.*, 2026). However, wider adoption requires appropriate technologies, finance, technical knowledge, extension services, and supportive government policies. Overall, these practices support climate-smart agribusiness by reducing waste, creating income and employment, conserving resources, and reducing environmental pollution (Koul *et al.*, 2024).

Circular Economy

The circular economy is an approach that keeps resources in productive use for as long as possible through reuse, recycling, recovery, and regeneration, replacing the traditional "take–make–dispose" model. In agriculture, it involves recycling crop residues and livestock waste into organic fertilizers, renewable energy, and other valuable products while returning nutrients to the soil. This approach minimizes waste generation, improves resource efficiency, reduces dependence on virgin materials, and lowers greenhouse gas emissions. By promoting sustainable resource use, the circular economy enhances environmental protection, strengthens agricultural resilience, and supports climate-smart agribusiness and sustainable food systems (Aryee *et al.*, 2025) .

Climate-Smart Waste Management Principles

Climate-smart waste management promotes practices that enhance agricultural productivity, strengthen resilience to climate change, and reduce greenhouse gas emissions through the sustainable use of agricultural waste. It supports climate-smart agriculture by improving resource efficiency while minimizing environmental impacts. The key principles include:

- **Waste reduction:** Minimize waste generation through improved harvesting, storage, processing, and post-harvest handling.
- **Resource recovery:** Convert agricultural residues into valuable products such as compost, biochar, biogas, livestock feed, and organic fertilizers.
- **Recycling and nutrient cycling:** Return nutrients from crop residues and animal manure to the soil to improve fertility and reduce dependence on synthetic fertilizers.
- **Renewable energy production:** Utilize agricultural waste to generate clean energy through technologies such as anaerobic digestion and biomass conversion.
- **Environmentally sound disposal:** Safely dispose of non-recyclable waste to prevent soil, water, and air pollution.
- **Greenhouse gas mitigation:** Reduce emissions by avoiding open burning and adopting low-emission waste management practices.
- **Climate resilience:** Improve soil health, conserve natural resources, and enhance the capacity of farming systems to withstand climate-related stresses.

Together, these principles promote sustainable agricultural production, environmental conservation, and climate-smart agribusiness by maximizing resource efficiency and reducing environmental pollution (Koul *et al.*, 2024).

Importance of Climate-Smart Agribusiness

Climate-smart agribusiness is a sustainable way of producing, processing, and marketing agricultural products that increases productivity and income, helps farmers adapt to climate change, and protects the environment through the efficient use of natural resources. Climate-smart agribusiness is essential for achieving sustainable agricultural production while addressing the impacts of climate change. Its importance includes:

- **Enhancing productivity** through improved technologies and sustainable farming practices.

- **Strengthening climate resilience** by helping farmers adapt to drought, floods, erratic rainfall, and rising temperatures.
- **Reducing greenhouse gas emissions** through low-carbon practices such as agroforestry, renewable energy, and sustainable waste management.
- **Promoting resource efficiency** by encouraging the efficient use of land, water, energy, and nutrients through recycling and circular economy practices.
- **Improving farmers' incomes** by increasing productivity, reducing losses, and creating value-added products from agricultural waste.
- **Enhancing food security** through stable and sustainable agricultural production.
- **Supporting environmental sustainability** by conserving soil, protecting biodiversity, improving water quality, and reducing pollution.

In a nut shell, climate-smart agribusiness integrates productivity, resilience, environmental protection, and economic development, making it a key strategy for sustainable agrifood systems and the achievement of the Sustainable Development Goals (Koul *et al.*, 2024).

4.0 Practical Resource-Efficient Waste Management Approaches

Resource-efficient agricultural waste management focuses on converting agricultural residues into valuable products that improve farm productivity, generate income, and reduce environmental pollution. Instead of disposing of crop residues and livestock waste through open burning or indiscriminate dumping, sustainable technologies recover nutrients, energy, and other useful materials for agricultural and industrial use. In Nigeria, abundant agricultural wastes such as cassava peels, rice husks, maize stalks, poultry litter, cattle manure, and oil palm residues provide enormous opportunities for climate-smart agribusiness, renewable energy production, and sustainable rural development (Adeleye *et al.*, 2024; Ahuchaogu *et al.*, 2026).

Composting

Composting is one of the simplest and most affordable methods of agricultural waste management. It is the controlled decomposition of organic materials by microorganisms under aerobic conditions to produce compost, a nutrient-rich organic fertilizer. Common materials used include crop residues, vegetable wastes, fruit peels, poultry litter, cattle dung, goat manure, and household organic waste.

Compost improves soil structure, increases water-holding capacity, enhances microbial activity, and supplies essential plant nutrients. It also reduces dependence on chemical fertilizers, lowers production costs, and minimizes pollution caused by open burning of crop residues. By improving soil organic matter and reducing methane emissions from unmanaged waste, composting contributes to climate-smart agriculture and sustainable soil management.

In Nigeria, composting is increasingly practiced by vegetable, maize, and rice farmers. Poultry manure, cassava peels, rice husks, and market wastes are commonly converted into compost for crop production. Agricultural research institutions and extension programmes continue to promote composting because it is affordable, environmentally friendly, and suitable for smallholder farmers

Organic Fertilizer from Animal Manure

Animal manure is another valuable resource that can be processed into organic fertilizer. Poultry droppings, cattle dung, pig manure, sheep manure, and goat manure contain essential nutrients such as nitrogen, phosphorus, potassium, calcium, and micronutrients needed for crop growth. Proper composting or curing reduces pathogens and improves the safety and quality of manure before field application.

Organic manure improves soil fertility, increases soil organic matter, enhances nutrient cycling, and strengthens soil water retention. It also reduces dependence on synthetic fertilizers while supporting circular agriculture by returning nutrients to the soil. Consequently, farmers benefit from improved crop yields, lower production costs, and healthier soils.

Across Nigeria, poultry manure is widely applied in vegetable farming, while cattle dung is commonly used for maize, rice, cassava, and yam production. Some commercial livestock farms now process manure into packaged organic fertilizers, creating additional income while reducing environmental pollution.

Biogas Production

Biogas production converts biodegradable agricultural waste into renewable energy through anaerobic digestion. Livestock manure, crop residues, food-processing wastes, and other biodegradable materials are decomposed by microorganisms in the absence of oxygen to produce methane-rich biogas and nutrient-rich residue. The gas is used for cooking, heating, electricity generation, and other farm operations, while the nutrient rich residue serves as an excellent organic fertilizer.

Biogas technology reduces greenhouse gas emissions by capturing methane that would otherwise escape into the atmosphere. It also reduces dependence on firewood, charcoal, kerosene, and fossil fuels, thereby conserving forests and lowering carbon emissions. The recycling of nutrient rich residue further improves soil fertility and resource efficiency.

In Nigeria, biogas technology is gradually expanding among livestock farms, universities, research institutes, and agro-industries. Bio digesters utilizing cattle dung, poultry manure, pig waste, and abattoir residues have been established in several states to generate clean energy and organic fertilizer. Although challenges such as high installation costs and limited technical expertise remain, growing public and private investment is encouraging wider adoption of this technology.

Livestock Feed from Cassava Peels and Crop Residues

Converting cassava peels and crop residues into livestock feed is an effective waste-to-wealth strategy that reduces feed costs and environmental pollution. Materials such as cassava peels, maize stover, rice straw, sorghum stalks, and groundnut haulms can be dried, ground, fermented, or ensiled to improve their nutritional value and safety for animals. Using these by-products as feed improves resource efficiency, reduces waste disposal problems, and lowers dependence on expensive ingredients such as maize and soybean meal. Proper processing also reduces harmful substances in cassava peels and improves their digestibility for cattle, sheep, goats, and pigs.

Nigeria produces large quantities of cassava peels, creating opportunities for affordable livestock feed production. Institutions such as the International Institute of Tropical Agriculture (IITA) and the National Root Crops Research Institute (NRCRI) support improved processing methods. Overall, using agricultural waste as animal feed reduces costs, creates income opportunities, and supports climate-smart agribusiness and circular economy practices (**Tunde *et al.*, 2025).**

Biochar Production

Biochar production is a resource-efficient waste management practice that converts agricultural residues into a stable, carbon-rich material through pyrolysis, where organic materials are heated with little oxygen. Common materials used include rice husks, maize cobs, cassava stems, coconut shells, groundnut shells, sawdust, and oil palm residues. Instead of burning or discarding these wastes, they can be converted into biochar and applied to farmland to improve soil quality and environmental sustainability (Joseph et al., 2024; Lehmann et al., 2022).

Biochar improves soil structure, increases water-holding capacity, retains nutrients, and supports beneficial soil microorganisms. It can also reduce nutrient losses and improve fertilizer efficiency, helping farmers reduce dependence on inorganic fertilizers. In Nigeria, biochar production is gaining attention as farmers and research institutions explore the use of rice husks, maize cobs, cassava stems, and other residues. Overall, biochar supports soil fertility, carbon storage, climate-smart agriculture, and sustainable agricultural waste management (Lehmann et al., 2022).

Biomass Briquettes

Biomass briquettes are renewable solid fuels produced by compressing agricultural residues into compact blocks for cooking, heating, and small-scale industrial energy. Raw materials commonly used include rice husks, sawdust, maize cobs, groundnut shells, coconut shells, sugarcane bagasse, cassava stalks, and oil palm residues. After drying and grinding, the materials are compressed using manual or mechanical briquetting machines to produce dense, easy-to-store fuels with higher energy efficiency than loose biomass.

Briquette production offers an effective solution to agricultural waste disposal while providing a sustainable alternative to firewood and charcoal. It reduces open burning of crop residues, lowers greenhouse gas emissions, conserves forests, and creates new income opportunities for farmers and rural entrepreneurs. Briquetting also supports rural energy security by providing affordable and cleaner household fuel.

In Nigeria, biomass briquette production is expanding as demand for renewable energy grows. Small and medium-scale enterprises utilize rice husks, sawdust, maize cobs, and oil palm residues to produce briquettes for domestic and commercial use. Several universities, research institutes, and private organizations have introduced low-cost briquetting technologies suitable for rural communities, thereby promoting renewable energy, employment generation, and sustainable agribusiness.

Mushroom Cultivation Using Agricultural Waste

Mushroom cultivation is a practical waste-to-wealth strategy that converts agricultural residues into nutritious food while reducing environmental pollution. Edible mushrooms, especially oyster mushrooms (*Pleurotus* spp.), can be grown on materials such as rice straw, maize stalks, corn cobs, sawdust, cassava peels, banana leaves, oil palm residues, and sugarcane bagasse. These materials serve as growing substrates after simple processing, while the spent substrate can be reused as compost, livestock feed, or soil conditioner.

Mushroom production supports climate-smart agriculture by using agricultural waste that might otherwise be burned or dumped. It helps reduce pollution, improve food and nutrition security, and provide additional income for farming households. Mushrooms are rich in protein, vitamins, minerals, and dietary fibre. The enterprise also requires relatively little land and water, making it suitable for smallholder farmers, women, and youth.

In Nigeria, mushroom farming is gaining attention among farmers, entrepreneurs, cooperatives, and research institutions. The use of agricultural waste for mushroom production creates employment, diversifies income, and supports sustainable waste management. Overall, mushroom cultivation demonstrates how agricultural residues can be converted into valuable products that promote food security, income generation, environmental protection, and sustainable agricultural development (IRENA, 2024).

5.0 Benefits of Resource-Efficient Waste Management

Resource-efficient agricultural waste management offers significant environmental, economic, social, and climate-related benefits that support sustainable agricultural development. By converting agricultural residues into useful products such as compost, organic fertilizers, biogas, biochar, livestock feed, biomass briquettes, and mushroom substrates, farmers can maximize resource use, reduce waste, and improve productivity. These practices promote a circular bioeconomy in which agricultural waste is continuously reused and recycled, creating value while minimizing environmental degradation (Zhang et al., 2020).

Environmental Benefits

Resource-efficient waste management protects the environment by reducing indiscriminate dumping, open burning, and uncontrolled decomposition of agricultural waste. Sustainable practices such as composting, biochar production, and organic fertilizer application improve soil fertility, increase soil organic matter, enhance water-holding capacity, and promote beneficial microbial activity. They also reduce soil erosion, conserve natural resources, improve biodiversity, and minimize air, soil, and water pollution.

Economic Benefits

Agricultural waste can be transformed into marketable products, including compost, organic fertilizers, livestock feed, biogas, biomass briquettes, biochar, and edible mushrooms. These products provide additional income while reducing expenditure on fertilizers, animal feed, and energy. Waste valorization also promotes small-scale enterprises involved in waste collection, processing, and marketing, creating employment opportunities and supporting rural economic growth.

Social Benefits

The adoption of resource-efficient waste management improves rural livelihoods by creating jobs for farmers, women, youth, and agribusiness entrepreneurs. Proper waste management also improves sanitation by reducing offensive odours, disease vectors, and environmental pollution. In addition, training and extension programmes that promote waste utilization technologies enhance farmers' knowledge, encourage innovation, and strengthen community participation in sustainable agricultural development.

Climate Change Mitigation

Resource-efficient waste management contributes to climate change mitigation by reducing greenhouse gas emissions associated with open burning and uncontrolled decomposition of agricultural residues. Technologies such as composting, biogas production, biomass briquetting, and biochar application recover valuable resources while lowering carbon emissions. Biogas systems capture methane for renewable energy, whereas biochar stores carbon in the soil, contributing to long-term carbon sequestration and reducing dependence on fossil fuels and fuelwood.

Food Security

Effective waste management enhances food security by improving soil fertility, increasing crop and livestock productivity, and lowering production costs. Organic fertilizers and biochar improve soil health, while processed crop residues provide affordable livestock feed. Renewable energy from biogas supports food processing and preservation, reducing post-harvest losses. Additional income from waste-derived products also enables farmers to invest in improved technologies and farm inputs, resulting in more resilient and productive farming systems.

Overall, resource-efficient agricultural waste management integrates environmental conservation, economic development, climate resilience, and food security. Its adoption strengthens climate-smart agribusiness by promoting sustainable resource utilization, improving farmers' livelihoods, and supporting the long-term sustainability of agricultural production systems.

6.0 Climate-Smart Agribusiness Financing as an Enabler

The successful adoption of resource-efficient agricultural waste management depends not only on technical knowledge but also on access to adequate financing. Many climate-smart technologies, including composting facilities, biogas digesters, biochar kilns, biomass briquetting machines, organic fertilizer processing units, and mushroom production systems, require substantial initial investment that is often beyond the reach of smallholder farmers. Climate-smart agribusiness financing helps bridge this gap by providing affordable credit, grants, investments, and other financial support that enable farmers and agribusinesses to adopt, expand, and commercialize sustainable waste management technologies.

Green Credit

Green credit provides loans and financial products specifically designed to support environmentally sustainable agricultural activities. It enables farmers and agribusinesses to invest in renewable energy, organic fertilizer production, waste recycling, and other climate-smart technologies. Green loans often offer lower interest rates, flexible repayment terms, and technical support, encouraging the adoption of environmentally friendly practices.

Agricultural Cooperatives

Agricultural cooperatives improve farmers' access to finance through collective savings, cooperative loans, and group guarantees. They help members obtain funding for composting facilities, biogas plants, livestock feed processing, and biomass briquetting enterprises. Cooperatives also provide extension services, training, input procurement, and market access, making it easier for smallholder farmers to adopt resource-efficient technologies.

Commercial Bank Loans

Commercial banks provide medium- and long-term financing for investments in climate-smart agribusiness. These loans support the purchase of equipment, renewable energy systems, and waste-processing technologies. However, access is often limited by collateral requirements, high transaction costs, and limited financial literacy among rural farmers.

Development Finance

Development finance institutions and international development partners support climate-smart agriculture through concessional loans, grants, technical assistance, and capacity-building programmes. Their support reduces financial barriers, promotes innovation, and facilitates the adoption of sustainable waste management technologies, particularly among smallholder farmers and rural enterprises.

Public–Private Partnerships

Public–private partnerships bring together governments, private investors, research institutions, financial organizations, and development agencies to finance and implement climate-smart agricultural projects. These collaborations promote investment in waste recycling infrastructure, renewable energy, organic fertilizer production, and other sustainable agribusiness ventures while strengthening technology transfer and expanding access to modern waste management solutions.

Carbon Financing

Carbon financing provides financial rewards for activities that reduce greenhouse gas emissions or increase carbon sequestration. Practices such as biogas production, composting, biochar application, agroforestry, and biomass energy generation can generate carbon credits, creating additional income for farmers while encouraging investment in low-carbon agricultural technologies.

Overall, climate-smart agribusiness financing is a key enabler of resource-efficient waste management. By improving access to affordable finance and encouraging investment in sustainable technologies, it promotes agricultural productivity, environmental protection, rural employment, and long-term climate resilience.

Table 2: Climate-Smart Financing Options Supporting Agricultural Waste Management

Financing Option	Description	Waste Management Technologies Supported	Major Benefits
Green Credit	Environmentally focused. Loans provided by financial institutions	Biogas plants, composting, biochar production, organic fertilizer processing	Affordable financing promotes sustainable investment, reduces pollution
Agricultural cooperatives	Cooperative savings, group lending, and shared investment mechanisms	Composting, livestock feed processing, briquetting, mushroom production	Easier credit access, lower financial risk, collective investment
Commercial Bank Loans	Agricultural credit facilities from commercial banks	Renewable energy systems, waste processing equipment, organic fertilizer production	Business expansion, technology acquisition, increased productivity
Development Finance	Grants, concessional loans, and technical support from development institutions	Climate-smart agriculture, circular economy projects, renewable energy, waste valorization	Affordable funding, capacity building, innovation support
Public–Private Partnerships (PPPs)	Joint investment between governments and private organizations	Waste recycling infrastructure, biomass energy, composting facilities	Infrastructure development, technology transfer, private investment
Carbon Financing	Revenue generated through carbon credit markets for emission reduction projects	Biogas, biochar, composting, biomass energy, agroforestry	Additional farm income, greenhouse gas mitigation,

			supports low-carbon agriculture

Source: Adapted from World Bank (2024).

Climate-smart agribusiness financing is therefore a critical enabler of resource-efficient agricultural waste management. By improving access to affordable financial resources and encouraging investment in environmentally sustainable technologies, these financing mechanisms accelerate the adoption of waste-to-wealth innovations, strengthen climate resilience, improve farm profitability, and contribute to sustainable agricultural transformation.

7.0 Challenges of Resource-Efficient Agricultural Waste Management

Despite its environmental, economic, and social benefits, the adoption of resource-efficient agricultural waste management remains limited in many developing countries, including Nigeria. Technologies such as composting, biogas production, biochar production, biomass briquetting, mushroom cultivation, and organic fertilizer processing have great potential to improve agricultural productivity and environmental sustainability, but several barriers hinder their widespread use (Iqbal *et al.*, 2021). Some of these barriers include:

Poor Awareness

Many farmers and rural communities have limited awareness of the economic and environmental value of agricultural waste. Crop residues and livestock manure are often burned or discarded instead of being converted into valuable products such as compost, livestock feed, or renewable energy. Limited training and inadequate access to information also reduce the adoption of waste-to-wealth technologies.

High Technology Cost

The high cost of acquiring and maintaining equipment such as biogas digesters, biochar kilns, briquetting machines, and composting facilities discourages investment by smallholder farmers. Limited technical expertise further increases operational costs and slows technology adoption.

Poor Infrastructure

Inadequate rural infrastructure, including poor road networks, unreliable electricity, insufficient water supply, and limited processing and storage facilities, hinders the collection, transportation, processing, and marketing of agricultural waste and waste-derived products.

Weak Extension Services

Extension services are often underfunded and lack the capacity to train farmers on modern waste management technologies. As a result, many farmers do not receive the technical support needed to adopt and maintain climate-smart waste management practices.

Limited Access to Finance

Many farmers struggle to obtain affordable credit due to high interest rates, collateral requirements, and limited access to financial institutions. This restricts investment in waste-processing equipment and other climate-smart technologies.

Weak Policy Implementation

Although policies promoting sustainable agriculture and environmental protection exist, inadequate funding, weak coordination, and poor enforcement limit their effectiveness. Strengthening institutional collaboration and policy implementation is essential for promoting sustainable waste utilization.

Poor Market Development

Markets for recycled products such as compost, biochar, biomass briquettes, and organic fertilizers remain underdeveloped because of low consumer awareness, inadequate product standards, weak value chains, and limited market access.

Overall, overcoming these challenges requires greater investment in infrastructure, financing, technology dissemination, extension services, market development, and effective policy implementation. Addressing these constraints will accelerate the adoption of resource-efficient agricultural waste management, strengthen climate-smart agribusiness, improve farmers' livelihoods, and promote sustainable agricultural development.

8.0 Policy Directions and Future Opportunities

Achieving resource-efficient agricultural waste management requires supportive policies, strategic investments, and collaboration among governments, research institutions, the private sector, and farming communities. As climate-smart agriculture gains importance, policies that promote waste valorization, renewable energy, and circular bioeconomy practices will enhance agricultural productivity, environmental sustainability, and rural livelihoods (Bauwens et al., 2020). They include:

Government Incentives

Government support is essential for expanding climate-smart waste management. Incentives such as subsidies, tax relief, low-interest loans, grants, and equipment financing can encourage investment in composting, biogas production, biomass briquetting, biochar production, and organic fertilizer processing. Improved rural infrastructure, extension services, and farmer training will further promote technology adoption.

Research and Innovation

Research institutions and universities should develop affordable, efficient, and locally adaptable waste management technologies. Innovations in composting, bio digesters, biochar production, livestock feed processing, and biomass utilization can improve resource efficiency and increase the adoption of sustainable waste-to-wealth practices.

Youth Participation

Agricultural waste management offers promising business opportunities for young people in compost production, mushroom cultivation, organic fertilizer manufacturing, biomass briquetting, renewable energy, and recycling enterprises. Providing entrepreneurship training, access to finance, and business development support can stimulate innovation, create employment, and strengthen rural economies.

Digital Agriculture

Digital technologies such as mobile applications, remote sensing, Geographic Information Systems (GIS), drones, the Internet of Things (IoT), and artificial intelligence can improve waste collection, processing, marketing, and access to extension services. These technologies enhance decision-making, operational efficiency, and climate resilience.

Circular Bio economy

Promoting a circular bio economy encourages the reuse, recycling, and recovery of agricultural waste to produce fertilizers, livestock feed, renewable energy, and other bio-based products. This approach improves resource efficiency, reduces greenhouse gas emissions, conserves natural resources, and supports sustainable agricultural development.

Private Sector Investment

Private sector participation is essential for expanding waste recycling, renewable energy production, organic fertilizer manufacturing, and other climate-smart agribusiness ventures. Investments, supported by public–private partnerships and favourable business policies, can accelerate technology transfer, infrastructure development, value-chain expansion, and job creation.

Overall, strengthening government support, research, youth engagement, digital agriculture, circular bio economy initiatives, and private sector investment will accelerate the adoption of resource-efficient agricultural waste management. These policy directions will improve agricultural productivity, environmental sustainability, food security, rural employment, and climate resilience while promoting long-term sustainable agribusiness development.

9.0 Conclusion

Resource-efficient agricultural waste management is a key component of climate-smart agribusiness, transforming agricultural residues from environmental burdens into valuable resources. Through practices such as composting, organic fertilizer production, biogas generation, biochar production, biomass briquetting, livestock feed processing, and mushroom cultivation, agricultural waste can be converted into products that improve soil fertility, generate renewable energy, reduce greenhouse gas emissions, and create additional income for farmers.

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