Quantifying the Impact of Biochar to Enhance Environmental Quality Through a Bibliometric Review

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Abstract. As a bioproduct from the thermal decomposition of biomass, biochar has various applications in diversified fields. Biochar is gaining attention for its potential to solve some of environmental issues, including but not limited to climate change mitigation, waste management, soil fertility improvement, and pollution remediation The present study employs bibliometric techniques to visually represent the current status and emerging patterns of biochar exploration within environmental frameworks. This bibliometric scrutiny is designed to assess the influence of biochar on diverse environmental systems by examining the scholarly works encompassing 19822 documents retrieved from the Scopus repository. The study focuses on publications dated between 1889 and 2024 and is limited to the subject area "ENVI." The visual analysis results demonstrate that the number of publications expanded dramatically since 2010, and the growth trend will continue. China was the most contributing country in biochar research regarding the number of publications (51,83%), then USA and India (14,31% and 7,68%). Clustering analysis further reveals distinct thematic clusters within soil and plant growth; emissions and environmental impact; and adsorption and pollutant removal. By mapping the citation networks and collaboration patterns, we provide insights into the interdisciplinary nature of biochar research and its global research distribution This review highlights research gaps and future directions while summarizing the current state of knowledge to maximize the environmental impact of biochar. Our findings underscore the need for integrated approaches that combine biochar application with sustainable environmental management practices.

Keywords: bibliometric, carbon, charcoal, climate change, environment.

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INTRODUCTION

The global environmental situation is now deteriorating. The rapidly increasing population and anthropogenic activities has increased the level of waste, natural resources degradation, environmental degradation and climate change. Unsustainable agricultural practices and deforestation have contributed to soil degradation which has resulted in a decline in soil fertility of about 24% of the world's land [1]. It's been reported the average surface air temperature rose by 1.53°C, while the global surface temperature is projected to rise by 0.87°C with 410.53 ppm, CH4 at 1853 ppb, and N2O at 328.9 ppb [2]. New solutions are needed to help mitigate these negative impacts and restore ecosystem balance to cope with this situation. One approach that has received a lot of attention in the last decade is the use of biochar, which has shown great potential in carbon sequestration, climate change mitigation, waste management, bioenergy production, soil improvement, and pollution prevention [3],[4].

Biochar derived from a combination of "bio" and "charcoal" is a solid product formed from the thermochemical transformation of biomass (usually called pyrolysis) at high temperatures (above 250°C) in the presence of oxygen a limited in [5]. This process driven biochar to has unique properties such as high surface area, porosity and specific chemical groups etc. [6]. Stud- ies show that biochar could be used to improve soil fertility, store carbon and reduce greenhouse gas emissions [7]. Studies have also shown that biochar can increase soil fertility [8],[9], increase crop yields, and contribute to better soil moisture retention [10]. A study found that biochar significantly improved soil properties, including pH, porosity, cation exchange capacity, water holding capacity, and reduced nutrient leaching rate [11]. The ability of biochar to improve soil quality can reduce greenhouse gas emissions on farmland [12]. Which drive biochar as an effective tool for climate change mitigation. Besides, biochar plays an important role in bio mitigation [13],[14], e.g. it chelates heavy metal pollutants in the environment [15].

Although biochar has been extensively researched in the last decade, and its benefits have been widely reported, it is not yet widely accepted. Significant knowledge gaps remain to be addressed. One of the main challenges is the lack of a full understanding of how biochar interacts with soil types and the environment, and its environmental sustainability. The use of bibliometric analysis will help to find the gaps. Bibliometric analysis enables researchers to examine research progress, identify knowledge gaps, and determine future research directions [16]. The results of the literature data analysis can help researchers understand the aspects of biochar that have been studied and ap- plied worldwide.

As a data-driven research tool, bibliometrics provides in-depth insights into citation patterns, researcher collaboration, and emerging research areas. Biochar research has grown significantly over the past decade, especially in terms of climate change mitigation and soil fertility improvement [17]. International cooperation plays an important role in the development and practical application of biochar-related knowledge [18].

Developed countries such as the United States, China, and Canada still leading the scientific literature in this area [19].

This article aims to conduct a comprehensive bibliometric review to evaluate and quantify the impact of biochar in improving environmental quality. Through the analysis of the available literature on Scopus, the research questions this study seeks to answer are 1) the publication trends; 2) the most prolific authors in the field; 3) the most active countries in the field; 4) the most highly cited documents in the field; 5) the most common keywords and themes; 6) the patterns of co-authorship in the field; 7) the key themes and topics that emerge from co-occur- rence analyses of author keywords and title/abstract terms in the literature on biochar and the environment.

METHOD

A systematic literature search was conducted from the Scopus Collection database using the keyword of (TITLE("biochar"OR"charcoal"OR"pyrolysis residue"OR"black carbon"OR"active carbon"OR"pyrolytic carbon"OR" biomass carbon"OR"bio-based carbon") AND PUBYEAR > 1889 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA,"ENVI"))). A total of 19822 documents were collected from the database on 20 July 2024. The flow diagram of the research strategy is figured out in Figure 1 [20]. The citation analysis was conducted using ‘Harzing Publish or Perish’ software in order to obtain the citation metrics and other frequencies. Besides that, other frequencies were also calculated, and the graph and chart are designed using bibli-oMagika® [21], [22] and Excel.

Lastly, the downloaded data were imported into the VOSviewer 1.6.17 software to make network maps for relationships between authors and countries and plot co-occurrence maps of author keywords used in the publications [23]. VOSviewer is a visualization software developed by Nees Jan Van Eck and Ludo Waltman from Leiden University in the Netherlands [24]. It is a free-to-use scientometric software, which has been used for creating network maps, concerning different parameters including author, citation, organization, country, and keyword co-occur-rence [25]. This software offers distinct benefits in mapping and clustering. VOSviewer uses factors (such as distance and density) to deconstruct the clustering relationship between nodes [26].

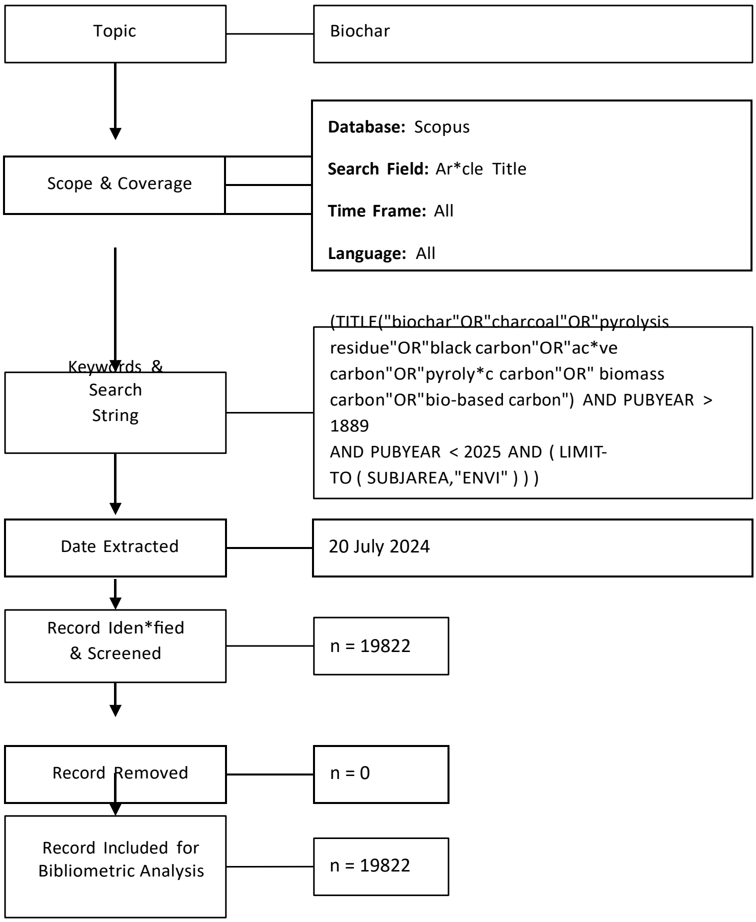


Fig 1. Flow diagram of the search strategy.

RESULTS AND DISCUSSION

The sample period for this paper is from 1890 to 2024; the data was retrieved from the Scopus database on 20 July 2024. The details of all 19844 papers are presented in Table 1, including publication years, total author appearances, subject areas, document types, and funding sponsors. These offer valuable insights into the multifaceted nature of scholarly communication. The involvement of 141 countries and 19 languages underscores the global reach and diversity of the research findings. The contribution of 32 institutions and 160 funding sponsors highlights the international and collaborative nature of the research. The information is described in more detail in the following tables and figures.

Table 1. Main information regarding selected papers.

Description	Result
Publication Years	1890-2024
Total Publications	19822
Total Author Appearances	160
Total Subject Area	24
Document Types	11
Source of Documents	32
Keywords	92
Institutions	32
Funding Sponsor	160
Country	141
Language	19

Based on Table 2, information was obtained about the dominance of journal articles in publications on biochar for environmental utilization, which constitutes 87.85% of the total output This prevalence indicates a robust engagement with empirical research and theoretical advancements within the biochar domain, suggesting that researchers primarily focus on disseminating original findings through peer-reviewed journals. This is in line with the results of other research that conducted a bibliometric analysis of biochar management for the environment based on data from Web of Science [17],[18],[19],[27], which found that the number of publications in journal articles was more than 80%.

Table 2. Document Type.

Document Type	Total Publications	Percentage (%)
Article	17413	87,85
Conference Paper	736	3,71
Book Chapter	420	2,12
Note	47	0,24
Review	1012	5,11
Editorial	26	0,13
Book	14	0,07
Short Survey	7	0,04
Undefined	5	0,03
Total	19822	**100.00**

Source: Generated by the author(s) using biblioMagika®

The results of the analysis of the source of the document (Table 3) also show that most (94.27%) journals are the main sources of information dissemination related to the use of biochar in the environment. Conference proceedings, book series, and books represent a minor fraction of the total publications (5.64%), indicating their limited impact within the biochar research landscape. The minimal presence of trade publications and undefined sources suggests a lack of active participation from industry and other relevant stakeholders. This predominance of journal articles may restrict access to research findings for non-academic audiences, potentially impeding the application of knowledge in practical contexts. To rectify this disparity, future research initiatives should consider exploring diverse publication platforms and formats that can engage a wider audience and enhance knowledge transfer beyond conventional academic boundaries [27],[28].

Table 3. Source Type.

Source Type	Total Publications	Percentage (%)
Journals	18687	94,27
Conference Proceedings	656	3,31
Book Series	86	0,43
Books	377	1,90
Trade Publications	15	0,08
Undefined	1	0,01
Total	**19822**	**100.00**

Source: Generated by the author(s) using biblioMagika®

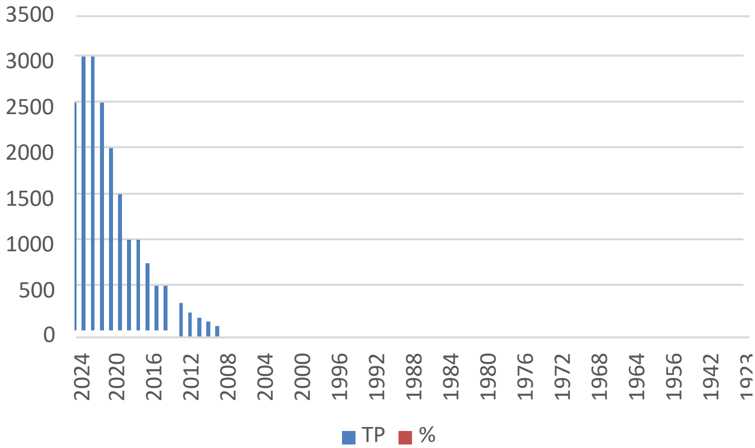
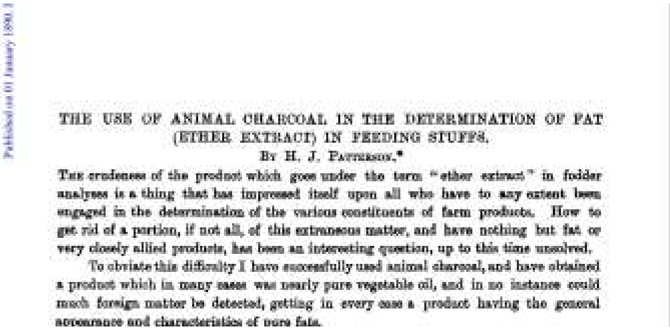


Fig 2. Publication Growth
Source: Generated by the author(s) using biblioMagika®

The analysis of the provided data reveals a significant upward trend in the volume of publications related to biochar over recent years. The number of publications dramatically increase started in 2010 and continues year, until in 2023 it reaches 3,073. This surge indicates growing global interest and research focus on biochar's potential applications, particularly in environmental sustainability and soil health improvement. When compared to other bibliometric research on biochar in many aspects related to environmental issues, most state that 2010 was the year that biochar-related publications began to increase sharply and continue to this day [17};[18];[19];[27],[28],[29]. This showed the expanding role of biochar in multifunctional environmental solutions, from pollutant removal to climate change mitigation. These results underscore the growing importance of biochar as a key ingredient in academic and applied research, thus shaping the future of biochar in ecological restoration and sustainable agriculture.

Another interesting finding in this study was that the first article regarding biochar for environmental use was published in 1890, and is well archived by Scopus, so it can still be traced (Figure 3). This article was published on January 1, 1980 in the American Chemical Journal. This article discusses the use of animal charcoal in the determination of fat ether extract in feeding stuff. This showed that biochar has been used for a very long time and its function for the environment is known.


Published on 01 January 1890.

THE USE OF ANIMAL CHARCOAL IN THE DETERMINATION OF FAT (ETHER EXTRACT) IN FEEDING STUFFS.

By H. J. Patterson.*

The crudeness of the product which goes under the term "ether extract" in fodder analyses is a thing that has impressed itself upon all who have to any extent been engaged in the determination of the various constituents of farm products. How to get rid of a portion, if not all, of this extraneous matter, and have nothing but fat or very closely allied products, has been an interesting question, up to this time unsolved.

To obviate this difficulty I have successfully used animal charcoal, and have obtained a product which in many cases was nearly pure vegetable oil, and in no instance could much foreign matter be detected, getting in every case a product having the general appearance and characteristics of pure fats.

Fig 3. The first article related to biochar for the environment was published in Scopus, which was published on January 1, 1980.

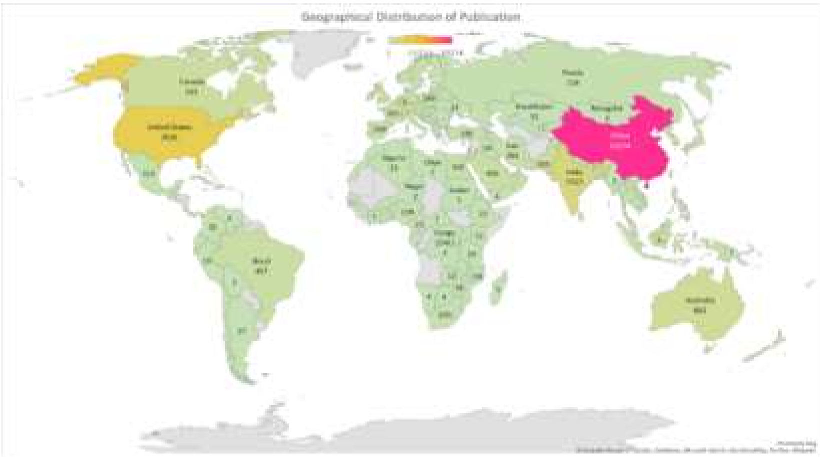


Fig 4. Worldwide scientific production indexed by Scopus on labor relations.
Source: Generated by the author(s) using iipmaps.com

Fig 4 showed the distribution of countries contributing to research on biochar for the environment. The top five countries are China, the United States, India, South Korea, and Australia. China contributes 51.83% (10,274 papers) to the total. Several studies suggest that this is because China is a major agricultural nation with a large population, where agriculture holds a significant and strategic role in the national economy [30],[31]. This also demonstrates the rapid development of biochar research in China, establishing the country as a global reference point [18],[19].

Tabel 4. The Top 10 Most Productive Authors For Related Publications To Biochar

Author Name	Number of Publication	Country	Affiliation
Ok, Y.S.	245	South Korea	Korea University & International ESG Association
Tsang, D.C.W.	149	China	The Hong Kong University of Science and Technology
Wang, H.	131	China	Harbin Institute of Technology
Gao, B.	121	United State	University of Florida
Rinklebe, J.	109	Germany	University of Wuppertal
Cao, X.	98	China	Shanghai Jiao Tong University
Zhang, Z.	88	China	Hebei University of Technology
Vithanage, M.	81	Srilangka	University of Sri Jayewardenepura
MaÅ¡ek, O.	77	Slovakia	Trnava University
Joseph, S.	74	Australia	UNSW Sidney

An analysis of the data on the most prolific authors in biochar research (Tabel 4) showed a dominance of researchers from South Korea and China. Ok, Y.S. and Tsang, D.C.W. emerged as the most prolific authors, with 245 and 149 publications respectively. However, contributions from other countries such as the United States, Germany, and Australia are also significant, indi- cating a growing global interest in biochar research. The affiliations of these researchers with prestigious universities and research institutions such as Korea University and Harbin Institute of Technology indicate strong institutional support for biochar research. Overall, the data sug- gests a significant emphasis on biochar research in Asia, especially South Korea and China, alongside an increasing number of international collaborations in this area.

The relationship between the authors is presented in Figure 5. This visualization supports the previous data, indicating the dominance of some authors. However, from the data, we can also conclude that the authors are interconnected, which illustrates that there is a collaboration in biochar research that is global and involves researchers from various cultural and institutional backgrounds. The same thing was also found by [17],[18],[27],[28], who stated that the network of researchers in the field of biochar is very strong, which highlight that this research group is very active and interacts with each other.

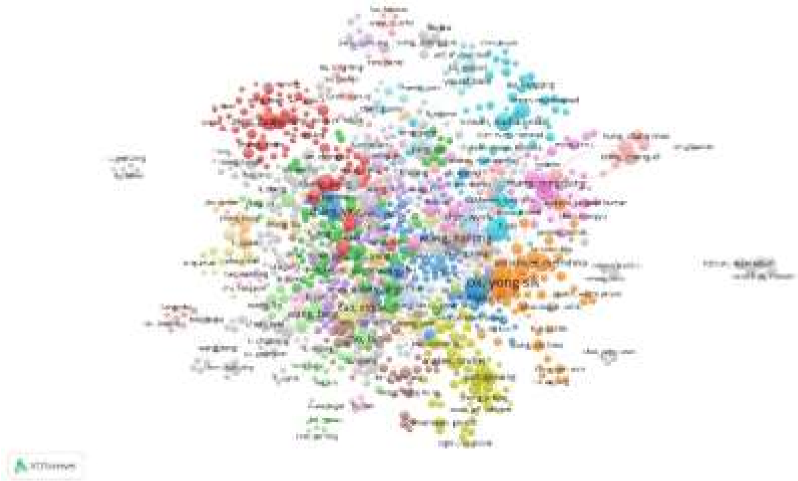


Fig 5. Network Visualization Based on The Author

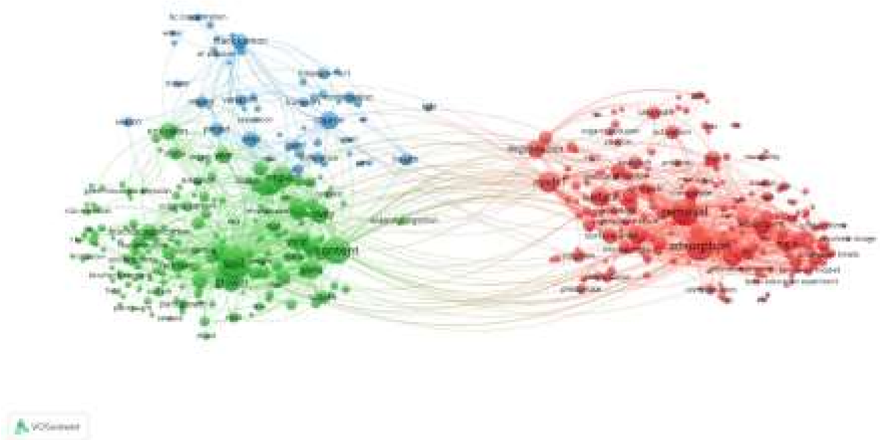


Fig 6. Cluster Visualization of The Research Themes.

Figure 6 presents three clusters in the bibliometric analysis results. The first cluster was soil and biochar application. This topic focused on the impact of biochar on soil and plant growth. Terms such as soil, plant growth, fertilizer, and biochar application indicate that research in this cluster is related to the benefits of biochar in improving soil fertility, enhancing plant growth, and managing organic carbon in the soil. It is also linked to the mitigation of greenhouse gas emissions, suggesting the application of biochar within the context of climate change and agriculture. Research publications have emphasized the benefits of biochar application, particularly in enhancing soil carbon sequestration and reducing greenhouse gas emissions, thus offering the potential for global climate change mitigation [4], [32]. The efficacy of biochar in attaining carbon neutrality objectives is primarily attributable to its dual mechanisms of carbon sequestration and emission mitigation [33]. The substantial aromatic carbon content inherent in biochar serves as the fundamental basis for its carbon sequestration capabilities [34], [35].

The second cluster is adsorption and pollutant removal. This cluster emphasizes the application of biochar in pollutant removal through adsorption processes. Terms such as adsorption, removal, surface area, composite, and catalyst indicate that research in this cluster focuses on the use of biochar and related materials for adsorbing pollutants from water or air, with particular attention to enhancing adsorption capacity through biochar surface engineering. The distinctive physicochemical characteristics of biochar, encompassing its extensive specific surface area [36], porous morphology [37], abundance of surface functional groups [38], and mineral constituents [39], render it a highly efficacious adsorbent for pollutant remediation [40]. A preponderance of research has demonstrated biochar's remarkable capacity for the sequestration of various contaminants, including heavy metals, organic pollutants, and other deleterious substances [41], [42].

The third cluster focuses on black carbon and environmental impacts. This cluster appears to encompass research related to black carbon and its environmental effects. Terms such as black carbon, emission, variation, and source indicate a focus on black carbon emissions, as well as the geographic and temporal variations in its distribution and its impacts on health and climate. There is a significant interaction between the first and second clusters, indicating a connection between research on biochar for soil and plants and its use in pollutant removal. This suggests the exploration of multifunctional biochar, which can enhance soil fertility while simultaneously reducing pollutants. The third cluster is more isolated compared to the other two, but it remains connected through topics related to emissions and black carbon sources, which may be associated with broader environmental impacts.

This cluster also provides recommendations for further research, such as the need for integrative studies on the multifunctionality of biochar in soil and pollutant removal. Further exploration of biochar in managing black carbon emissions is also crucial, particularly considering its impact on climate change and public health. Additional research on the socio-economic aspects of biochar use in various contexts, as well as the development of interdisciplinary models between agriculture, waste management, and climate change, could offer more comprehensive solutions.

CONCLUSION

The results of the bibliometric analysis of biochar-related publications concerning the environment indicate that this topic has been developing over the past century. The analysis also indicates that the majority of the publications are in the form of scientific journals, which may contribute to the challenges in practical applications. Furthermore, a dominance of Asian researchers and publications was observed in this field. However, the researchers have engaged in international collaborations, signaling promising development. There are three major research clusters identified: soil and biochar application, adsorption and pollutant removal, and black carbon and environmental effects. These clusters are interconnected. Future research recommendations emphasize the need for integrating multifunctional biochar across various fields, alongside considering socioeconomic aspects to ensure biochar becomes a viable solution for environmental improvement.

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