

Editorial

Biochar and Circular Economy Approaches in Environmental Sustainability

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Adv Environ Eng Res
2025, volume 6, issue 4
doi:10.21926/aeer.2504035

Received: December 21, 2025
Accepted: December 22, 2025
Published: December 24, 2025

Abstract

The rising concerns of soil erosion, organic waste generation and global warming have shown the need to address them through multifaceted methods that transcend conventional linear models of resource utilization. Circular economy is a regenerative model that is anchored on caring about waste valorisation, resource effectiveness and environmental fortitude. In this paradigm, biochar has been developed as a multifunctional compound capable of integrating waste management, soil rehabilitation, climate control and renewable energy infrastructure. Manufactured through thermochemical treatment of biomass, biochar uses, organic waste into a stable, carbon rich resource material with a long term environmental capacity. This editorial expounds on the application of biochar in promoting circular-economy thinking on environmental sustainability and its role in sustaining the environment by curbing carbon emissions, fostering civilisation, and enabling agro-industrial symbiosis. Through linking the dots in the relationships between scientific data, policy application and practice, this editorial illustrates the opportunities of biochar as a tactical tool in transitioning to circular, low-carbon, and regenerative environmental frameworks.



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Keywords

Soil health; environmental sustainable; circular economy

1. Introduction

Their mounting needs for soil erosion control, appropriate management of organic wastes, and global warming mitigation are such that they necessitate an overhaul of environmental sustainability in various agricultural, industrial, and urban environments. The traditional linear development models that are characterized by removal, consumption, and disposal are not equal to these challenges that are interdependent. The cycle economy has been a relatively attractive paradigm that guarantees the balance between environmental safety and socio-economic increase with the advent of the post-measuring sustainability paradigm of regeneration and resource efficacy. Biochar has attracted growing scholarly interest as a scientifically grounded intervention that may synergistically benefit waste valorisation, climate reduction, and ecosystem restoration [1-3].

The niche of biochar lies between soil science, waste management and climate policy. It is produced through thermochemical alteration of biomass under conditions of no oxygen hence, organic remains are transformed to the stable, carbon-based material, which offers long-term environmental benefits. The properties that have made biochar the most outstanding among other sustainability interventions include that, it is multi purposeful; the formation of garbage is minimized, the soil is made healthier, pollution is minimized and carbon is captured [4, 5]. This combination of benefits, therefore, makes biochar especially pertinent to circular-economy approaches built on the concepts of material cycles and the regeneration of natural systems, rather than diminishing environmental impact.

The systematic cycle of biochar circular economy modal and sustainable cycle has been presented in Figure 1 and Figure 2. This Editorial discusses why biochar is becoming increasingly important in the context of the circular economy and why such an application has greater environmental sustainability implications. Instead of considering biochar as a univocally-purpose treatment of soil, the discourse anticipates the systemic opportunities of biochar to change the treatment, reuse, and inclusion of organic resources in productive landscapes.

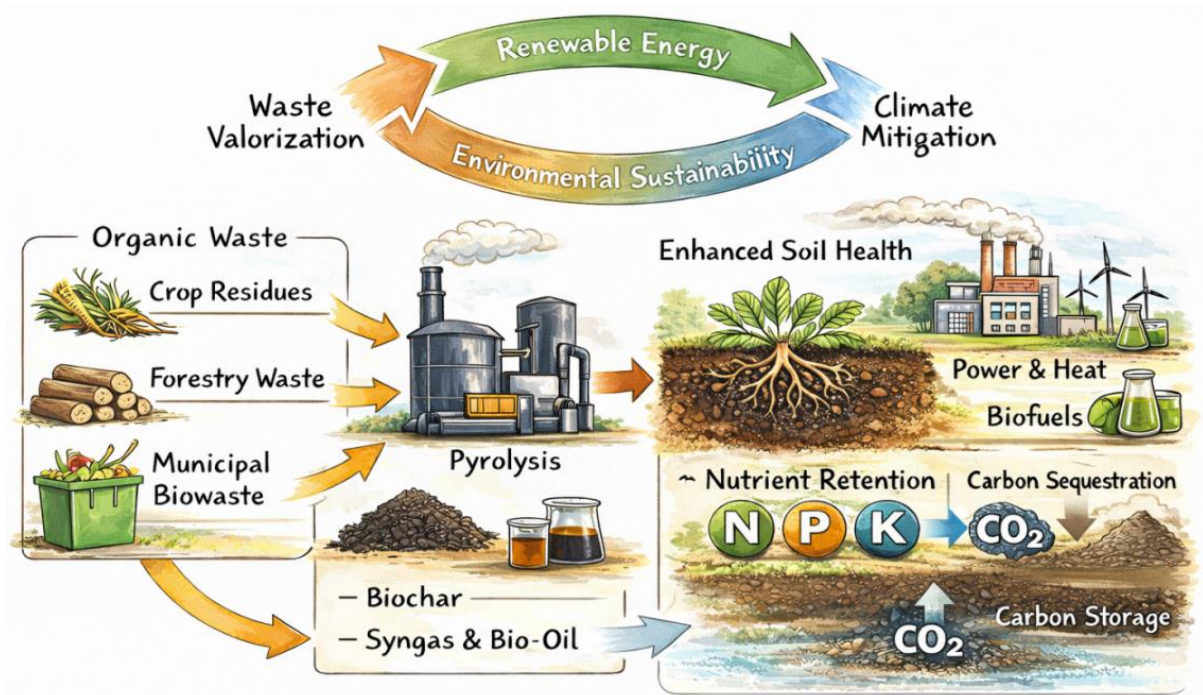


Figure 1 The systematic cycle of biochar circular economy modal.

**BIOCHAR & THE CIRCULAR ECONOMY
A SUSTAINABLE CYCLE**

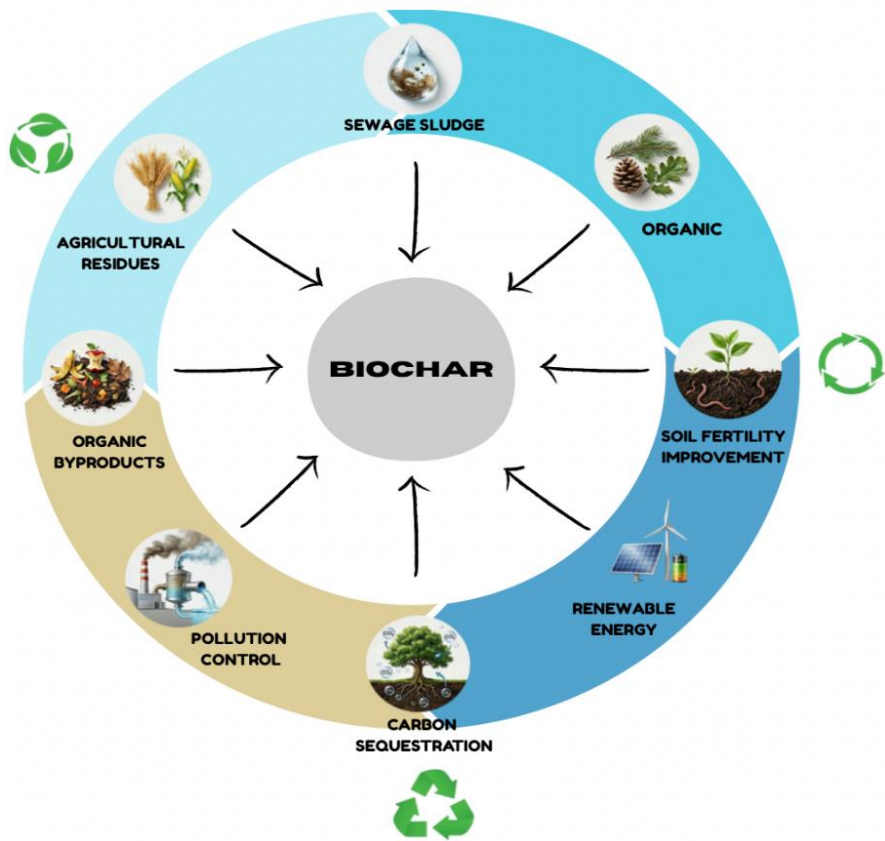


Figure 2 Biochar and the circular economy a sustainable cycle.

2. Biochar: Reframing Waste as a Resource

Biochar represents a paradigm shift in organic waste management and requires a redefinition of organic waste as an asset rather than a liability. Historically, agricultural wastes, forestry by-products, sewage sludge, and other organic effluents have been said to cause pollution, greenhouse effect, and health risks to the population. Biochar production offers a different route for treating these wastes, turning them into a stable carbonaceous product with long-term environmental benefits [4-6].

This shift to disposal to valorisation is just in line with the principles of the circular economy. Pyrolysis stabilises the carbon in solid form rather than allowing biomass residues to decompose or burn in an open fire, which would produce a lot of carbon dioxide, methane and other pollutants. As a result, biochar systems will resolve the issue of waste management besides aiding the production of renewable energy [7].

Besides its carbon sequestration properties, biochar also contains significant levels of mineral nutrients, which are derived from the biomass. These nutrients, when found in the soils, recycle into the biogeochemical cycles, and therefore, facilitate the growth of plants and eliminate the dependence on exogenic inputs of fertilizers. This material recycling characteristic supports the vision of a circular economy of getting the maximum value of materials and the minimum amount of waste.

3. Environmental Benefits That Are Systemically Relevant

3.1 Soil Health and Sustainable Production

The contribution of biochar to improving soil health has been extensively recorded; however, it is vital to note that it offers more than just a high yield on marginal productivity. Biochar application leads to better resilience of agroecosystems to an upward climatic variability by increasing the soil structure, improving the water-holding capacity, and maximizing the retention of nutrients in soils [6, 8]. Such properties have been helpful, particularly in the deficient and marginal soils where people do not expect long-lasting returns when using traditional inputs.

Biochar has been known to result in the progression of the microhabitat that supports diverse communities of the microbial soil in the fertile soil settings, and has been known to facilitate the cycle of nutrients, as well as the stabilization of organic matter. Such adaptations are fundamentally changing in a way that can potentially sustain the functionality of the soil over a span of decades, which will offer a switch-over of the input-based agriculture to more regenerative and resource-use-saving systems.

3.2 Carbon Sequestering and Mitigation of Global Warming

The ability of biochar to hold carbon throughout the years is one of the most significant properties of biochar. Unlike recently added organic material, which is easily broken down, biochar is composed primarily of aromatic carbon structures that do not degrade easily by microbes. This carbon, in the case of incorporation into soils, is likely to stay stable over centuries and thus effectively eliminates carbon dioxide action in the active carbon cycle in the atmosphere at the time [9-11].

Notably, the benefits of biochar-based systems are not confined to the reduction of carbon concentrations but also include larger climatic benefits. Biochar also helps to reduce the emissions of methane and nitrous oxide, which are two potent greenhouse gases, by diverting organic waste from landfills and open burning. In agricultural soils, it has been found that biochar modulates processes of transformation of nitrogen, hence lowering the emissions of nitrous oxide in special conditions. All of these effects reinforce the decision to consider biochar as a legitimate solution to the negative emissions package and the policies of climate-neutrality.

3.3 Pollution Control and Environmental Cleaning

Biochar has a highly porous structure and unique surface chemistry, which provides a high affinity capacity for a wide range of contaminants such as heavy metals, pesticides, and organic pollutants. When added to polluted soils, biochar is able to immobilize harmful elements to the extent that they are no longer available for transport into food chains [12]. Consequently, biochar is a critical tool in land remediation, especially in areas where industrial releases or the overuse of agrochemicals are a problem.

Beyond the use of soil applications, biochar is being explored more for its role in water treatment applications. Modified biochars with particular surface characteristics may filter out nutrients, pharmaceuticals, and other emerging contaminants from wastewater. These applications broaden the relevance of biochar [beyond agriculture], emphasizing the potential of biochar for integrated environmental management systems.

4. Biochar in the Circular Economy Practice

The chairs of reduction, reuse, and recycling are considered to be the principles around which the circular economy is being formulated. Biochar deserves to conform to these ideals, as it reduces reliance on artificial inputs by making nutrient-use efficiency, transforming organic residues into feedstocks instead of wastes, and making it easy to recycle carbon and nutrients into productive systems [13, 14]. Environmental sustainability outcomes and the systematic cycle of biochar in soil-plant have been depicted in Figure 3 and Figure 4. Circular systems with biochar as their core can be implemented in agro-industrial landscapes. Biochar can be produced in-store by taking the residues of rice mills, sugar factories, or oilseed processing plants in order to convert them into biochar and reintroduce them to the adjacent fields. Local loops of this nature lower the cost of transportation, cut down the emission level, and enhance the self-sufficiency of the regions in resources. These systems, when combined with decentralized pyrolysis technologies, have specific applicability in the rural and peri-urban environments.

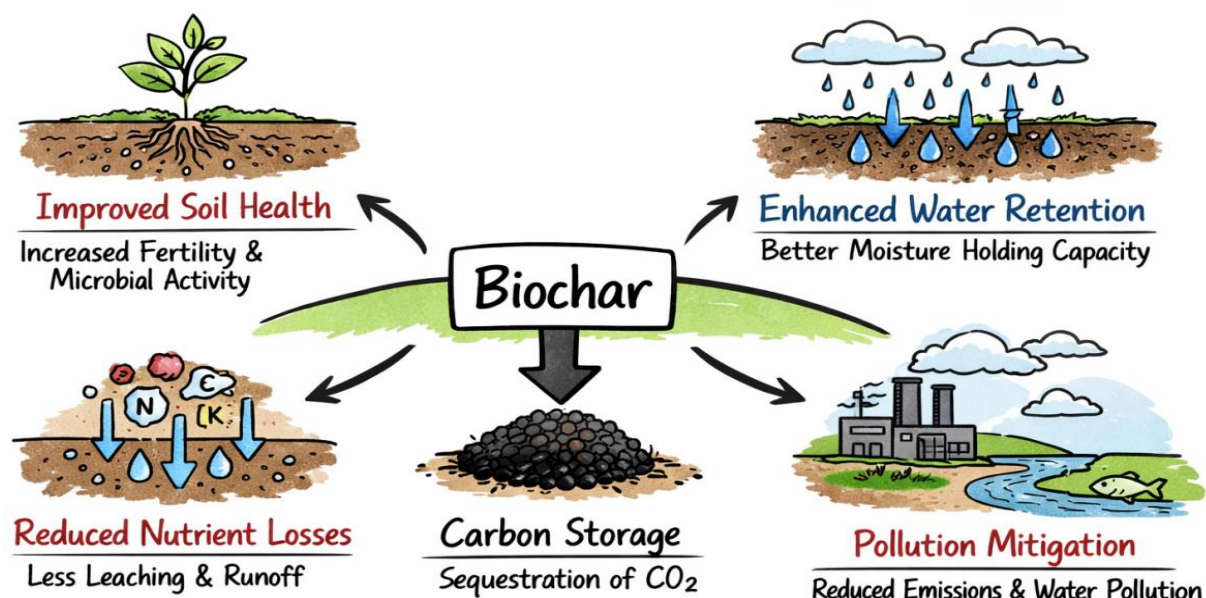


Figure 3 Environmental sustainability outcomes of biochar application.

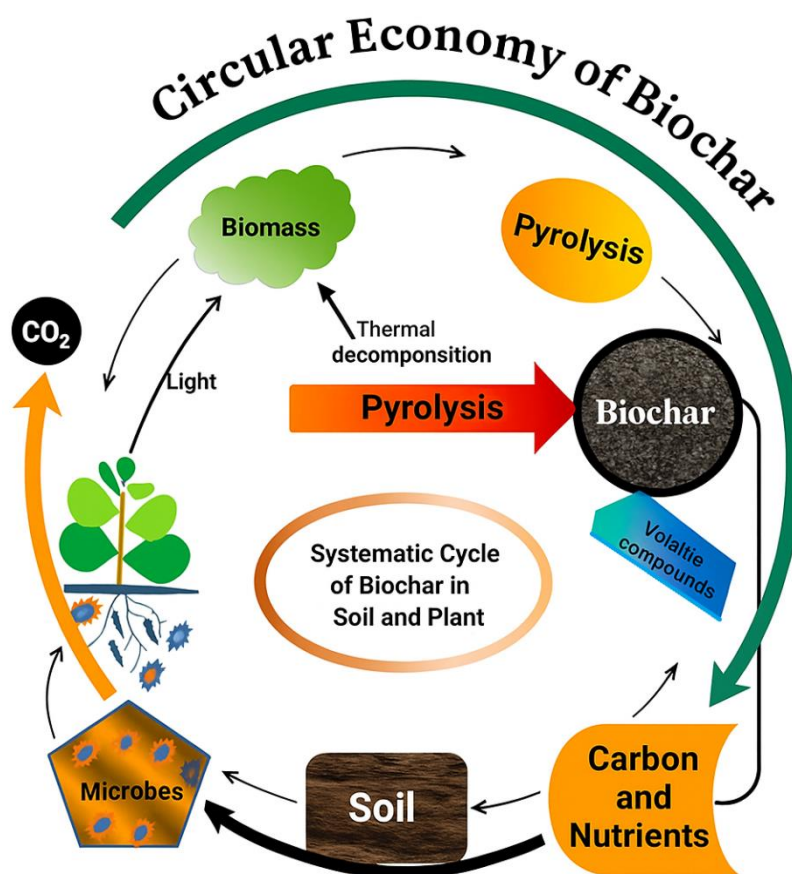


Figure 4 Systematic cycle of biochar in the soil-plant system.

City settings are also promising in regard to circular biochar systems. When the municipal organic waste is treated in a safe manner, the waste can be made into biochar that can be used in the urban green areas, stormwater management, and soil restoration. These applications depict how biochar can grasp the concept of circularity in rural and urban ecosystems.

5. The New Opportunities in Environmental Sustainability

5.1 Climate-Resilient Landscapes

The worsening of climatic extremities creates a great urgency for robust landscapes. Biochar-amended soils are more resistant to drought and erosion, and thus, they become more resilient to climatic perturbations. In land restoration projects, biochar helps to enable faster plant growth, enhances soil stability, and encourages the replenishment of organic carbon reserves to foster the recovery of ecosystems in the long term [15].

5.2 Water Resource Protection

Agricultural landscapes are also driven by the exportation of nutrients that subsequently cause water pollution. Biochar helps to protect the surface and groundwater quality through the augmentation of nutrient retention and the diminution of erosion and leaching. In built wetlands and filtration systems, biochar-based media have the potential to supplement the purification of pollutants, providing alternative low-cost solutions to wastewater treatment and re-use of water.

5.3 Sustainable Innovation and Industrial Symbiosis

Biochar provides the routes in the process of industrial symbiosis, whereby it is a waste stream used in other sectors as input. Agricultural and forestry waste, as well as specific industrial byproducts, can be utilized in biochar production systems, thus creating value chains that do not conflict with economic incentives but achieve economic goals through environmental concerns. These symbiotic associations play a crucial role in the promotion of transitions to a circular economy on a large scale.

5.4 Research and Policy Necessities

In spite of the heavy empirical evidence, there is an inconsistency in the adoption of biochar. The inconsistency of the policy framework, lack of standardized quality specification, and limited awareness among end users are all hindering wider implementation. The potential to implement biochar in waste management laws, climate control programs, and soil quality and health initiatives can significantly accelerate its usage.

In particular, standardization is very important for biochar produced from complex feedstocks such as sewage sludge. There must be clear guidelines on safety, contaminant limits, and performance to convey some trust to agronomists, industry, and regulators. Simultaneously, scientific studies should continue to justify the production mechanisms and assess the sustainability of such intervention on a long-term basis, and other applications of works, not being an agrarian one.

5.5 Toward a Circular and Regenerative Future

The transition to a circular economy demands a combination of solutions that could satisfy technical efficacy, social acceptance, economic viability, and environmental sustainability simultaneously. Biochar is one such thrilling contract in this paradigm; it harmonizes most of the

objectives of sustainability with the conversion of the waste into a market commodity, carbon reduction in the atmosphere, improved functioning, and renewable energy infrastructures [1, 3, 11].

Achievement of the maximum potential of biochar involves complex collaboration with diverse groups of stakeholders. The researchers must be constantly generating valid and context-specific empirical data. It requires policymakers to come up with institutions that are empowering and encourage circular practices. Practitioners, in their turn, are to adapt technologies to the local needs and circumstances. All these building blocks, when combined, can take building to a more business-to-business sustainable approach for a niche-market commodity.

6. Conclusion

Biochar no longer has a restricted value and importance as a soil amendment tool. When institutionalized as a form of a circular economy, however, it is a strategic intervention that can react in response to some of the most urgent environmental challenges of modern society. Its effectiveness can mainly be attributed to its ability to integrate, which incorporates the elements of waste management, climate reduction, soil reconstruction, food security, scientific innovation, and policy relevance. Taking into consideration the changing priorities of environmental sustainability, biochar can be considered an interesting case of how the approach of circular thinking can be converted into a material, long-term gain for ecosystems and society.

Author Contributions

The author did all the research work for this study.

Competing Interests

The authors have declared that no competing interests exist.

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