WASTE-DERIVED BIOCHAR FOR SUSTAINABLE RURAL REVITALIZATION

EDITED BY
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WILEY

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Library of Congress Cataloging-in-Publication Data:

Names: Sun, Yuqing (Assistant professor) editor | Tsang, Daniel C. W. editor
Title: Waste-derived biochar for sustainable rural revitalization / edited by Yuqing Sun, Daniel C.W. Tsang.
Description: Hoboken, New Jersey: Wiley, [2026] | Includes bibliographical references and index.
Identifiers: LCCN 2025030995 | ISBN 9781394250271 hardback | ISBN 9781394250295 adobe pdf | ISBN 9781394250288 epub | ISBN 9781394250301
Subjects: LCSH: Biochar | Rural development | Sustainable agriculture
Classification: LCC TP248.B55 W36 2026
LC record available at https://lccn.loc.gov/2025030995

Cover Design: Wiley
Cover Image: © fotoVoyager/Getty Images

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Preface

With advancements in agricultural productivity and rural living standards, the daily generation of waste biomass resources—such as crop residues, fruit tree prunings, animal manure, food waste, and domestic sludge—has risen significantly. However, the indiscriminate disposal and open burning of these wastes pose severe threats to rural ecosystems. The high-value utilization of waste biomass presents a viable pathway toward establishing zero-waste communities, fostering a circular economy, and supporting global pollution mitigation efforts. Furthermore, it contributes to achieving carbon emission peaks and carbon neutrality goals. Among emerging solutions, pyrolysis (300–700 °C under oxygen-limited conditions) converts waste biomass into a carbon-rich solid known as biochar.

This book synthesizes the latest research developments, state-of-the-art knowledge, and practical case studies while providing scientific insights, identifying current challenges, and outlining future directions for biochar technologies as a novel, cost-effective, and eco-friendly approach to sustainable rural revitalization. It systematically reviews application-oriented biochar production technologies using rural waste biomass, emphasizing the tailored selection of pyrolysis conditions and pre-/post-treatment methods. Additionally, the book explores diverse applications of biochar in rural development, including:

- Renewable biofuels
- Clean compost conditioners
- Organic seedling substrates
- Slow-release fertilizers and green pesticides
- Targeted plant disease suppression
- Farmland soil conditioning and amendment
- Adsorbents/catalysts for agricultural wastewater treatment
- Carbon sequestration in soils
- Low-carbon construction materials

This book also evaluates these technologies through Technical and Economic Analysis (TEA), Environmental, Social, and Governance (ESG) frameworks, and discusses potential environmental risks.

This work will serve as a valuable reference for engineers, scientists, researchers, and graduate students in waste recycling and management, sustainable rural development, environmental engineering, civil engineering, chemical engineering, and related fields.

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Tailored Biochar Production from Waste Biomass Resource in Rural Areas

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1.1 Introduction

The conceptual foundation for biomass conversion into biochar was first proposed by Seifritz in 1993. Over a decade later, Marris (2006) expanded upon this idea through a comprehensive theoretical investigation, which subsequently stimulated widespread academic interest following the publication of his research. With progressive advancements in scientific knowledge and technological innovation, biochar-related methodologies have undergone continuous refinement and development.

Biochar represents a carbon-dense solid substance generated via thermochemical decomposition of biomass in oxygen-restricted environments. Recent scientific investigations have expanded the range of organic feedstocks suitable for biochar fabrication, encompassing not only conventional lignocellulosic biomass but also agricultural byproducts, food waste, livestock excreta, and residual sludge from wastewater treatment. The heterogeneous nature and complex treatment requirements of municipal and rural solid waste streams demand novel processing methodologies. Current research demonstrates that such waste materials exhibit considerable potential as precursor substances for biochar generation. This transformation process offers a dual benefit: it enables effective waste valorization while simultaneously providing an environmentally sustainable strategy for solid waste treatment.

Biochar exhibits a well-developed porous architecture, considerable surface area, and numerous stable surface functional moieties, endowing it with versatile

Waste-derived Biochar for Sustainable Rural Revitalization, First Edition. Edited by Yuqing Sun and Daniel C.W. Tsang.
Published 2026 by John Wiley & Sons, Inc.

applications across multiple environmental domains. These include but are not limited to soil enhancement and reclamation, aquatic contaminant mitigation, water resource regeneration, carbon capture and storage, as well as renewable energy applications. The material's effectiveness arises principally from its capacity to modulate carbon transformation processes, alleviate contamination by organic compounds and heavy metals, and modify microbial community dynamics and metabolic functions (Zhu et al. 2014). The remediation performance of biochar is fundamentally governed by its physicochemical characteristics, which are in turn dictated by production parameters and precursor materials. Consequently, systematic investigation of biochar fabrication methodologies and feedstock selection constitutes a critical research focus for optimizing its functional properties and environmental applications.

Contemporary advancements in biochar production technology have reached a sophisticated stage of development. Tailored synthesis approaches now enable the fabrication of high-performance biochar materials optimized for specific applications. This technological evolution is primarily motivated by the need to identify ideal preparation parameters that account for the heterogeneous nature of solid waste feedstocks, diverse application scenarios, and varying remediation objectives. With environmental pollution challenges growing increasingly intricate and multifaceted, there emerges a pressing requirement for biochar with superior functional characteristics. To meet these evolving demands, researchers are focusing on developing biochar-based composite materials through various modification strategies that augment conventional production techniques. Such engineered materials demonstrate enhanced capacity for pollutant sequestration and environmental remediation. In practical implementation, comprehensive assessment of biochar applications must consider multiple factors: the material's intrinsic properties and remediation performance, resource conversion efficiency, as well as the associated energy consumption and economic viability of production processes. This multidimensional evaluation framework ensures both optimal resource utilization and environmentally sustainable practices.

1.2 Overview of Rural Solid Wastes

In the context of accelerated economic growth in recent decades, environmental conservation has often been overlooked, resulting in numerous ecological challenges. These environmental disturbances not only compromise ecosystem equilibrium but also impose constraints on sustainable economic progress. This dual impact has consequently elevated environmental concerns to a prominent position in public discourse. Among various environmental pollutants, solid waste—classified as one of the "three major waste streams"—holds particular significance due to its direct relevance to public life. The management and treatment