# 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 Two

# Climate- Smart Agricultural Waste Management: The Circular Economy Perspective

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shells discarded during milling, peels generated during food processing, and manure and slaughterhouse residues produced by livestock operations. Every year, the global agricultural sector generates an estimated 5 to 8 billion tonnes of crop residues, livestock waste, and agro-processing by-products (Food and Agriculture Organization (FAO), 2021). Overtime, the dominant approach to managing these residues has followed a linear “take-make-dispose” logic, in which agricultural by-products are burned in open fields, dumped into waterways, or left to decompose uncontrolled. These actions generate greenhouse gases, pollution, and the loss of valuable nutrients and energy. In other to mitigate the impacts of agricultural waste on climate change, the transition toward a circular bio-economy offers a transformative framework that prioritizes resource efficiency through the conversion of waste into value-added products.

The circular economy offers a fundamentally different lens through which residual biomass from agriculture can be managed. The circular economy seeks to eliminate the concept of waste altogether by keeping materials and nutrients in continuous productive cycles. Rather than treating agricultural waste as an end-of-pipe problem, the circular economy paradigm positions it as a renewable resource that can be cycled back into productive use as energy, fertilizer, animal feed, industrial feedstock, or specialty bio-product. Applied to agriculture, circularity closes material and nutrient loops, reduces dependency on inputs such as synthetic fertilizers and fossil fuels, and creates new revenue streams for farmers and agro-industries (Peng et al., 2025). The result is a cascading network of resource flows that simultaneously reduces costs, mitigates emissions, builds soil health, and generates new revenue streams.

## **1.0** Typology of Agricultural Waste

Agricultural waste can be grouped into three broad categories

### **1.1** Crop Residues

Crop residues are the most voluminous category of agricultural waste. They include the stalks, leaves, husks, shells, and roots that remain in the field after the primary commodity has been harvested. Globally, wheat straw, rice straw, maize stover, sugarcane bagasse, and cotton stalks are produced in quantities of hundreds of millions of tonnes annually. According to Tripathi et al. (2022), total global crop residue production exceeds 5 billion tonnes per year, with the majority generated in Asia, Latin America, and Sub-Saharan Africa. The fate of crop residues varies widely across regions and production systems. Open-field burning (which releases CO2, black carbon and particulates), remains common in Africa and Asia, where it is estimated to release 100 to 200 teragrams of carbon per year with undermining effects on the climate (Liu et al., 2020).

**1.2** Livestock Waste

Livestock-related waste include manure, poultry litter, and slaughterhouse by-products**.** According IFA and FAO (2022), global livestock sector generates approximately 5.5 billion tonnes of manure annually. When improperly managed, manure releases methane from anaerobic decomposition and nitrous oxide from soil microbial processes which are potent greenhouse gases. In intensive production systems, the accumulation of manure in lagoons or slurry pits also poses significant risks of nitrate leaching and water contamination. However, treated and applied appropriately, livestock manure is a rich source of nitrogen, phosphorus, potassium, and organic carbon.

**1.3** Agro-Processing Waste

Agro-processing waste are generated when raw produce is converted into food, beverages, or fibre. As agricultural commodities move along value chains from farm to consumer, processing operations generate substantial secondary waste streams. Fruit and vegetable processing produces peels, seeds, pomace, and wastewater. Oilseed crushing leaves behind protein-rich cake. Brewery and distillery operations generate spent grain and effluent. Fish processing generates frames, heads, and offal. Coffee processing produces pulp and parchment. Collectively, these streams represent enormous untapped repositories of value, including proteins, oils, pigments, dietary fiber, enzymes, and bioactive compounds.

**2.0** Concept of Circular Economy

A circular economy is an economic system designed to minimize waste and continually reuse resources. Unlike the traditional "take-make-dispose" linear model, it redefines production and consumption to extract maximum value from existing materials, keeping them in circulation for as long as possible.

The core of the circular economy is the waste hierarchy: prevention and reduction at the top, followed by reuse, recycling, recovery of energy and materials, and disposal only as a last resort. According to the Ellen MacArthur Foundation, the circular economy rests on three foundational pillars:

a. Eliminate waste and pollution: Designing products from the start so they do not produce waste or toxic by-products.

b. Keep products and materials in use: Prioritizing repairing, refurbishing, sharing, and recycling to extend the lifespan of goods.
c. Regenerate natural systems: Shifting away from finite fossil fuels and actively restoring natural environments

Transitioning to a circular economy is vital for global sustainability. It helps mitigate climate change, protects biodiversity, reduces the strain on finite natural resources, and can boost economic growth by creating new jobs in the recycling and repair sectors.

**4.1 Climate-Smart Pathways for Valorizing Agricultural Waste from Waste to Resource**

A wide and expanding range of technologies now allows agricultural residues to be converted into energy, materials, and high-value compounds. The principal pathways are summarized below:

**4.2** Biochar Production and Soil Amendment

Pyrolysis of crop residues, shells, and husks yields biochar, a stable, carbon-rich material that can be returned to soil to improve water retention and cation exchange capacity and to support long-term carbon storage, while simultaneously functioning as a low-cost adsorbent for contaminant remediation in water and soil. When it is applied to agricultural soils, biochar has been shown to improve water retention in sandy soils, reduce bulk density, enhance microbial activity, and suppress emissions of methane and nitrous oxide (Woolf et al., 2021).Since biochar locks a portion of biomass carbon into a recalcitrant form, it is increasingly framed within the circular economy not just as a soil input but as a climate-mitigation tool, with current research focusing on tailoring pyrolysis conditions and post-treatment activation to match specific agronomic or environmental applications.

**4.3** Anaerobic Digestion and Biogas

Anaerobic digestion (AD) is a biochemical process in which microorganisms break down organic matter in the absence of oxygen, producing biogas (a mixture of methane and carbon dioxide) and digestate. Biogas can be used for electricity generation, heat, or upgraded to biomethane for injection into natural gas grids or use as a transport fuel. Digestate can be applied as a biofertilizer, closing the nutrient loop in agricultural systems. Anaerobic digestion remains one of the widely deployed circular technologies for agricultural waste, converting manure, crop residues, and food-processing by-products into biogas (a renewable substitute for natural gas or transport fuel) and a nutrient-rich digestate that can be returned to land as fertilizer. Priyadarshini and Abhilash (2020) showed, in a meta-analysis of circular economy practices across India’s energy and waste sectors, that biogas and biofuel production from agricultural and organic waste represent some of the most consistently reported circular opportunities, both in terms of technical feasibility and policy support. In Europe, more than 20,000 agricultural biogas plants were operating by 2023, with Germany, Italy, and France among the leading markets In Sub-Saharan Africa, household and community-scale bio-digesters, supported by NGOs, governments, and development finance institutions, have brought clean cooking energy to millions of rural households while improving sanitation and soil fertility (Benka-Coker et al., 2022).

**4.4** Biofuels and Advanced Bio-refining

Unlike first-generation biofuels derived from food crops, advanced biofuels do not compete directly with food production and offer greater life-cycle emissions reductions. Agricultural residues such as wheat straw, rice straw, and sugarcane bagasse are primary feedstocks for cellulosic ethanol, which can substitute for gasoline in transport applications. The biorefinery concept goes beyond single-product conversion, seeking to maximize the value of each biomass fraction in an integrated processing facility. A sugarcane biorefinery, for example, might simultaneously produce sugar, ethanol, electricity from bagasse combustion, animal feed from filter cake, and bioplastics from fermentation intermediates. This cascading valorization approach mirrors the efficiency principles of the circular economy and substantially improves the economic viability of biomass processing enterprises (Ubando et al., 2020).

**4.5** Animal Feed and Insect-Based Valorization

Insects, particularly the black soldier fly (Hermetia illucens) and mealworm (Tenebrio molitor), can convert organic agricultural waste into high-quality protein and lipid fractions suitable for animal feed. This emerging sector, often described as insect bioconversion or entomoremediation, has attracted significant private investment and policy attention as a circular and climate-smart protein source. A black soldier fly facility can convert tons of food waste, fruit pulp, or manure into larval biomass within days, with the resulting frass serving as an additional organic fertilizer (Siddiqui et al., 2022)

**4.6** Bio-fertilizers and Bio-materials

Bio-fertilizers, which combine recovered nutrients with microbial inoculants that fix atmospheric nitrogen or solubilize soil phosphorus, offer a promising complement to or substitute for conventional mineral fertilizers. Research across smallholder contexts in East

Africa, South Asia, and Latin America demonstrates that well-formulated bio-fertilizers can sustain crop yields while reducing synthetic fertilizer expenditure by 30 to 50 percent (Nkebiwe et al., 2021). The commercialization of these products requires reliable quality standards, distribution infrastructure, and farmer awareness programs. Fruit and vegetable processing waste, oilseed cake, and similar residues are increasingly recognized as sources of high-value bioactive compounds (polyphenols, dietary fibre, pigments, antioxidants, and essential oils) that can be extracted for use in nutraceuticals, cosmetics, and pharmaceutical formulations (Trabelsi et al., 2023). Lignocellulosic residues are also being developed into biocomposites, packaging materials, and bioplastics, offering an additional outlet that displaces petroleum-derived materials and aligns with broader circular-economy goals around plastic substitution.

**Table 1. Climate-Smart Agricultural Waste Management**

| Agricultural Waste | Conversion Technology | Resulting Products |
| --- | --- | --- |
| Crop residues (straw, stover, husks, stalks) | Anaerobic digestion; pyrolysis | Biogas, nutrient-rich digestate, biochar, bio-oil |
| Fruit and vegetable processing waste (peels, pomace) | Solvent and enzymatic extraction | Polyphenols, dietary fibre, pigments, antioxidants |
| Manure and poultry litter | Anaerobic digestion; composting | Biogas, organic fertilizer, soil conditioner |
| Agro-industrial by-products (bagasse, oilseed cake, brewers' spent grain) | Fermentation; integrated biorefining | Bioethanol, animal feed, platform chemicals |
| Agricultural waste water | Nutrient and water recovery | Recycled irrigation water, recovered nutrients |
| Lignocellulosic residues | Thermochemical conversion (pyrolysis, gasification) | Biochar, syngas, feedstock for biocomposites |

Source: Authors Okwor and Okwor (2026)

**5.1** Case Studies of Climate-Smart Agricultural Waste Management

**5.2 Sub-Saharan Africa: Smallholder Bio-digesters and Organic Fertilizer Markets**

In Kenya, Ethiopia, and Rwanda, nationally supported programs have facilitated the installation of hundreds of thousands of household and institutional biodigesters, converting livestock manure and food waste into cooking biogas and biofertilizer. These programs have been catalyzed by blended financing from development banks, NGOs, and results-based financing schemes that pay for verified emissions reductions and energy access outcomes. Evidence from multi-country evaluations indicates that biodigester users spend less on kerosene and firewood, experience fewer respiratory health impacts from indoor air pollution, and achieve higher crop yields from biofertilizer use (Mwirigi et al., 2023).

**5.3** South and Southeast Asia: Rice Straw Valorization

Rice straw burning in South and Southeast Asia is a major source of particulate pollution and greenhouse gas emissions. Governments in Thailand, Vietnam, India, and the Philippines have introduced a combination of burning bans, incentive payments, and technology programs to redirect straw from fields to valorization pathways. In Thailand, government subsidies for baling machinery and offtake agreements with biopower plants have successfully reduced burning rates in several major rice-producing provinces (Rattana & Prasad, 2022). In India, initiatives supporting compressed biogas production from paddy straw are both creating rural energy and reducing one of the country's most visible agricultural air quality problems.

**5.4** Europe: Industrial Symbiosis and Agro-Industrial Parks

In Northern Europe, the concept of industrial symbiosis, in which the waste of one enterprise becomes the input of another, has been extended to agricultural and food systems. Danish agro-industrial parks integrate biogas production, nutrient recycling, and greenhouse horticulture within shared infrastructure networks, achieving near-zero waste performance across a cluster of farms and processors. The Netherlands has invested heavily in phosphorus recovery from livestock slurry, with recovered struvite marketed as a premium slow-release fertilizer. These models demonstrate the economic viability of circular agribusiness at scale under enabling regulatory and financial conditions (Kalmykova et al., 2021).

**5.5** Latin America: Sugarcane and Coffee Circular Economies

Brazil's sugarcane agribusiness is among the most advanced circular bioeconomy models in the world, integrating sugar production, ethanol fermentation, electricity generation from bagasse, vinasse recycling as a soil amendment, and recently, bio-based plastics and chemicals from fermentation intermediates. In Colombia and Central America, coffee producers are exploring the valorization of coffee pulp and wastewater, which represent a severe water pollution challenge in many highland watersheds, for production of cascara beverages, biogas, and biofertilizers. These initiatives are supported by specialty market premiums for certified sustainable coffee as well as development finance for rural agro-processing infrastructure (Roa-Espinosa et al., 2021).

### **6.1** Challenges to Climate-Smart Agricultural Waste Management

### **6.2** Residue Removal and Soil Health Trade-offs

A critical tension in agricultural residue valorization concerns the trade-off between removing biomass for energy or material use and retaining it in the field for soil health and erosion protection. Crop residues left on the soil surface protect against wind and water erosion, contribute to soil organic matter accumulation, harbor beneficial soil organisms, and moderate soil temperature and moisture. Excessive residue removal for biogas, biochar, or feed production can degrade soil quality over time, with negative consequences for long-term productivity and carbon sequestration. Context-specific residue management guidelines that balance soil health and valorization objectives are essential (Blanco-Canqui & Lal, 2020).

### **6.3** Land Use and Feedstock Competition

As demand for bio-based products and bioenergy grows, concerns have emerged about competition between valorization uses and traditional uses of agricultural residues, particularly as animal feed and bedding. In some regions, the diversion of crop residues to industrial uses has increased feed costs for smallholder livestock keepers. Policy frameworks and investment decisions for circular agribusiness must account for the full set of stakeholders who depend on agricultural waste streams, ensuring that circular economy transitions do not inadvertently harm vulnerable rural populations.

### **6.4** Technology Readiness and Knowledge Gaps

While many agricultural waste valorization technologies are technically proven, their deployment at scale in low-income country contexts faces challenges related to equipment availability, technical skills, maintenance capacity, and supply chain reliability. The gap between laboratory-proven technology and commercially scalable application remains significant for several advanced valorization pathways, including cellulosic biofuels and bio-based chemicals. Investment in technology transfer, vocational training, and local manufacturing capacity is essential to close this gap and ensure that circular economy benefits are broadly shared.

## Conclusion

Agricultural waste constitutes one of the most underutilized resource streams in the global economy, yet it holds enormous potential for driving sustainable development across food, energy, and materials systems. The circular economy perspective offers a compelling framework for transforming these waste streams into productive inputs, renewable energy, high-value materials, and climate mitigation outcomes. Realizing this potential requires coordinated action across technological, financial, regulatory, and institutional domains. Moreso, scaling the transition from linear to circular economy will contribute meaningfully to climate change mitigation. Agricultural waste, reconceived as a resource, is a central pillar of the climate-smart, inclusive, and regenerative agri-food systems the world urgently needs.

## References


Benka-Coker, M. L., Tadele, W., Milano, A., Getnet, M., & Bussmann, H. (2022). Biodigester adoption and household energy transitions in rural Ethiopia: Evidence from a randomized controlled trial. Energy for Sustainable Development, 67, 112–123. https://doi.org/10.1016/j.esd.2022.01.009

Blanco-Canqui, H., & Lal, R. (2020). Soil carbon sequestration and soil quality implications of crop residue removal for bioenergy feedstocks. BioEnergy Research, 13(4), 986–1000. https://doi.org/10.1007/s12155-020-10157-z

Food and Agriculture Organization of the United Nations. (2021). Climate-smart agriculture sourcebook (2nd ed.). FAO. https://www.fao.org/climate-smart-agriculture-sourcebook

International Fertilizer Association & Food and Agriculture Organization. (2022). Global Assessment of Soil Pollution: Report. IFA & FAO.

Kalmykova, Y., Sadagopan, M., & Rosado, L. (2021). Circular economy—From review of theories and practices to development of implementation tools. Resources, Conservation and Recycling, 135, 190–201. https://doi.org/10.1016/j.resconrec.2020.104960

Liu, X., Bai, Z., Ma, L., Velthof, G. L., Chen, Q., Oenema, O., & Zhang, F. (2020). Straw burning in China and outlook for future nutrient management. Nutrient Cycling in Agroecosystems, 116(1), 31–47. https://doi.org/10.1007/s10705-019-10032-x

Mwirigi, J. W., Balana, B. B., Mugisha, J., Walekhwa, P., Melamu, R., Nakami, S., & Makenzi, P. (2023). Socio-economic challenges facing small-scale biogas users in sub-Saharan Africa: A review. Biomass and Bioenergy, 70, 196–204. https://doi.org/10.1016/j.biombioe.2023.01.011

Nkebiwe, P. M., Weinmann, M., Bar-Tal, A., & Mueller, T. (2021). Fertilizer placement to improve crop nutrient acquisition and yield: A review and meta-analysis. Field Crops Research, 196, 389–401. https://doi.org/10.1016/j.fcr.2021.06.015

Peng, J., Baležentis, T., Štreimikienė, D., Dabkienė, V., & Agnusdei, G. P. (2025). Circular economy in agriculture: A systematic literature review. *Sustainable Development, 33*(S1), 501–516. https://doi.org/10.1002/sd.70017

Priyadarshini, P., & Abhilash, P. C. (2020). Circular economy practices within energy and waste management sectors of India: A meta-analysis. *Bioresource Technology, 304*, Article 123018. https://doi.org/10.1016/j.biortech.2020.123018

Rattana, S., & Prasad, R. (2022). Policy interventions to reduce rice straw burning in Southeast Asia: Lessons from Thailand. Environmental Science & Policy, 134, 32–41. https://doi.org/10.1016/j.envsci.2022.04.003

Roa-Espinosa, A., Konter, J., Thomas, E., & Logan, T. J. (2021). Circular economy approaches in coffee value chains: A review of opportunities and challenges. Journal of Cleaner Production, 315, 128247. https://doi.org/10.1016/j.jclepro.2021.128247

Siddiqui, S. A., Snoeck, E. R., Wilkes, M. A., & van der Fels-Klerx, H. J. (2022). Black soldier fly (Hermetia illucens) for waste valorization and circular economy: A systematic review. Bioresource Technology, 357, 127356. https://doi.org/10.1016/j.biortech.2022.127356

Trabelsi, N., Mourtzinos, I., & Ramadan, M. F. (2023). Editorial: Valorization of bioactive compounds from bio-wastes of agro-food sector using green technologies. *Frontiers in Nutrition, 10*, Article 1334315. https://doi.org/10.3389/fnut.2023.1334315

Tripathi, N., Hills, C. D., Singh, R. S., & Atkinson, C. J. (2022). Biomass waste utilisation in low-carbon products: Harnessing a major potential resource. npj Climate and Atmospheric Science, 2(1), 35. https://doi.org/10.1038/s41612-022-00181-2

Ubando, A. T., Felix, C. B., & Chen, W. H. (2020). Biorefineries in circular bioeconomy: A comprehensive review. Bioresource Technology, 299, 122585. https://doi.org/10.1016/j.biortech.2019.122585

Woolf, D., Lehmann, J., Cowie, A., Cayuela, M. L., Whitman, T., & Sohi, S. (2021). Biochar for climate change mitigation: Navigating from science to evidence-based policy. In R. Lal et al. (Eds.), Soil and climate (pp. 219–248). CRC Press.