ISSN: 2837-4509
Iris Online Journal of
Arts and Social Sciences
DOI: 10.33552/IOJASS.2026.02.000546
Iris Publishers

Review Article

Agricultural Transition through Green Technologies: A Bibliometric Study on Biogas, Biochar, and Low-Carbon Agriculture in Sustainability Transitions

Apostolos Goulas[1*] and Ilias Tsotsas[2]

[1]*University of Thessaly, Department of Planning and Regional Development, Volos, Greece*

[2]*International Hellenic University, Department of Business Administration, Serres, Greece*

Corresponding author: Apostolos Goulas, University of Thessaly, Department of Planning and Regional Development, Volos, Greece

Received Date: April 20, 2026

Published Date: May 05, 2026

Abstract

Agriculture, as a key sector of the global economy, faces increasing pressures from climate change, with greenhouse gas emissions accounting for approximately 24% of global emissions, combined with the depletion of natural resources and the rapid increase in demand for food, requiring innovative solutions such as the circular bioeconomy and the integration of renewable energy sources. The purpose of this bibliometric study is to systematically map the literature on agricultural transition through green technologies, with an emphasis on biogas, biochar, and low-carbon practices, in order to highlight the interactions that reinforce sustainability policies at the European and international levels. The methodology is based on the analysis of data from Scopus for the period 2020-2025, using VOS viewer to visualize collaboration networks and thematic groups, applying filters to English publications and thematic searches (e.g. biogas OR biochar AND agriculture). The results reveal four main thematic pillars (anaerobic digestion and circular bioenergy, carbon sequestration through pyrolysis, biomass for rural development and climate-resilient agriculture) with an upward trend in the EU after 2020 (Green Deal), identifying gaps such as economic scaling.

Introduction

Climate change has been affecting many sectors for several years now. One important sector that has been affected is agriculture, which is called upon to manage this significant change, facing on the one hand pressure to reduce gas emissions and on the other hand the ever-increasing demand for food. In recent years, agriculture has been confronted with the depletion of natural resources and the need to reduce greenhouse gas emissions, which account for approximately 24% of global emissions (Kabeyi & Olanrewaju [1]; Moshahary et al. [2]). In this context, technological innovations that contribute to the circular economy and to reducing emissions from the agri-food system are considered critical elements of a sustainable transition (Yadav et al. [3]). This study synthesizes current scientific activity around three important green transition technologies in agriculture, namely biogas and its digestion product, biochar and integrated carbon sequestration processes, as well as low-carbon practices in the agroecosystem. This bibliometric study focuses on the evolution of research (2020-2024) on these technologies, using data from Scopus and visualization with VOS viewers, to identify thematic groups such as agricultural waste management, carbon sequestration, and sustainable energy. The publication of articles over the last five years (2020-2025) from the European Union highlights the need for a systematic assessment of the contribution of these technologies to improving productivity, economic sustainability, and climate resilience in the agricultural sector, in light of policy dynamics and environmental impacts. For this reason, this document aims to understand the dynamics of research, the main thematic areas, and the interactions between technological innovations, environmental performance, and socioeconomic impacts at the European level.

The purpose of this study is to systematically map the literature on agricultural transition through green technologies, with an emphasis on biogas, biochar, and low-carbon agriculture, in order to identify the links that support sustainability policies.

Specifically, the following research questions are examined:

i. What are the main thematic clusters and interactions between biogas, biochar, and low-carbon practices in sustainability research?

ii. How is the contribution of these technologies to emission reduction and the circular economy evolving at the European and international levels?

Anaerobic digestion of agricultural waste, such as manure, produces biogas and biomethane, reducing uncontrolled methane emissions and providing digestate as a natural fertilizer, contributing to a closed nutrient cycle. Biochar from biomass pyrolysis sequesters carbon in the long term, improves soil physicochemical properties, and reduces N_2O emissions, as confirmed by LCA studies (Pavesi et al. [4]; Devi et al. [5]; Wrzesińska-Jędrusiak [6]). Finally, the integration of biomass into renewable energy sources enhances rural development and the Sustainable Development Goals (Mona et al. [7]). This analysis reveals four clusters (e.g., circular bioenergy, carbon sequestration), providing a basis for future applications.

Methodology

To conduct the bibliometric analysis and study of research activity related to the green transition in agriculture, with an emphasis on biogas, biocarbon, and low-carbon agriculture technologies, the Scopus database was used. Scopus was selected because of its broad coverage of high-quality academic publications and its ability to provide detailed metadata, such as keywords, authors, countries, and publication sources.

The following keywords were used to search for the documents:

("biogas" OR "anaerobic digestion") AND ("agriculture" OR "farm") AND ("sustainab*" OR "transition*") OR ("biochar*" AND ("agricultur*" OR "soil*") AND ("carbon sequ*" OR "low-carbon")) OR (("low-carbon agricult*" OR "low carbon farm*") AND ("sustainab* transition*" OR "GHG reduc*")) **.

The search was conducted in titles, abstracts, and keywords to ensure coverage of the widest possible range of relevant literature.

Initially, the search yielded 739 publications, but certain restrictions were applied to ensure methodological consistency and to focus on the most recent European and international developments. More specifically:

i. Time frame (2020–2024): selected to study the latest trends and practices in sustainable and low-carbon agriculture, with an emphasis on technologies that are part of the green transition.

ii. Type of publication: scientific articles and conference proceedings were included, as conferences often provide early indications of emerging trends and research ideas that have not yet reached the stage of publication in journals.

iii. Language restriction: to ensure consistency in the interpretation of results and the possibility of comparative analysis, only articles in English were taken into account.

iv. Thematic and geographical focus: priority was given to studies concerning rural sustainability and green technologies, with a particular emphasis on the European level, due to the intense political and scientific activity surrounding the agricultural transition in the region.

The bibliometric analysis and data visualization were performed using VOS viewer software (version 1.6.20), which was selected for its reliability and ease of use in mapping bibliometric networks. Specifically, the co-occurrence analysis function of VOS viewer was used, which analyzed the authors' keywords to identify the dominant thematic fields and the correlations between them.

Results

The results of the bibliometric analysis revealed four main thematic groups that show how research is progressing towards the green transition in agriculture and circular bioeconomy. The first group focuses on anaerobic digestion, biogas, and agricultural waste, converting them into energy and fertilizer through the circular economy. The second group highlights biochar and pyrolysis as tools for carbon sequestration, while improving soils and reducing emissions. The third group emphasizes biomass and renewable energy sources, which support the economic development of rural areas and sustainable development goals. Finally, the fourth group links climate change to soil fertility and sustainable practices, promoting resilient production systems. Overall, a coherent research landscape emerges that combines technology, the environment, and the economy.

Cluster 1

In the first cluster, we encounter the concepts of "anaerobic digestion," "biogas," "biomethane," "digestate," "manure," "waste management," "bioenergy," "circular economy," and "sustainability." These terms create a field that is at the heart of sustainability transitions as they describe the replacement of linear, fossil fuel-based energy systems with circular models of agricultural waste utilization. One of the key technologies of the circular bioeconomy is the anaerobic digestion of animal waste to produce biogas and biomethane, as it allows for the simultaneous production of renewable energy and the reduction of greenhouse gas emissions from agriculture by preventing uncontrolled methane emissions from manure management (Pan et al., [8]; Ahlberg Eliasson et al., [9]; Mancini & Raggi [10]).

At the same time, the by-product of the process, digested waste, is increasingly recognized as an organic biological fertilizer with a high content of available nutrients, which can replace inorganic fertilizers, improve soil fertility, and reduce nutrient losses and nitrogen leaching. The use of digestion by-products in both open agricultural systems and greenhouse substrates enhance nutrient recycling between animal and plant production, reduces dependence on energy-intensive chemical fertilizers, and contributes to the emerging agroecological and climate-neutral transition of the agri-food economy (Forbord & Hansen [11]; Fagerström et al, [12]).

Cluster 2

The second cluster is directly linked to transitions towards sustainability, as it focuses on restructuring the carbon cycle in agroecosystems. In this cluster, we find terms such as "biochar," "carbon dioxide removal," "carbon storage," "life cycle assessment," and "pyrolysis," all of which are linked to transitions to sustainability. The production of biochar through the pyrolysis of agricultural waste and biomass has been established as an important strategy for carbon sequestration and long-term storage, as it converts short-lived carbon into more stable forms that can remain in the soil for many years. (Karan et al., [13]). When biochar is absorbed into the soil, it improves fertility and physicochemical properties, often increasing crop yields while reducing nitrous oxide and methane emissions, making it a key tool for climate-smart and sustainable agriculture. Furthermore, life cycle studies show that producing biochar from biomass waste streams, such as woody waste and forest residues, can result in a net negative emissions balance when integrated into carbon dioxide capture technologies and within a circular bioeconomy that supports important sustainability transitions in the agri-food sector. (Karan et al., [13]; Huang et al., [14]; Goulas [15]; Goulas and Papachatzis [16])

Cluster 3

In the third cluster, terms such as "agriculture," "biomass," "renewable energy," and "sustainable development" emphasize the use of agricultural biomass as a key driver for the energy and development transition of rural areas. Recent reviews of biomass point out that bioenergy can reduce greenhouse gas emissions, utilize agricultural waste, and contribute to the circular economy, provided that it is integrated into appropriately designed sustainability frameworks (Saravanan et al., [17]). At the same time, reports by international organizations show that the use of renewable energy sources in agri-food systems (bioenergy from biomass) can increase farmers' productivity and incomes, reduce dependence on fossil fuels, and accelerate the achievement of the Sustainable Development Goals and the Paris Agreement. At the regional level, biomass assessment studies show that the use of agricultural, forestry, and industrial waste produces energy that not only reduces waste but also creates new sources of income and green jobs, strengthening local bio economies and supporting more equitable and resilient rural development (Chang et al., [18]).

Cluster 4

The terms "climate change," "soil fertility," and "sustainable agriculture" link the climate crisis to soil resource management and the transition to more resilient agri-food systems. According to the literature, climate change affects soil fertility through changes in temperature, rainfall patterns, and the frequency of extreme weather events, resulting in faster erosion, reduced organic matter, and shrinking productivity (Nigussie [19]). At the same time, research on sustainable agriculture emphasizes that improving soil quality through organic fertilization, organic matter management, cover crops, and climate-smart agricultural practices is a key means of ensuring food production, increasing the resilience of agroecosystems, and enhancing the soil's capacity to sequester carbon (Kabato et al., [20]). In this context, soil interventions such as targeted fertility management and the adoption of practices that improve soil structure, soil moisture, and biodiversity, are considered vital strategies for the transition to truly sustainable agriculture, which contributes both to adaptation to climate change and to mitigation of its effects. **(Table 1) (Figure 1)**

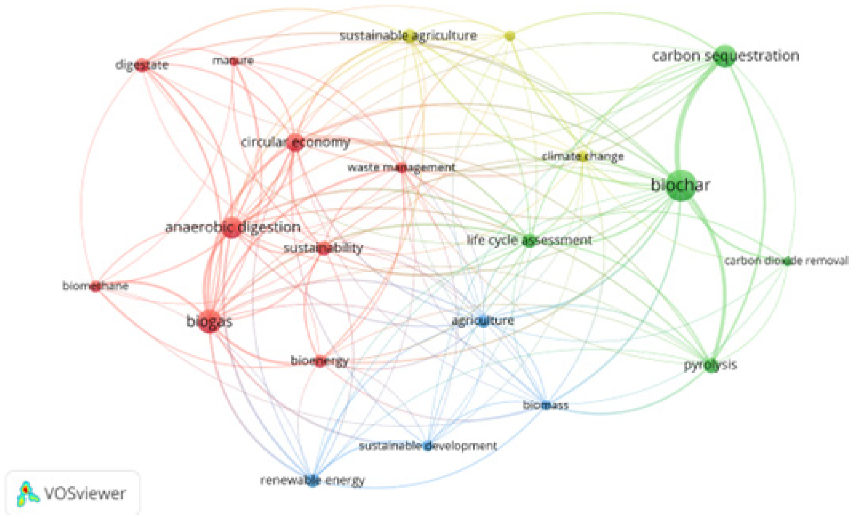

Figure 1: Co-occurrence map of keywords from the bibliometric analysis, highlighting the main thematic clusters around circular bioenergy, biocarbon, biomass, and sustainable agriculture.

Table1: Table of thematic clusters of co-occurring keywords, grouping terms around circular bioenergy, biocarbon and carbon sequestration, biomass and renewable energy sources, and sustainable agriculture.

N/A	Agricultural waste management and circular bioenergy *(Cluster 1)*	Biochar and carbon capture *(Cluster 2)*	Biomass and renewable energy in the agricultural sector *(Cluster 3)*	Climate change, soil fertility, and sustainable agriculture *(Cluster 4)*
1	Anaerobic digestion	Biochar	Agriculture	Climate Change
2	Bioenergy	Carbon Dioxide Removal	Biomass	Soil Fertility
3	Biogas	Carbon Sequestration	Renewable Energy	Sustainable Agriculture
4	Biomethane	Life Cycle Assessment	Sustainable Development	
5	Circular economy	Pyrolisis		

6	Digestate			
7	Manure			
8	Sustainability			
9	Waste Management			

Conclusion

This bibliometric study systematically maps the literature on agricultural transition through green technologies, with an emphasis on biogas, biochar, and low-carbon practices, revealing key thematic pillars and interactions that support sustainability policies. Specifically, three main thematic clusters are identified:

a) The bioenergy utilization of agricultural residues through biogas for energy production and waste reduction,

b) Soil improvement and carbon sequestration through biochar, and

c) Integrated low-emission practices are incorporated into circular economy systems, with strong interconnections between them that promote multidisciplinary approaches.

The contribution of these technologies to reducing emissions and strengthening the circular economy is increasing at European and international level, especially since 2020, with Europe leading the way in biogas and biochar applications thanks to policies such as the Green Deal (Fetting [21]), while internationally there has been expansion in Asia and Latin America through improved resources and economic incentives.

These findings represent an innovative scientific contribution, as they provide measurable tools for policy design and the identification of knowledge gaps, enhance the dialogue on climate-smart agriculture, and propose cross-sectoral collaboration for the expansion of applications.

Acknowledgement

None

Conflict of Interest

No conflict of interest.

References

1. Kabeyi M J B, Olanrewaju O A (2022) Biogas production and applications in the sustainable energy transition. Journal of Energy 2022(1): 8750221.
2. Moshahary J, Choudhury M, Ahmed P, Sarma B, Nath R K, et al., (2024) A bibliometric analysis of biochar in sustainable agriculture. International Journal of Research in Agronomy 7: 173-179.
3. Yadav P, Yadav S, Singh D, Giri B S (2022) Sustainable rural waste management using biogas technology: An analytical hierarchy process decision framework. Chemosphere 301: 134737.
4. Pavesi R, Orsi L, Zanderighi L (2024) Seeds of change: A bibliometric study on sustainable technologies and business strategies in agriculture. Journal of Infrastructure, Policy and Development 8(12): 1-22.
5. Devi M K, Manikandan S, Oviyapriya M, Selvaraj M, Assiri M A, et al., (2022) Recent advances in biogas production using Agro-Industrial Waste: A comprehensive review outlook of Techno-Economic analysis. Bioresource Technology 363: 127871.
6. Wrzesińska Jędrusiak E, Muradin M, Herkowiak M, Łaska Zieja B, Myczko, A (2022) Environmental performance of the innovative, patented mixing system in an agricultural biogas plant based on LCA approach. Journal of Cleaner Production 349: 131420.
7. Mona S, Malyan S K, Saini N, Deepak B, Pugazhendhi A, et al., (2021) Towards sustainable agriculture with carbon sequestration, and greenhouse gas mitigation using algal biochar. Chemosphere 275: 129856.
8. Pan S Y, Tsai C Y, Liu C W, Wang S W, Kim H, et al., (2021) Anaerobic co-digestion of agricultural wastes toward circular bioeconomy. Iscience 24(7).
9. Ahlberg Eliasson, K., Westerholm, M., Isaksson, S., & Schnürer, A (2021) Anaerobic digestion of animal manure and influence of organic loading rate and temperature on process performance, microbiology, and methane emission from digestates. Frontiers in Energy Research 9.
10. Mancini E, Raggi A (2021) A review of circularity and sustainability in anaerobic digestion processes. Journal of Environmental Management 291: 112695.
11. Forbord M, Hansen L (2020) Enacting sustainable transitions: A case of biogas production and public transport in Trøndelag, Norway. Journal of Cleaner Production 254: 120156.
12. Fagerström A, Al Seadi T, Rasi S, Briseid, T (2018) The role of anaerobic digestion and biogas in the circular economy. Cork, Ireland: IEA Bioenergy 8: 1-24.
13. Karan S K, Woolf D, Azzi E S, Sundberg C, Wood S A (2023) Potential for biochar carbon sequestration from crop residues: A global spatially explicit assessment. GCB Bioenergy 15(12): 1424-1436.
14. Huang Y, Tao B, Lal R, Lorenz K, Jacinthe P. A., et al., (2023) A global synthesis of biochar's sustainability in climate-smart agriculture-Evidence from field and laboratory experiments. Renewable and Sustainable Energy Reviews 172: 113042.
15. Goulas A (2025) Shaping Agribusiness in the New Digital Era: Bridging Tradition with Innovation, for the Agribusinesses in Thessaly Greece. Economics and Business Quarterly Reviews 8(1): 18 - 25.
16. Goulas A, Papachatzis, A (2024) Farm to Fork Strategy: A sustainable solution for rural communities. Annals of the University of Craiova 29(65): 209 - 2014.
17. Saravanan A, Ragini Y P, Karishma S, Hemavathy R V, Jyotsna M (2025) A review on advancing sustainable energy: The role of biomass and bioenergy in a circular economy. Sustainable Futures 10: 100835.
18. Chang J H, Selvaraj S, Manikandan S, Nagarani S, Senthilkumar A, et al., (2025) A comprehensive review of biomass utilization for sustainable biofuel and biocomponent development. Biomass and Bioenergy 202: 108167.
19. Nigussie Z (2024) The Effect of Climate Change on Soil Health: A Review. Int. J. Energy Environ. Sci 9: 52-58.
20. Kabato W, Hailegnaw N, Mutum L, Molnar Z (2025) Managing soil health for climate resilience and crop productivity in a changing environment. Science of the Total Environment, 1000, 180460.
21. Fetting C (2020) The European green deal. ESDN report December 2(9): 53.