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Social Awareness as a Catalyst for Biochar Adoption in the Agricultural and Forestry Sectors

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ABSTRACT

Biochar, a carbon-rich material produced from the pyrolysis of organic matter, has garnered attention for its potential agricultural and environmental benefits, including soil improvement, enhanced crop yields and climate change mitigation. Despite its promise, biochar adoption has been hindered by limited social awareness, particularly in industrialised countries. This review explores the factors influencing biochar's acceptance in agriculture and forestry, focusing on the social aspects that affect its integration. A systematic literature review was conducted to identify studies on social awareness and acceptance, revealing significant barriers such as a lack of knowledge among farmers, high production costs and insufficient infrastructure. In industrialised countries, while technical research on biochar has progressed, farmers often remain unfamiliar with its benefits, and resistance to adoption is common. Studies show that social factors such as age, education level and access to funding play a crucial role in biochar adoption. Furthermore, a lack of government incentives and unclear regulatory frameworks exacerbate the challenge. Conversely, studies from lower-income countries suggest that small-scale, cost-effective biochar production systems may hold promise. The review also identifies strategies to enhance biochar's social acceptance, including targeted education programs, financial incentives and clearer regulatory standards. Despite varying levels of social awareness, the literature suggests that with increased outreach, biochar could significantly contribute to sustainable agricultural practices globally. This review underscores the need for further research into the social dimensions of biochar adoption and the implementation of policies to foster its widespread use.

1 | Introduction

Biochar is a carbon-rich material produced through the thermochemical transformation of organic matter under oxygen-limited conditions (EBC 2022). It has garnered significant interest from the agronomy and forestry scientific communities due to its potential use as a soil amendment that enhances various soil properties, raises agricultural production, and assists in climate change mitigation (Hagenbo et al. 2022; Lefebvre et al. 2024; Lehmann et al. 2021). Biochar can be produced from a plethora of feedstocks (Schmidt et al. 2021), including forest biomass (Janiszewska et al. 2021; Zhang et al. 2023), crop residues (Colantoni et al. 2016), animal manure (Rathnayake et al. 2023), sewage sludge (Rangabhashiyam et al. 2022) and food waste (Liu et al. 2020). The pyrolytic process typically occurs at temperatures between 350°C and 1000°C (EBC 2022). The final product's properties and quality are influenced by factors such as production temperature, feedstock type, reaction time and pre-treatment processes (Rajabi Hamedani et al. 2019; Cueva et al. 2022; Mašek et al. 2018; Kamali et al. 2022). Wood-based biochars tend to have the highest surface area, those produced from grass biomass showed the highest cation exchange capacity (CEC), and manure-based biochars the highest nitrogen (N) and phosphorus (P) contents. Higher ash content and pH values, as well as greater persistence in soil, are typically observed in biochars produced at temperatures above 500°C (Ippolito et al. 2020).

Numerous effects of biochar on the physical, biological and chemical properties and functions of soil as well as on plant growth have been documented in the literature (Schmidt et al. 2021). Furthermore, different studies also reported the reduction of greenhouse gas emissions from soil through carbon sequestration in a stable form by biochar and the alteration of soil conditions (Li et al. 2018; Lyu et al. 2022). Reviews including meta-analyses demonstrate that biochar generally decreases soil acidity and raises buffering capacity (Shi et al. 2019); it also decreases bulk density and increases accessible nutrients (Hossain et al. 2020), water retention, aggregate stability and dissolved and total organic carbon as well as cation exchange capacity (Kroeger et al. 2020; Yuan et al. 2023). Biochar has the potential to boost microbial activity, fasten the cycle of nutrients, and lessen nitrogen volatilization and leaching (Lehmann and Joseph 2015; Pokharel et al. 2020). Furthermore, its use can have a positive impact on the capability of a plant to germinate seeds, flowering, pest resistance and resilience towards abiotic stressors (Hasnain et al. 2023; Joseph et al. 2021). Biochar stores carbon in a stable form, reducing CO_2 emissions to the atmosphere (Woolf et al. 2010) and it can also contribute to the reduction of methane (CH_4) and nitrous oxide (N_2O) emissions by limiting processes that lead to the release of these gases (Van Zwieten et al. 2015).

These beneficial qualities of biochar cause a positive effect on crop growth, with an increase in yield ranging from 10% to 42% (Biederman and Harpole 2013; Liu et al. 2022; Melo et al. 2022; Ye et al. 2020), even if in some cases decreased crop performance after biochar application is reported in the literature (Abukari et al. 2022; Jeffery et al. 2017; Kammann et al. 2011). Biochar seems particularly beneficial in degraded and nutrient-poor soils, while its application to fertile and healthy soils does not always positively affect crop yield (Abukari et al. 2022; Bo et al. 2023; Hussain et al. 2017). Generally, research demonstrating favourable outcomes has often employed biochar application rates ranging from 5 to 20 Mg ha^{-1}, while low rates (< 1 Mg ha^{-1} biochar) of biochar–fertilizer mixtures have also resulted in higher yields (Joseph et al. 2021).

Biochar also holds promise for mitigating climate change by reducing carbon emissions from the forestry and agriculture sectors (Neogi et al. 2022; Sri Shalini et al. 2021). Carbon stored in biochar remains in the soil significantly longer than in non-pyrolysed lignocellulosic biomass, enhancing soil carbon storage (Chagas et al. 2022; Kuzyakov et al. 2014). Additionally, by changing the soil properties and subsequently the microbial pool, biochar application can reduce methane, nitrous oxide and other greenhouse gas emissions (Jiang et al. 2023; Lyu et al. 2022).

Even if the potential benefits of the use of biochar in soil applications are widely recognized, some challenges and question marks remain. Despite its enormous potential to increase the overall sustainability of the agriculture and forestry sectors, biochar has yet to achieve widespread deployment (Campion et al. 2023; Haghighi Mood et al. 2022). Current global demand for biochar is approximately 500 times lower than that for chemical fertilizers (Grand View Research 2019; International Fertilizer Industry Association 2021). This limited demand may be partly due to biochar's higher production costs relative to commercial fertilizers, particularly in high-income countries (Pourhashem et al. 2019). On the other hand, studies indicate that in lower-income countries, small-scale local biochar production (with daily feedstock capacities between 0 and 2 Mg) can be cost-effective (Robb et al. 2020).

One significant barrier to the broader adoption of biochar in agriculture and forestry is limited social awareness (Campion et al. 2023; Salo et al. 2024). Despite researchers' efforts, many potential stakeholders, including farmers and foresters, remain largely unaware of biochar and its benefits (Dal Ferro et al. 2020). This review aims to summarize the current knowledge on social awareness and acceptance of biochar among practitioners. Our goal is to assess how well farmers and foresters understand biochar's properties and applications, as well as identify potential steps to increase social acceptance and foster biochar's application in agriculture and forestry.

2 | Materials and Methods

To identify studies addressing social awareness and acceptance of biochar in agriculture and forestry, a systematic literature review was conducted in the first half of 2024 using the Scopus, Web of Science and Google Scholar databases (the latter to capture possible grey literature such as theses, technical reports etc.). The search query was as follows:

- *Query*: ("social life cycle assessment" OR "social-LCA" OR "social assessment" OR "social analysis" OR "social impact*" OR "social sustainability" OR "social acceptance" OR "social awareness") AND ("biochar*")

We did not apply any time restriction to the literature search. After removing duplicates and screening the manuscripts, additional literature was identified through snowball sampling from the reference lists of the papers (Jalali and Wohlin 2012). The final refined database consisted of 29 sources: 21 scientific papers, one book chapter, three master's theses, two doctoral dissertations, one technical report and one conference proceeding (Figure 1a). The topic has been widely studied in Europe, with additional research from Africa and Asia, while fewer studies were found for North America and Oceania (Figure 1b).

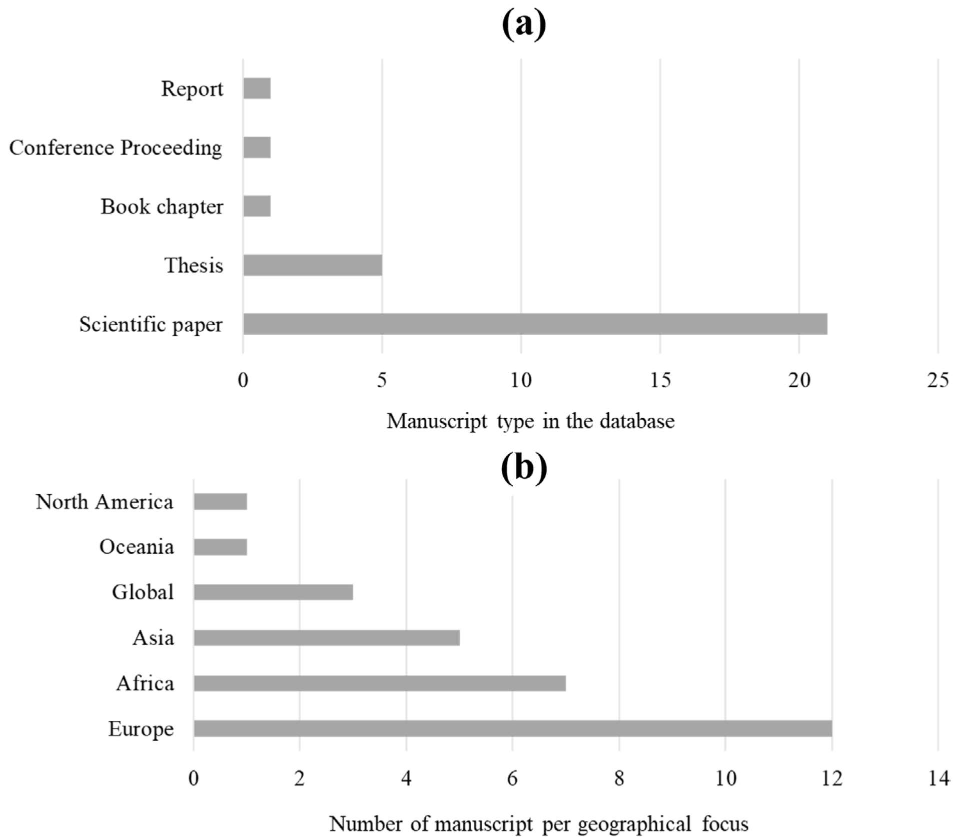

FIGURE 1 | (a) Number of manuscripts per each type in the database and (b) geographical focus of the manuscripts in the database.

3 | Social Awareness About Biochar in Industrialized Countries

In industrialized countries, despite extensive research on the technical, biological and chemical properties of biochar, the deployment of a functional biochar system remains distant. Lack of awareness among farmers has consistently emerged as a key barrier. A survey conducted in Australia (August–September 2013) on preferred carbon sequestration practices found that biochar was among the least favoured options, likely due to limited understanding of its nature and benefits (Dumbrell et al. 2016). Similar findings were observed in Northern Italy, where biochar ranked low among innovative soil management strategies in workshops with various stakeholders, primarily due to unfamiliarity and lack of perception (Dal Ferro et al. 2020). Social and cultural barriers for biochar adoption include farmer skepticism, resistance to new ideas, lack of production equipment, limited availability and insufficient information on biochar's potential benefits (Shackley et al. 2016).

Further studies support these findings. In a 2017 survey in Norway, researchers noted that 95% of participating farmers had never produced biochar, although about 60% had access to surplus biomass suitable for on-farm biochar production (Otte and Vik 2017). Over 80% of farmers had limited knowledge of biochar, with over 70% citing information availability as crucial in deciding to use it. The study highlighted factors that could drive biochar adoption in the agriculture sector, such as low-cost production methods, simple technologies for self-production, as well as government subsidies for soil carbon storage (Otte and Vik 2017). Jansen (2023) identified high production costs and the absence of a stable, farmer-friendly carbon market as primary constraints. In Finland, awareness gaps along the value chain, specifically regarding practical research, raw materials and conversion technologies, were the main obstacles (Salo 2018).

These trends are, however, not universal Latawiec et al. (2017) conducted similar research in Poland, using a sample of 161 farmers. In this study, 27% of respondents were familiar with the term ‘biochar’, a higher proportion than in Norway, as reported by Otte and Vik (2017). Knowledge of biochar was notably higher among farmers without agricultural education (36%) than those with higher-level agricultural training (31%). While 43% of respondents were unwilling to use biochar, 20% expressed interest, and 37% were uncertain due to operational cost concerns despite recognizing benefits in soil quality and crop yield (Latawiec et al. 2017).

Recent research has sought to deepen our understanding of the challenges hindering the social acceptance of biochar. It suggests that the integration of biochar into soil—rendering it essentially invisible—may contribute to this difficulty, particularly among non-technical stakeholders. For instance, stakeholders have demonstrated a preference for more visibly impactful initiatives, like large-scale solar panel projects, over biochar-based approaches to climate change mitigation (Nicholas et al. 2022; Stoknes et al. 2021). Conversely, the main obstacle deterring biochar's application for bioremediation of polluted soils is the lack of specific technical regulations and legislation (Arenyeka 2018). This regulatory gap hinders the formal recognition of this material as an effective remediation tool, limiting its integration into official remediation protocols. Without the introduction of standardized guidelines on production and application, there is variability in quality and effectiveness of the applied biochar, complicating its consistent implementation in environmental restoration projects. Addressing these regulatory and standardization issues could enhance the acceptance of biochar and promote its role in sustainable bioremediation strategies (Arenyeka 2018).

Amongst the studies reviewed, one argued that social awareness and public acceptance of biochar is not a principal issue for its implementation in European agriculture (Verde and Chiaramonti 2021). The authors reported that the primary limitation is the lack of financial incentives for greenhouse gas removal and soil carbon restoration. It is suggested that with such incentives, biochar adoption would increase independently of public awareness (Verde and Chiaramonti 2021). Other studies recommend programs defining biochar as a product with environmental benefits, which could help build social awareness by informing stakeholders about its economic and environmental advantages (Pourhashem et al. 2019).

Research efforts in the application of biochar in agriculture have predominantly been carried out for the Chinese context (Jiang et al. 2023; Liu et al. 2022). However, a preliminary analysis of the various studies details a state of the situation of social awareness quite similar to the context of other industrialised countries (Clare et al. 2014). Research on this topic indicates that farmers are more likely to adopt biochar practices if: (i) they have higher levels of education; (ii) greater access to funding; (iii) membership in farmers' organizations; and (iv) frequent interactions with extension agents and other information sources (Grace 2018). Furthermore, it is suggested that government initiatives and investments play a key role in shaping more effective outreach strategies to engage farmers. This could include hiring additional extension agents and enhancing media campaigns to educate farmers on the innovative uses and potential benefits of biochar, emphasizing both improved crop yields and reduced environmental impacts (Grace 2018).

A summary of the main barriers identified in this review and the influencing factors is reported in Figure 2a,b respectively.

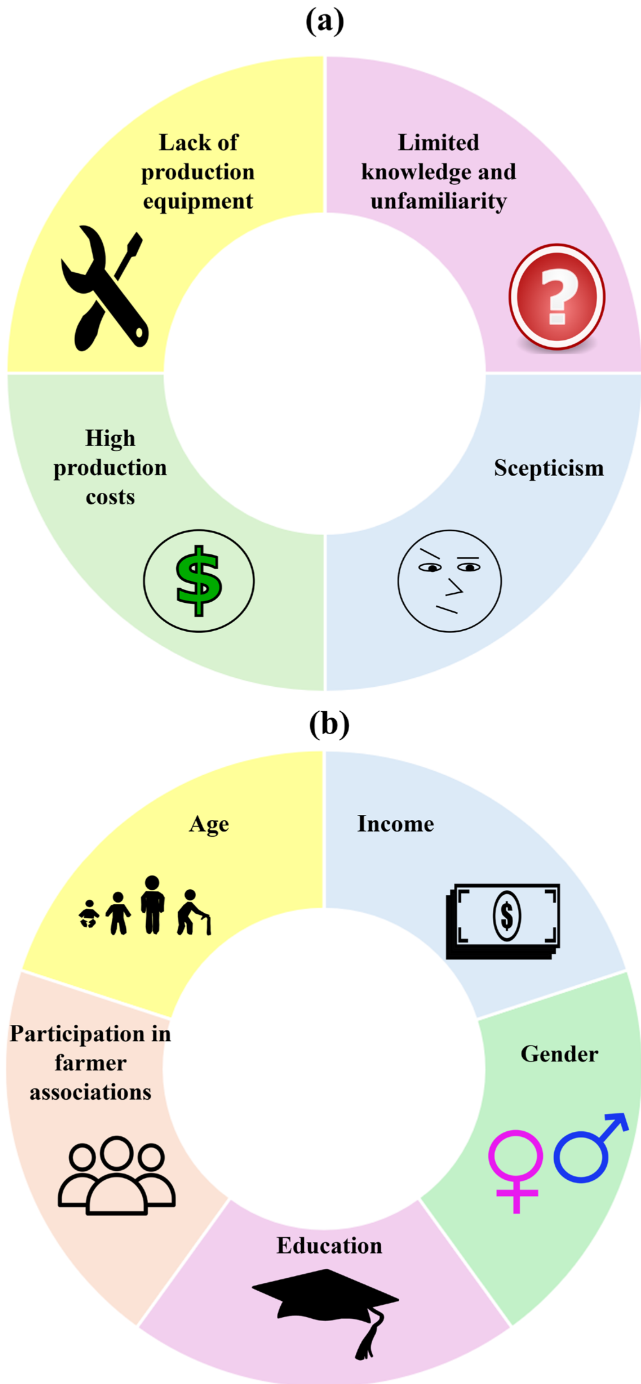

FIGURE 2 | (a) Identified barriers to biochar implementation, along with main influencing factors (b). *Source:* Own elaboration.

4 | Social Awareness About Biochar in Developing Countries

The application of biochar in agriculture could be even more beneficial in developing countries. Literature states that biochar is most effective in degraded and poor soils, for instance those of the African savannas (Hussain et al. 2017). Furthermore, differently from the European context where the production of vegetal charcoal has been abandoned (Mencarelli et al. 2023), charcoal is still a major source of energy for cooking in the African territory (Mahmoud et al. 2021). However, this can also represent an obstacle for the application of biochar in agriculture, as the local population can be more prone to see it as an energy source rather than a soil amendment, as reported by the results of different biochar initiatives in Tanzania (Eltigani et al. 2022; Hansson et al. 2021). Scarce willingness to adopt biochar for agricultural purposes was also reported in a simulation study carried out in Zimbabwe. The authors highlighted that the negative perceptions of the farmers in relation to biochar use were among the biggest obstacles for its large-scale application (Gwenzi et al. 2015). The initial funding for the implementation of the pyrolytic units is an important reason limiting the widespread adoption of biochar. This situation is still common despite substantial external capital grants and training programs (Rogers et al. 2021). The same study concluded that the use of biochar is influenced by age, income level, gender and education level. According to the authors, the sluggish adoption of biochar can be attributed to several factors, including a failure to empower women, whose participation is hindered by patriarchal institutions and poor income, lack of formal education beyond the elementary level and no involvement of the younger population. Based on these results, the study suggested a workable strategy to introduce farmers to biochar technology, which involves creating capacity through education and on-farm demonstrations conducted in the form of 'farmer-field schools' (Rogers et al. 2021). This approach could boost self-assurance and assuage worries about the technology. Public credit guarantee schemes should be developed with farmers to provide them with the funding required to support the investment. Young people and women should be prioritized in these programs, as the first group is recognized as more easily adaptable to newer technology systems and the second generally has a lower level of financial independence and personal empowerment (Rogers et al. 2021).

Positive experiences of biochar application in agriculture in African countries have been documented. Pyrolytic cooking burners were provided to chosen households in Kenyan territory, and the recipients were trained on the application of biochar to the soil. Studies were carried out based on the opinions and experiences of the households to evaluate the application feasibility and the effects after 2 years of utilizing the cooking stoves and applying biochar. The majority of the sample (87%) planned to continue the utilization of biochar as a soil amendment, with only 13% of respondents saying they would rather reuse it for energy purposes (Mahmoud et al. 2021). Half of the respondents said that the procedure of collecting, drying, storing, and, most importantly, chopping the feedstock into appropriate sizes made the biochar production process time-consuming. Despite this difficulty, biochar production would not be discontinued, as the participants of the project saw benefits for soil productivity, energy efficiency and increased household economics (Mahmoud et al. 2021). A participatory trial of production and application of biochar by small farmers was developed in Ghana and registered a 93% increase in lettuce yield and significant enthusiasm from the farmers regarding the easiness of use of the kiln. The success of the initiative was largely due to the wide availability of feedstock (in this case, rice husk) and the simplicity of biochar production (Steiner et al. 2018). The availability of feedstock and easy access to the production technology were also confirmed to be fundamental drivers of willingness to adopt biochar in Nigerian agriculture (Ajewole 2010).

The application of decentralised solutions for biochar production seems to be an interesting approach (Fytili and Zabaniotou 2018). In the case of developing countries, small-scale solutions are suggested, at the scale of village or small groups of producers with a daily biochar throughput capacity ranging from 0 to 2 Mg (Robb et al. 2020). The focus on small scale and adoption by a community instead of an individual ensures that the initial investment of the pyrolytic unit is not supported by a single family. Additionally, it eliminates the need to transport the feedstock for long distances, thus optimizing the logistics and relying on local raw materials. However, it is essential to involve local communities and account for the diverse conditions across small farm settings, factors that can ultimately determine the success or failure of biochar initiatives (Müller et al. 2019).

Focusing on social awareness in developing countries outside the African continent, we found contrasting literature results from two different studies carried out in Bangladesh and Thailand. The application of biochar was very appreciated in Bangladesh, where local farmers observed up to 60% yield increase in cabbage and kohlrabi crops and stated to be highly willing to adopt this methodology in their cropping systems (Sutradhar et al. 2021). Contrarily, in a survey conducted in the Amphawa district in Thailand, local farmers stated to not be enough familiar with biochar to introduce it as fertiliser in their crops. Additional marketing and information from public media were indicated as necessary to promote its application in rural communities (Niemmanee et al. 2019). This highlights once more the fundamental role of raising farmer awareness to foster the application of biochar in agricultural systems (Kamali et al. 2022).

5 | The Role of Social Life Cycle Assessment (S-LCA) in Biochar Research

When investigating the sustainability of a process or product, it is fundamental to take into consideration all three pillars of sustainability: economy, environment and society (World Commission on Environment and Development 1987). The evaluation of the social implications of a given process/product in an objective way is much more complex than when considering environmental and economic aspects due to the impossibility of quantifying terms such as 'well-being' or 'beneficial' (Lehmann et al. 2013). Recently, to tackle this issue, the Social Life Cycle Assessment (S-LCA) methodology has been developed (UNEP 2020), and it currently represents the most effective assessment method for the social sustainability of products and processes (UNEP 2020). S-LCA is based on the same logic as Life Cycle Assessment. The concept at the base of S-LCA is that the actions of businesses engaged in a given product life cycle will impact positively or negatively the well-being of the population (Sala et al. 2015). The S-LCA is regarded as a part of the Life Cycle Sustainability Assessment (LCSA) and may be carried out in conjunction with an LCA (Life Cycle Assessment—environmental impacts) and/or an LCC (Life Cycle Costing—economic impacts). Above all, S-LCA makes social hotspots in the product life cycle visible to involved stakeholders and provides pertinent information to businesses and policy makers (Backes and Traverso 2023; Finkbeiner et al. 2010).

Current LCA (Azzi et al. 2022; Patel and Panwar 2023; Xia et al. 2024) and LCC literature (Homagain et al. 2016; Lu and El Hanandeh 2019; Sahoo et al. 2021) on biochar production and utilisation is readily available, but, to the best of our knowledge, no research on S-LCA of biochar production has yet been published. During our systematic review of the literature, one PhD thesis dealing with LCSA of biochar production in Europe has been identified, thus also considering the S-LCA aspects (Rack 2017). In that thesis, the author considered biochar from olive cultivation residues, including the entire value chain, from feedstock quantification to biochar incorporation in the soil. A farm-scale scenario was assumed, in which the farmer is responsible for the cultivation and maintenance of the olive trees, leveraging local biochar production with a small-scale system and its direct application on farmer's own fields. The focus of the study was on four groups of stakeholders (workers, local community, society, value chain actors) and 21 impact subcategories, including child labour, fair salary, health and safety, local employment, level of community engagement, corruption and fair competition (Rack 2017). The author notes that there is no interaction with project stakeholders on this matter, hindering the acquisition of primary, site-specific data on the production facilities/farmers. Consequently, the subcategories were analysed according to the presence of national policy which addressed them. As an example of this approach, if considering the subcategory of forced labour, the author registered the existence of a policy which forbids its existence, i.e., as long as the policy is enforced by the appropriate authorities, there will be no impact. The main conclusions of this study, under its necessary limitations, were that biochar production at the farm scale does not produce substantial impacts (Rack 2017). However, the lack of interaction with stakeholders did not permit elaboration on the actual impacts related to both the foreground system (use and application of biochar) and the background system (systems related to all inputs necessary for the production, transportation, etc.). For instance, replacing synthetic fertiliser with an organic, locally produced alternative is likely to benefit the local community and ecosystem but could negatively affect upstream systems. On the other hand, using local waste for biochar production—potentially designated for a specific role in the value chain—may lead to unforeseen consequences. Context is relevant, and all analysis must consider the specific circumstances rather than being conducted in isolation. While not a critic of the referred approach, the reliance on policy—a document intentionally made broad to apply across an entire region—will lead to an assessment that cannot transcribe the project or production itself but rather the effectiveness of the agricultural legislation instead of its application. While no social assessment was identified in the studied body of work, some articles consider certain social aspects. An example of such is in the study by Rajabi Hamedani et al. (2019) which considers the economic gains, such as the production of energy or valorisation of pig manure, as social benefits to the producer. Otte and Vik (2017) and Rogers et al. (2021) follow a similar strategy, in which a social-technical framework is used to evaluate the direct economic benefits available to value chain actors. The first study developed a series of surveys to be disseminated through the farmer community to evaluate whether the predicted environmental and economic advantages of the use of biochar would move the population to adopt the new technology. As a complement to the various analyses related to social acceptance, this work underlines the difficulty in promoting small units of farmers to implement such technology, not for lack of information, but due to the lack of financial incentives and the work required for implementation, the latter of which might make the stakeholder prefer the simplicity in keeping business as usual. It is also suggested in the text that two extra stakeholders should be introduced into the question to facilitate implementation: the municipalities (local community stakeholder) and forest owners (value-chain actors). The study by Petelina et al. (2014) furthered research on the recovered body of work which considered social sustainability aspects. Unlike the former examples, it does not see biochar as a tool for the valorisation of a given residue but as a tool for soil remediation, suggesting the application of both commercially available and locally produced biochar. Two stakeholders were considered (Workers and Local community) and six subcategories of social assessment were taken into account. While this study was relatively small in scope, there was an attempt by the authors to promote the classification of the various scenarios according to perceived impact by the surveyed. Interestingly, the social categories were considered of lesser relevance when compared to the environmental and economic aspects. The authors suggested that this result was a consequence of the low representation of the local community in the pool of responders, especially considering that five out of the six chosen criteria were mainly related to the impact on this stakeholder.

While some work has been identified on the social aspects of the production and application of biochar, it remains a widely undiscussed subject and will undoubtedly require further investigation.

6 | Path Forward

As we navigate the complexities of sustainable agriculture and forestry practices (Yasmeen et al. 2021; Janiszewska-Latterini and Pizzi 2023; Michalski et al. 2023), social awareness emerges as a pivotal catalyst for the adoption of biochar. Despite all biochar's benefits, its widespread adoption faces challenges such as limited awareness among farmers and foresters about its advantages and integration into existing practices (Latawiec et al. 2017). Ultimately, the goal is to provide actionable insights into how increased social awareness can propel biochar from a promising innovation into a mainstream practice within agriculture and forestry sectors worldwide. One of the key legislative aspects that needs to be analyzed is the definition of agricultural and forestry waste. In many countries, including those in the European Union, biochar produced from agricultural and forestry waste can be treated as waste, complicating its classification, transportation and utilization. Ambiguous regulations lead to difficulties in registering biochar as a fertilizer or soil amendment. These actions require engagement from various stakeholders to understand the nature of the problem and collectively develop solutions beneficial for all parties. European legislation on waste management, fertilizers and circular economy emphasizes sustainable use of waste. However, biochar's classification remains unclear. New European Unions regulations on fertilizers (Regulation [EU] 2019/1009) outline certification procedures for organic fertilizers, but not all biochar products meet these standards. Moreover, differences in approaches exist across European countries, and biochar application aspects are still legally grey areas (Enaime et al. 2023). It is crucial to support farmers and foresters operationally by maintaining open dialogue at regional levels as well as through inter-ministerial consultations at government levels. Legislatively speaking, every fertilizer must undergo an approval process within each country, which involves high costs for research and certification. In developing countries, the usual lack of procedures for new types of fertilizers further complicates their implementation. Legislative issues hinder social acceptance because they impose additional concerns on users regarding implementing new solutions despite their undeniable practical value.

Market challenges are driving farmers and foresters to seek alternative sources of fertilizers. However, a lack of sufficient knowledge about biochar and its benefits for soil health limits its widespread application. The process of converting agricultural waste into biochar necessitates specialized infrastructure and storage space, which can be a significant barrier, especially in developing countries in Africa and Asia where appropriate technologies may be lacking. This often results in the production of low-quality biochar and improper usage, further complicating its adoption.

To address these issues, it is essential to conduct a thorough analysis of the barriers to biochar adoption while simultaneously increasing awareness of its potential as a factor influencing the profitability of agricultural and forestry operations. Advisory support, both technical and financial, provided to farmers and foresters by local governments can play a crucial role in this process. Initiatives could be implemented through dedicated social funds and investment programs that incentivize the use of biochar (Berbeć et al. 2023). Moreover, there is a critical concern regarding the risk of market monopolization in the biochar sector, particularly if large corporations dominate production. Such a scenario could significantly limit access to biochar for small and medium-sized farms and forest enterprises, limiting their ability to benefit from this practice and discouraging them from further use.

Social awareness and education play a crucial role in shaping the future applications of biochar and its acceptance among farmers and foresters. Many of them in various countries remain unaware of the benefits associated with biochar use. In developing countries, particularly in regions like Bangladesh, Thailand and parts of Africa, there is a pervasive distrust of new technologies. It is essential to highlight that improper application practices, coupled with a lack of appropriate regulations and education, pose risks for the misuse of biochar, potentially leading to soil degradation or environmental contamination. A collective effort is required from societies worldwide to share experiences and best practices regarding climate change adaptation and sustainable agricultural and forestry practices. Several inspiring programs funded by the European Commission focus on collaborative research between European countries and those in Asia and Africa. These programmes include Horizon Europe, LIFE Programme, African Research Initiative for Scientific Excellence (ARISE), Global Gateway and teamwork initiative. Engaging local communities in discussions about biochar, including testimonials from early adopters, can help build trust and encourage acceptance. In developing countries, specific challenges persist regarding the collection and processing of agricultural and forestry waste due to insufficient infrastructure. This limitation significantly complicates the potential for biochar production, which relies on the effective management of biomass feedstocks. Without adequate facilities for gathering and converting organic waste into biochar, the benefits of this sustainable solution remain largely unused. This includes not only physical facilities but also transportation networks that can facilitate the movement of biomass from farms and forests to processing sites. By addressing these infrastructural and educational gaps, developing countries can unlock the potential of biochar as a valuable resource for enhancing soil health, improving agricultural productivity and contributing to climate change mitigation efforts. Collaboration among stakeholders at local, national and international levels will be crucial in overcoming these challenges and fostering a sustainable future for agriculture and forestry practices in terms of biochar social awareness (Scholz et al. 2014). A summary of the possible solutions to the current barriers to biochar implementation is given in Figure 3.

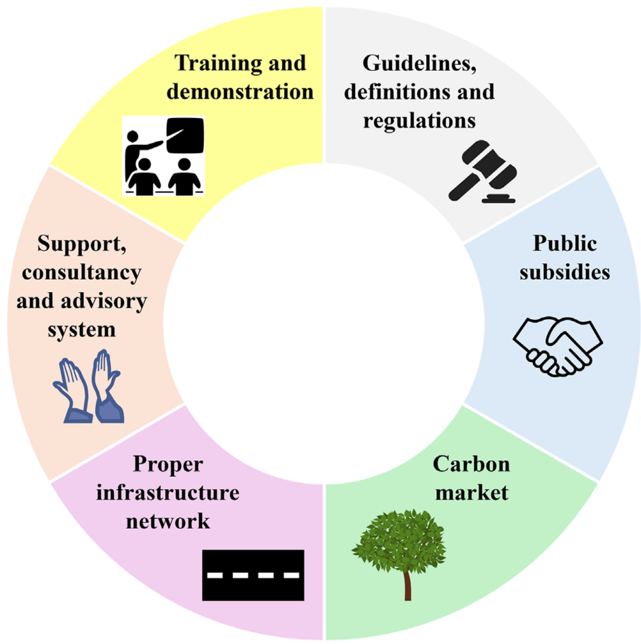

FIGURE 3 | Possible solutions to overcome the current barriers for biochar implementation.

7 | Conclusions and Key Points

Despite the enormous attention that biochar received from the scientific community for its potential benefits to the agriculture and forest sector, its application at the practical level is still negligible. Having been the environmental and economic aspects of biochar widely investigated, we started from the assumption that the bottleneck for biochar application consists of low social awareness from the end-users, including farmers and foresters. To investigate this aspect, we therefore developed this systematic literature review, with the goal of summarising the current knowledge about social awareness and social impacts of biochar application for agriculture and forestry. The main findings can be summarised as:

- In industrialised countries, the majority of farmers still have limited knowledge on biochar characteristics; therefore, increasing the knowledge about application ways and its benefits is probably the first step that scientists and policy makers should take.
- The possibility of producing biochar at the farm scale with a simple technology is fundamental to spread biochar application in agriculture.
- The development of a simple and effective carbon credit market remunerating farmers who apply biochar as a consequence of their reduced GHG emissions is another important instrument that should be considered and implemented at the governmental level.
- Careful monitoring of market trends is necessary to prevent monopolistic practices that could disadvantage smaller operators. Policies should encourage fair competition and equitable access to biochar resources.
- In developing countries, mostly in Africa, there is also a further social barrier for the application of biochar in

agriculture, related to people perception and treating biochar mostly as an energy carrier rather than a possible fertilizer for their crops.

- Extensive training and demonstration programmes are recommended to increase awareness toward biochar application in agriculture, with the same applying to economical subsidies allowing local farmers to purchase the kilns, also in associative forms at the level of small community.
- The lack of studies specifically dealing with Social Life Cycle Assessment (S-LCA) of biochar production and application in agriculture and forestry is an important knowledge gap to be urgently fulfilled.
- Unclear regulations discourage users due to the additional risks perceived in new technologies. It is important to work with policymakers to develop clear and comprehensive regulations for the use of biochar, as clear guidelines on quality and safety have the potential to reduce uncertainty and encourage users to adopt biochar.
- Regardless of biochar's technical potential benefits, their realization relies on how and whether people adopt biochar systems. Identifying sociocultural barriers to adoption is crucial for biochar's implementation success but can be challenging, often demanding a deep, location-specific understanding of people's needs, values and expectations.

Author Contributions

Dominika Janiszewska-Latterini: conceptualization, formal analysis, funding acquisition, investigation, methodology, writing – original draft, writing – review and editing. **Joana Ortigueira:** investigation, writing – review and editing. **Tiago F. Lopes:** funding acquisition, investigation, writing – review and editing. **Julia Gościańska-Łowińska:** conceptualization, investigation, writing – review and editing. **Dobrochna Augustyniak-Wysocka:** writing – review and editing. **Ewa Leszczyszyn:** writing – review and editing. **Catarina Nobre:** funding acquisition, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The authors have nothing to report.

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