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ABSTRACT

Biochar has been extensively studied in terms of technical and environmental aspects. The study of social aspects of biochar was infrequent. Research on the social aspects of biochar was more often linked with technological, environmental, or economic aspects. This study utilized initial data from socioeconomic aspects because socioeconomic research was more prevalent than socio-technical or socio-environmental research. The study employed a third-step analysis analysis. First, a bibliometric analysis was conducted to examine research topics related to the social economy of biochar from published articles in Scopus and Google Scholar. Data processing was used VOSviewer and the keyword "social economy of biochar." The results were several topics studied on the social economy of biochar and the most cited articles. The second step was overlay visualization figure analysis to find trends and future research topics. The third step was comparing the keywords from the bibliometric analysis with theoretical concepts related to social aspects. The bibliometric analysis of the socioeconomic aspects of biochar revealed that research focusing on the social and economic aspects was a significant area that still needs to be completed. The majority of biochar research centers on topics related to biochar processing technology, the environment, economics, and other aspects. These findings underscore the urgent need for research on the social aspects of biochar, which remains open for social science researchers. Future research is expected to conduct a more in-depth review of published articles to address the need for studies on the social aspects of biochar.

1. Introduction

Biochar research was often linked to technological, environmental, and agricultural. Biochar is a technology widely used for processing agricultural waste. Biochar, or solid charcoal-like material, is a carbonaceous substance or recalcitrant carbon produced through thermochemical decomposition at temperatures ranging from 300 to 900 °C in the absence or limited presence of oxygen (Van Fan et al., 2021; Wang et al., 2020). Biochar production can utilize crop residue (Anand et al., 2022), animal manure (Rathnayake et al., 2023), wastewater sludge (Hossain et al., 2010), or animal waste (Côrtes et al., 2019). The evolution of research on biochar was moving toward integrating social, economic, and environmental dimensions (Hersh et al., 2019). Biochar processing aims to manage agricultural waste to improve soil quality and agricultural production, ultimately promoting environmental protection. Biochar has been introduced as a technology to enhance the quality of agricultural land (Gonzalez et al., 2021a) and improve agricultural production (Kochanek et al., 2022; Rogers et al., 2021). On the environmental side, biochar has been studied as a technology that helps mitigate climate change (Hansson et al., 2021; Lehmann et al., 2021a), acts as an agent for wastewater treatment (Hersh et al., 2019; Xiang et al., 2020a), and rehabilitates former mining sites (Ghosh & Maiti, 2021). Biochar was often associated with sustainable land management; therefore, it was classified as a sustainable technology (Hansson et al., 2021).

Previous studies began to pay attention to the socioeconomic aspects of biochar beyond the technical aspects of biochar. Previous studies found that socioeconomic factors play a role in society's adoption and adaptation of biochar technology (Müller et al., 2019; Rogers et al., 2021). Biochar is a sustainable technology (Hansson et al., 2021) that is economically beneficial (Hersh et al., 2019; Rogers et al., 2021) and socially beneficial for communities (Anand et al., 2022). The socioeconomic aspects of biochar played a role in its management and business sustainability (Mohammed et al., 2024; Rogers et al., 2021). The sustainability of biochar use as an environmentally friendly technology requires community involvement (Hansson et al., 2021). Previous research indicated that these social and economic aspects were important to study.

The research on biochar management's technical or economic aspects overlooked that individuals or communities carried out biochar management. Social aspects could hinder biochar management (Hansson et al., 2021; Rogers et al., 2021). Focusing on the social aspects of the social economy of biochar was identified as a necessary area for future research (Kamali et al., 2022; Otte & Vik, 2017). Studies on the social aspects of biochar examined issues such as social acceptance and the applicability of biochar (Latawiec et al., 2017a). The social aspect of biochar processing was important because it involved social and organizational dimensions (Otte & Vik, 2017). Research on the social aspects of biochar was more often linked with technology, becoming the socio-technical aspect of biochar (Otte & Vik, 2017), economics, evolving into the socioeconomic aspect of biochar (Rogers et al., 2021), or environmental sustainability, turning into the social-ecological aspect of biochar (Müller et al., 2019). Based on an initial search on Google Scholar, research on socioeconomic aspects was the most prevalent compared to socio-technical and socio-ecological aspects. Therefore, this study examined the social aspects of biochar within the framework of socioeconomic research on biochar, as it has significant connections to the social aspects of biochar.

The previous research did not capture all topics within the socioeconomic aspects of biochar, specifically in the social aspect of biochar. The loss of data on all research topics makes it unable to estimate future research needs. The literature review was a method that could capture past research to assess future research needs (Webster & Watson, 2002). A literature review on the social aspects of biochar has not been found. Some literature reviews have examined the impact of socioeconomic factors on biochar development (Fytili & Zabaniotou, 2018; Hersh et al., 2019; Kochanek et al., 2022). However, these studies had yet to fully capture the overall influence of social and economic factors on biochar research

development. Bibliometric analysis involves mapping large amounts of publications-related data (Donthu et al., 2021; Ho, 2018). This method has been utilized to study the trend of biochar as a technology (Abdeljaoued et al., 2020; Arfaoui et al., 2019; Kumar et al., 2023). Nevertheless, there needs to be more bibliometric analysis focusing on the social and economic aspects of biochar.

This research elaborated on the comprehensive overview of socioeconomic factors for developing the future research need in the social aspects of biochar studies. Bibliometric analysis of biochar's socioeconomic factors can help identify the overall focus of researchers on biochar's socioeconomic factors, and future researchers can use this overview to promote communities' adoption and adaptation of biochar technology, or this as a social aspect of biochar research. Therefore, this research examined (1) the topics studied in biochar's socioeconomic factors, (2) the trend of these studies, (3) suggestions for future social-economic research topics, and (4) the future research needs for the social aspect of biochar.

1.1. Social Economy Research of Biochar

Socioeconomic factors are one of the leading topics in biochar research. Researchers examined economic aspects to determine the financial benefits of biochar processing (Oni et al., 2019; You et al., 2022). Economic studies were often linked with social aspects because the implementation of biochar technology considers economic gains and the sustainability of farmers' adoption. Social aspects in biochar processing play a crucial role in the sustainability of the business (Mohammed et al., 2024; Rogers et al., 2021).

As a field that receives special attention in biochar research, agriculture was widely studied from both social and economic perspectives. The impact of biochar technology implementation in agriculture can address social-economic sustainable development goals such as poverty alleviation, well-being, education, health and welfare, decent jobs and economic growth, reducing inequalities, and providing adequate settlements (Anand et al., 2022). Socioeconomic factors such as education, income, and age play a role in adopting biochar in household farming (Rogers et al., 2021). Socio-ecological factors such as livelihood practices and place-specific settings determined the adaptation barriers of agricultural communities (Müller et al., 2019). In conclusion, socioeconomic aspects in previous research encompass social and economic factors that affected the implementation, impact, and sustainability of biochar technology or enterprises.

1.2. Social Aspect of Biochar Research

The social aspect considers the laws governing the functioning of a society (Carter & Charles, 2009). Sociology examines social life as a science, with social phenomena as its object of study (Mueller, 1940). The scope of sociological studies was diverse, depending on the perspective on structures and systems within society (Carter & Charles, 2009). This diversity has led sociologists to formulate social indicators or aspects within sociology. In Toward a Social Report, a social indicator was defined as the condition of significant aspects of society. This definition has been criticized for focusing solely on output variables. Social indicators should also consider inputs, which are components of the social system model. A social indicator was an informative value empirically verified within a conceptualized social process (Land, 1971). Over time, the study of social aspects or indicators can be linked to other conceptualized concepts for social analysis, such as social justice, social change, and many others. The focus of such studies could also involve examining the social aspects of specific concepts, such as the social aspects of the circular economy (Padilla-Rivera et al., 2020), autism (Kałużna-Czaplińska et al., 2018), smart cities (Radziejowska & Sobotka, 2021), and many more. In conclusion, the social aspect, whether as an indicator, focus of study, or perspective, centers on the community and its elements as the subject of study.

Social aspects become the focus of biochar research when the study concentrates on the societal aspects of those implementing biochar technology. Studies on social aspects were linked to various focuses, such as technology, economics, and the environment. Technological, economic, and environmental aspects provide the context for society's involvement in developing biochar technology. Such research includes studies on the potential application of biochar technology in communities with specific ecological backgrounds (Müller et al., 2019), the acceptance and ability of farmers to implement biochar technology (Fytili & Zabaniotou, 2018; Latawiec et al., 2017b), or the social feasibility of the enterprise (V. Matrapazi & Zabaniotou, 2020). Society and the social aspects inherent to society were factors in biochar technology development (Kamali et al., 2022; Otte & Vik, 2017). Research focuses on people who run the economic aspects of biochar (Clare et al., 2014; Zilberman et al., 2023), the development of eco-friendly policies (Rittl et al., 2015a), or environmental justice (Saxe et al., 2019). Social aspects and other factors determined the implementation of biochar technology (Anand et al., 2022; Rogers et al., 2021). Biochar's emerging social research topics could include social aspects, community, social feasibility, society, humans as implementers, social justice, or social change.

Social aspects became part of biochar research when societal factors were considered in the study. The emerging social research topics in biochar could include social aspects, community, social feasibility, society, humans as implementers, social justice, or social change (Fytili & Zabaniotou, 2018; Kamali et al., 2022; Latawiec et al., 2017; V. K. Matrapazi & Zabaniotou, 2020; Müller et al., 2019; Otte & Vik, 2017).

2. Methods

This study employed bibliometric analysis because it could capture large datasets, provide patterns of interconnections between topics, identify trends in topic development, and offer suggestions for future research (Donthu et al., 2021). This research employed a third-step analysis approach. First, a bibliometric analysis is conducted to examine research topics related to the social economy of biochar. The research data utilizes journal articles published in Scopus and Google Scholar over the past ten years (2014-2024). Data collection was facilitated using Publish or Perish, which allowed for a literature review of the chosen theme (Al Husaeni et al., 2023). Publish or Perish revealed the most cited article data.

Data processing was conducted using VOSViewer edition 1.6.18 software. VOSViewer can present cluster data on research topics, trends in research topics through overlay visualization, links between topics through network visualization, and research density per topic through density visualization (Donthu et al., 2021; Van Eck & Waltman, 2010). The article collection used the keywords "social economy of biochar" in titles and keywords. This keyword usage follows methods employed by previous research (Purnomo, 2023a, 2023b). The data search yielded 30 articles from Scopus and 996 from Google Scholar. The articles indexed in Google Scholar had a total of 5,390 keywords. The research selected ten co-words from Google Scholar and two from Scopus. The number of co-words was the maximum number of co-words generated by VOSviewer. Co-words refer to the frequency of keyword appearances in the content, abstract, title, and keywords (Van Eck & Waltman, 2010).

The second step was to analyze the data. VOSviewer resulted in keywords as the study and cluster of the topic. The keyword data was processed by VOSviewer to produce overlay visualizations similar to previous studies (Purnomo, 2023d; Roestamy et al., 2023). Overlay visualization demonstrated the trend topics by year. The overlay visualization figure denoted the topic, the trend of a topic, the topic studied simultaneously, and the latest topic. Future research needs are the latest topics that have not been studied or studied simultaneously (Purnomo, 2023c, 2023d).

The third step was to conduct a social analysis of the results from the bibliometric analysis of the socioeconomic aspects of biochar. This analysis compares the keywords from the bibliometric analysis with theoretical concepts related to social aspects. The bibliometric analysis provided only keywords and did not include the origin of these keywords, making it challenging to examine the social aspects of biochar research. We searched the social keyword in the abstracts of the most cited articles and only analyzed the word in the keyword or researched topics resulting from VOSviewer.

3. Results and Discussion

3.1. Results

3.1.1. Research Developments and Most Cited Articles in The Field of Social Economy of Biochar

Figures 1 and 2 illustrate the number of publications on the "social economy of biochar" in Scopus and Google Scholar-indexed publications. The highest number of publications was in 2022. The number of publications in Google Scholar-indexed publications has been increasing since 2018-2022, while in Scopus, it has been increasing since 2020-2022. Both data sources show a decrease in the number of publications in 2023.

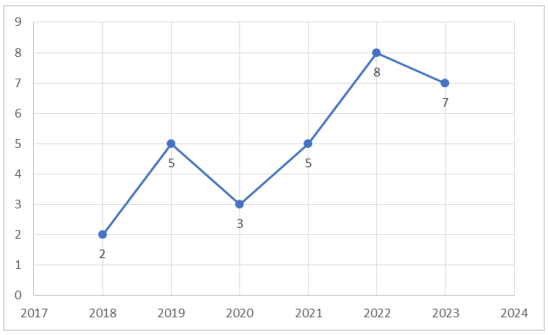

Figure 1 Number of Articles in Scopus

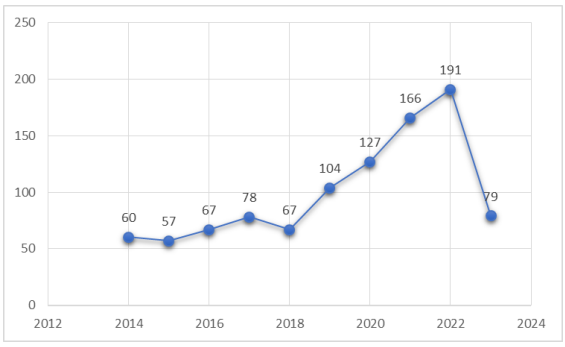

Figure 1 Number of Articles in Google Scholar

Table 1 demonstrated that the first most cited article in Scopus-indexed publications focuses on using biochar technology through the lens of social economy and policy (Bhuvaneshwari et al., 2019). Policy research is conducted in the social realm (Purnomo, 2023d). The third most cited article addresses social and economic publications, while other articles emphasize biochar processing technology.

Table 1 Most cited articles in Scopus-indexed publication

No.	Cites	Authors	Title	Web Journal	Document Type	Year
1	308	S. Bhuvaneshwari	Crop residue burning in India: Policy challenges and potential solutions	api.elsevier.com	Article	2019
2	189	Krasucka et al.	Engineered biochar – A sustainable solution for the removal of antibiotics from water	api.elsevier.com	Article	2021

3	90	Worlanyo & Jiangfeng	Evaluating the environmental and economic impact of mining for post-mined land restoration and land-use: A review	api.elsevier.com	Article	2021
4	70	Waqas et al.	Optimizing the process of food waste compost and valorizing its applications: A case study of Saudi Arabia	api.elsevier.com	Article	2018
5	45	Zhu et al.	Life-cycle assessment of pyrolysis processes for sustainable production of biochar from agro-residues	api.elsevier.com	Article	2022

Table 2 displayed the most cited articles in the social economy of biochar research in Google Scholar-indexed publications. The five most cited articles mainly focus on biochar processing technology related to the environment. The two most cited articles discussed cost aspects and essential concerns in biochar economic research. Previous studies found that biochar technology reduces wastewater treatment costs and makes agricultural costs effective and efficient (Patel et al., 2022; Xiang et al., 2020).

Table 2 Most cited articles in Google Scholar-indexed publication

No.	Cites	Authors	Title	Web Journal	Document Type	Year
1	3787	Lehmann et al.	Biochar for environmental management: Science, technology and implementation.	books.google.com	Book	2015
2	2979	Lehmann & Joseph	Biochar for environmental management: An introduction.	api.taylorfrancis.com	Article	2015
3	1259	Liu et al.	Development of biochar-based functional materials: Toward a sustainable platform carbon material.	ACS Publications	Article	2015
4	1141	Inyang et al.	A review of biochar as a low-cost adsorbent for aqueous heavy metal removal.	Taylor &Francis	Article	2016

5	1100	Fuss et al.	Negative emissions—Part 2: Costs, potentials and side effects.	iopscience.iop.org	Article	2018

3.1.2. Research Topics in The Field of Social Economy of Biochar

VOSviewer data processing resulted in research topics such as keywords and clusters. The results of the publication data processing using VOSviewer are shown in Figures 3 and 4. Each note revealed the research topic in the field of social-economic biochar. Figure 3 shows three clusters in Scopus-indexed publications. Figure 3 revealed that research topics in articles indexed in Scopus were biochar, water, antibiotics, removal, organic waste management, application, sustainable solutions, and circular economy.

Figure 4 demonstrated that the keyword "social economy of biochar" in Google Scholar-indexed publications was divided into five clusters. Items in each cluster represent keywords closely related to processing, raw materials, research methods, environmental impacts, and agriculture. Research topics in articles indexed in Google Scholar were biochar amendment, pyrolysis, biochar application, energy, nitrogen, preparation, biochar systems, food waste, techno-economic analysis of biofuels, reduction, heavy metals, conversion, wastewater, products, energy, metals, cadmium, carbon sequestration, composites, water, life cycle assessment, sludge, slow pyrolysis, treatment, surface, removal, rice straw, climate change mitigation, environmental benefits, techno-economic analysis, economic impact, circular economy, comparison, utilization, concept, synthesis, development, literature, amount, effect, perspective, critical review, type, property, yield, research, benefit, present study, year, socioeconomic, role, and agriculture.

Keywords indicating social and economic aspects in Google Scholar-indexed publications were the circular economy, economic viability, economic analysis, techno-economic analysis (Cluster 1), economic impact (Cluster 2), social economy (Cluster 3). and circular economy in Cluster 1 in Scopus-indexed papers.

3.1.3. The Trend and The Future Research Needs

Recent topics in the "social economy of biochar" research can be observed from the bright yellow color in the overlay visualization (Al Husaeni & Nandiyanto, 2022). Figure 3 indicated that the research shifted from applications, water, and antibiotics to biochar, removal, and organic waste management. The circular economy and sustainable solutions were the new topics, and they have yet to be extensively studied in conjunction with other topics in Scopus-indexed publications.

Figure 4 shows the research trend shifted from climate change mitigation, carbon sequestration, biochar system, biochar amendment, research, slow pyrolysis, year, effect, and agriculture. Then, the topics were nitrogen, type, energy, biofuel rice straw, removal, surface, development, role, water, heavy metal, preparation, and perspective. The latest topics were the circular economy, social economy, techno-economic analysis, critical review, cadmium, wastewater, concept, wastewater, conversion, remediation, and synthesis. This data suggests that, apart from being limited in quantity, research on the social economy of biochar is still in its early stages. These latest topics presented opportunities for further development in future research (Purnomo, 2022).

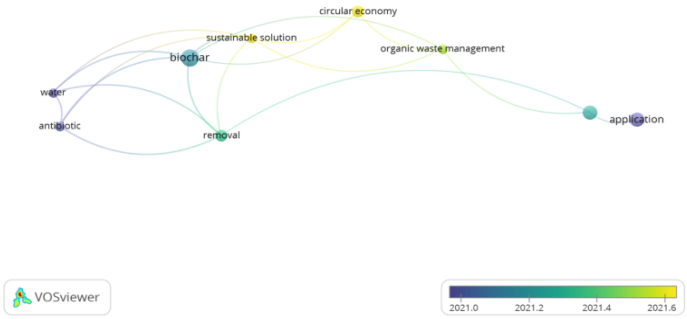

Figure 4 Overlay visualization social economy of biochar scopus-indexed ppublications

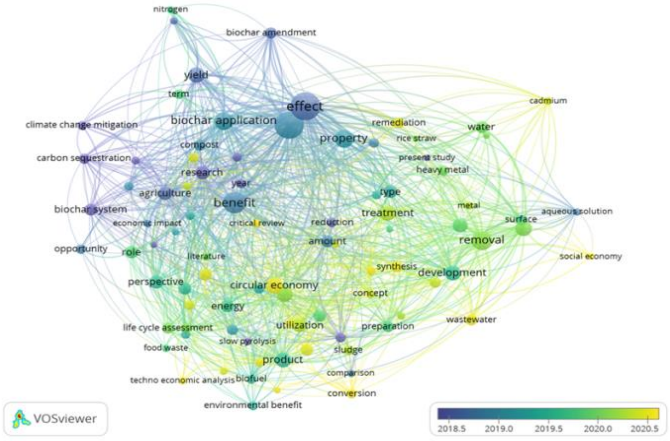

Figure 5 Overlay visualization social economy of biochar google scholar-indexed publications

Future research needs are the latest topics that have not been studied or studied simultaneously (Purnomo, 2023c; 2023d). The latest topic was discussed as a bright yellow marked in Figures 3 and 4. The topics that had not been studied simultaneously observed from the link between the topics. For example, the social economy topic was not studied simultaneously with the techno-economic analysis, life cycle assessment, circular economy, or biochar application topics. The topics that had not been studied were the topics outside the list found by VOSviewer.

3.1.4. Social Aspecs in Social Economy of Biochar Research

Figure 3 shows that the data processing of publications indexed in Scopus did not produce keywords directly related to social aspects. Figure 4 shows that the data processing of publications indexed in Google Scholar resulted in two keywords directly related to social aspects: "socioeconomic" and "role." The keyword "socioeconomic" directly includes the term social, and the keyword "role" pertains to a study within the social structure (Ritchie, 2020).

The most cited articles in publications indexed in Scopus focus on technological aspects (3 articles), environmental aspects (1 article), and policy aspects (1 article). The most cited articles in publications indexed in Google Scholar focus on environmental aspects (4 articles) and biochar processing technology (1 article). The social aspect of the social economy of biochar was potentially found in the policy aspects (Purnomo, 2023d). The environmental and technical aspects possibly contain social aspects (Hansson et al., 2021; Lehmann et al., 2021; Müller et al., 2019).

Further data exploration on the abstracts of these articles found that Articles 2 and 4 in Scopus-indexed publications included technical and economic aspects. Articles 1, 3, and 5 addressed social concerns and economic, environmental, and technical aspects of biochar management. Article 1 discussed the role of the government in policymaking, article 3 covered

social impact, and article 5 addressed social concerns alongside circular economy in biochar management. Article 1 in Google Scholar-indexed publications was a book with only one chapter addressing policy out of 35 chapters. Social and economic issues were discussed to complement the predominantly technical aspects of biochar management covered in the book. Article 2 was a chapter from the book in publication number 1, and it briefly mentioned social aspects as a benefit of biochar management. Articles 3, 4, and 5 focused on the technical aspects of biochar management.

The data revealed that research on social topics was still minimal within the scope of the socioeconomic aspects of biochar. Social aspects become part of biochar research when societal factors are considered in the study. The emerging socioeconomic research topics in biochar did not include social aspects, community, social feasibility, society, humans as implementers, social justice, or social change (Fytili & Zabaniotou, 2018; Kamali et al., 2022; Latawiec et al., 2017; Matrapazi & Zabaniotou, 2020; Müller et al., 2019; Otte & Vik, 2017).

3.2. Discussion

The topics studied in biochar's socioeconomic factors in Scopus and Google Scholar-indexed publications predominantly focused on the technical aspects of biochar management. The keywords directly related to social aspects were "socioeconomic" and "role." The keyword "role" refers to studies within the social structure (Ritchie, 2020). The keyword was the social economy, which means that social topics in biochar research were minimal. The inclusion of social aspects in the abstracts of the most-cited articles was generally limited to a supplementary role, with the primary focus being on other aspects of research. The data processed by VOSviewer displayed keywords in article titles and keywords. Previous studies using similar methods identified relevant keywords or topics (Purnomo, 2023a; Purnomo, 2023b). VOSviewer analyzed data based on titles and keywords, thus overlooking the content within the abstracts. Confirmation through the abstracts of the most-cited articles revealed attention to social aspects in articles with titles that did not explicitly include social aspects. Therefore, social aspects were not the main focus of those studies because they were not found in the title and keywords.

The study trend revealed that technical aspects remained consistently researched over the past 10 years. Environmental aspects emerged as a new topic in Scopus-indexed publications but were older in Google Scholar-indexed publications. The latest research topics in Scopus-indexed publications are the circular economy and sustainable solutions. Previous studies have researched this topic, including the circular economy (Fytili & Zabaniotou, 2018) and sustainable solutions (Hansson et al., 2021; Mohammed et al., 2024; You et al., 2022). The latest topics in Google Scholar-indexed publications were the circular economy, socio-economy, and techno-economic analysis. Previous studies have studied social economy (Mohammed et al., 2024; Rogers et al., 2021) and techno-economy analysis (Van Fan, Klemeš, & Lee, 2021). The previously researched keyword "circular economy" did not appear in the previous bibliometric data (Gonzalez et al., 2021; Patel et al., 2022). The latest topic was one of the potential future studies. The data revealed that socioeconomic topics were still promising, and the social aspect was infrequently studied.

When the study examined the societal aspects of those implementing biochar technology, social aspects became the focus of biochar research. The data in Figures 3 and 4 show that the central keywords in each cluster refer to biochar, biochar application, effect, benefit, and removal. Besides the keywords "effect" and "benefit," the other three refer to biochar. Research discussing "effect" examined the impact of biochar on agriculture (Shen et al., 2024). The term "benefit" in previous research was related to environmental benefits (Anand et al., 2022; Hersh et al., 2019) and economic benefits (Oni et al., 2019; You et al., 2022). None of the central keywords in each cluster directly refer to the social aspects of biochar. Research

focusing on the societal aspects of implementing biochar technology has yet to become mainstream in studies of the social economy of biochar.

Similar data was found in the most cited Scopus and Google Scholar-indexed articles. The study topics in the most cited articles primarily focus on biochar technology development and environmental aspects. One social topic that has received the most citations is policy. Previous research has highlighted the urgency of policy in the development of biochar (Rittl et al., 2015). The policy falls within social science studies (Carter & Charles, 2009). Articles on policy are among the most cited, indicating that social researchers frequently refer to policy aspects. Analysis of the abstract demonstrated that the social aspect was discussed in addition to the main topic. The data revealed the need for a social focus on biochar study.

The low number of publications in Scopus and Google Scholar indicates a need for more research on the social economy of biochar. However, this factor is crucial in adapting and adopting biochar in communities (Müller et al., 2019; Rogers et al., 2021). Biochar, as a sustainable technology (Hansson et al., 2021), will not be widely applied if it is not socially accepted (Fytili & Zabaniotou, 2018) and economically beneficial for the community (Hersh et al., 2019; Rogers et al. 2021). The limited number of studies on the social economy of biochar presents an opportunity for further research (Purnomo, 2023a; Purnomo, 2023b).

4. Conclusion

The bibliometric analysis of the socioeconomic aspects of biochar revealed that research focusing on the social aspects of biochar still needs to be completed. The majority of biochar research centers on topics related to biochar processing technology, the environment, economics, and other aspects that can be linked to various research focuses. The topic research trend revealed that the social economy of biochar was the latest issue. The social economy of biochar has the possibility for future research. The data processing of the "social economy of biochar" keyword found more keywords related to the economic aspect than the social aspect. The bibliometric analysis only identified two keywords directly related to social aspects. These findings suggest that the need for research on the social aspects of biochar remains open for social science researchers more than social economic issues. The social aspect was promising to be studied in biochar because it is infrequent, and there is a need to discuss elements of people, community, culture, and social structure in biochar processing.

This study provides an overview of the trends in socioeconomic research on biochar and the focus on social aspects within these studies. However, the study has limitations as it needs to review articles explicitly focusing on the social aspects of biochar. This limitation was due to limited specific social research on biochar. The limitation of bibliometric analysis, which cannot assess the context of each keyword, means that this analysis cannot directly conclude that research indexed in Scopus and Google Scholar from 2014 to 2024 needs more on the social aspects of biochar. This weakness prevents the study from offering specific recommendations on relevant social aspects of biochar research compared to previous studies. Future research is expected to conduct a more in-depth review of published articles to address the need for studies on the social aspects of biochar.

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