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Perspectives and Opportunities for the Intensive Use of Biochar in Brazil

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Abstract

The use of biochar technology in Brazil holds significant promise for advancing the principles of a circular economy, addressing pressing environmental challenges, and fostering sustainable development. Despite its great potential, biochar production and scale use remain strikingly limited in Brazil. Here, we explored the multifaceted potential of biochar in Brazil, focusing on its capacity to promote circularity, create novel inputs for agricultural and environmental purposes, and optimize infrastructure for the production and cycling of organic residues from diverse agricultural and energy production chains. Semi-structured interviews were conducted with stakeholders, and a workshop was organized with participants representing universities, public research institutes, private companies, and non-governmental organizations. We analyzed the current Brazilian scenario, identifying the main barriers preventing the widespread use of biochar in the country, as well as possible solutions in the economic, political, technological, R&D, and innovation sectors. Based on this assessment, our results show that stakeholders view the Brazilian biochar sector as emerging but constrained by regulatory uncertainty, market fragmentation, and logistical bottlenecks. They identified five priority levers for change: the creation of clear and credible regulatory frameworks, region-specific strategies for biomass use and on-farm deployment, integration of biochar into robust carbon market mechanisms, strengthening of targeted research and demonstration projects, and development of business models that combine agricultural benefits, carbon removal, and co-products.

Keywords: biochar; biochar technology; desirable future scenarios for Brazil biochar; biochar business

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1. Introduction

Owing to the diversity of soil, climate, and vegetation across the Americas, a wide range of sustainable agricultural practices can be adopted to benefit from more sustainable agricultural and pasture management than in other areas of the world. This variety enhances the continent's ability to reduce emissions and increase carbon sequestration (Denny et al., 2024). Incorporating biochar technology into land management strategies offers a multifaceted solution to several pressing agricultural and environmental challenges (Pierson et al., 2024). The use of biochar in soil is a win-win strategy for simultaneously achieving greenhouse gas (GHG) mitigation and increasing carbon persistence in soil (Yin et al., 2022). Biochar production is one of the few established methods for scaling up carbon dioxide removal (CDR) on a sufficiently large scale to become an important climate change mitigation factor (Woolf et al., 2021). Lefebvre (2023) illustrated the significant role that biochar can play in global CDR strategies, especially in countries with greater agricultural production and larger populations, with Brazil ranking third worldwide, with a carbon sequestration potential of 303 Mt CO_2e per year.

Despite its great potential, biochar production and scale use remain strikingly limited in Brazil, representing missed opportunities for carbon sequestration, improved agricultural practices, recovery of degraded pastures, production of inputs, energy, nutrient cycling, and environmental benefits. Therefore, the main objective of this study was to clearly and concisely present the current scenario of biochar production and use in Brazil, providing reflections on how the country might overcome its main barriers in the future.

2. Methodology

This study was conducted in two phases. The first phase characterized the current situation of biochar production and use through semi-structured interviews with subject matter experts. The second phase explored desirable future trajectories for expanding and improving biochar production and applications across different regions and sectors. Because the Brazilian biochar sector is still at an early stage of development, this study adopted a qualitative approach. In such emerging contexts, expert knowledge and stakeholder perspectives are essential to identify key drivers, constraints, and opportunities. Scenario methods provide a structured way to translate these perspectives into internally consistent narratives that can support strategic planning and policy discussions for biochar in Brazil.

In the first phase of the study, the interviews delved into a broader context, exploring the policy, environmental, social, technological, and economic aspects. Participants were selected based on their expertise in biochar research and involvement in the private biochar sector. Snowball sampling was employed to expand the participant pool and invite additional experts, as recommended by the initial interviewees. Further details are provided in the Supplementary Material. A SWOT matrix was applied to synthesize the interview material and to support technological mapping and scenario analysis. This matrix integrates four dimensions that inform decision making: strengths (S), weaknesses (W), opportunities (O), and threats (T). For the SWOT classification, participants were asked to assign each topic to one of these four categories using a structured questionnaire.

In the second phase, key challenges and barriers to the expansion of biochar use in Brazil were identified through a multi stakeholder hybrid workshop entitled "The Future of Biochar in Brazil," held on 29 February 2024 at the International Institute for Sustainability in Rio de Janeiro, Brazil. Further details are provided in the Supplementary Material. Discussions focused on the technical, socioeconomic, political, and environmental dimensions of biochar deployment in Brazil and included collaborative exercises grounded in strategic design to develop actionable strategies for scaling biochar production and use in the country. The overall analytical process combined SWOT-based coding of interview data, a co-creative workshop to refine and re-prioritize drivers and constraints, and the construction and validation of desirable future scenarios for the Brazilian biochar sector (more details in the supplementary material).

3. Results and Discussion

3.1 Background on the Brazilian biochar sector

In Brazil, the discussion about biochar has intensified in recent years, driven by the need to manage large volumes of agricultural and agroindustrial residues, to improve soil quality and to expand negative emissions technologies. A national bibliometric analysis identified 261 peer-reviewed articles on the agricultural use of biochar in Brazil between 2003 and 2021, with publication numbers increasing over time and reaching their maximum in 2021(Arias et al., 2023). Most of this Brazilian research is concentrated in public universities and federal research institutions, especially the Brazilian Agricultural Research Corporation (EMBRAPA). Brazilian biochar studies have mainly focused on soil fertility, carbon sequestration, and environmental quality. Most studies use plant residues as feedstock, especially wood residues (50%) and materials from the sugar–energy industry (14%) (Arias et al., 2023). An earlier critical review highlighted that biochar has become a technology of particular interest in Brazilian agriculture because of the large amount of wasted biomass in Brazil. Biochar has emerged as an obvious option to rapidly, inexpensively, and opportunely store carbon and improve soil quality, and partners alongside other low-carbon practices such as no-tillage cropping systems, integrated crop-livestock-forestry systems, afforestation, and degraded land restoration (Novotny et al., 2015).

In terms of production capacity, the scientific literature indicates that biochar generation in Brazil is currently dominated by experimental and pilot-scale units, complemented by industrial facilities. A recent global review of biochar from laboratory to industry scale identified Brazil as having substantial potential to expand biochar production because of the large volumes of waste biomass. For example, this assessment reported approximately 8.2 million tons per year of wood processing residues, approximately 2.5 million tons per year of sewage sludge, and approximately 81.8 million tons per year of municipal solid waste, all of which are suitable feedstocks for thermochemical conversion into biochar (Prochnow et al., 2024). In Brazil, NetZero currently operates two industrial biochar plants, located in Lajinha (Minas Gerais) and Brejetuba (Espírito Santo). Each unit has an annual production capacity of approximately 4,000 t of biochar derived from agricultural residues (NetZero 2025).

The field application of biochar in Brazil has so far taken place mainly occurred in experimental settings rather than as a widespread commercial practice. The bibliometric survey shows that most Brazilian agricultural biochar studies are still conducted at the laboratory or greenhouse scale, with a smaller but growing set of field experiments (Arias et al., 2023). Pasture systems have received particular attention because degraded pasturelands cover a large proportion of Brazilian agricultural land. A landmark field study in the Atlantic Forest biome applied 15 Mg ha^{-1} of biochar produced from Gliricidia residues to small pasture plots (2x2 m) and reported average increases of roughly 27% in Brachiaria production over two years, along with higher soil pH, cation exchange capacity, and macronutrient content (Latawiec et al., 2019).

3.2. Current situation of biochar in Brazil

Drawing on insights from leading experts, a comprehensive overview of the current biochar landscape in Brazil was compiled. This section delved into the key themes gleaned from the expert interviews, providing a structured exploration of the status of this promising technology in the country. Figure 1 shows the results of the SWOT analysis of the Brazilian scenario for large-scale biochar production based on the expert interviews.

Figure 1. SWOT analysis (strengths, weaknesses, opportunities, threats).

One of the main strengths identified by interviewees was the potential of biochar to combat climate change. Brazil is one of three global regions notable for their concentration of countries with a high biochar carbon impact (Lefebvre et al., 2023).

High biomass availability was identified as both a strength and an opportunity. Brazilian agricultural production of grains and sugar cane is dominated by three major crops: sugar cane (71%), soybeans (15%), and corn (11%); other crop grains represent approximately 3% of the country's agricultural production according to the National Supply Company (CONAB, 2024). Figure 2 illustrates the distribution of agricultural production in Brazil by macro-region, using CONAB reference data from the eighth survey of the 2023–2024 grain and sugarcane harvest, which are included here as contextual baseline information for the national production geography (CONAB, 2024).The Central-West and Southeast regions collectively account for up to 77.1% of Brazil's agricultural grain and sugar cane production, highlighting their strategic importance in national production.

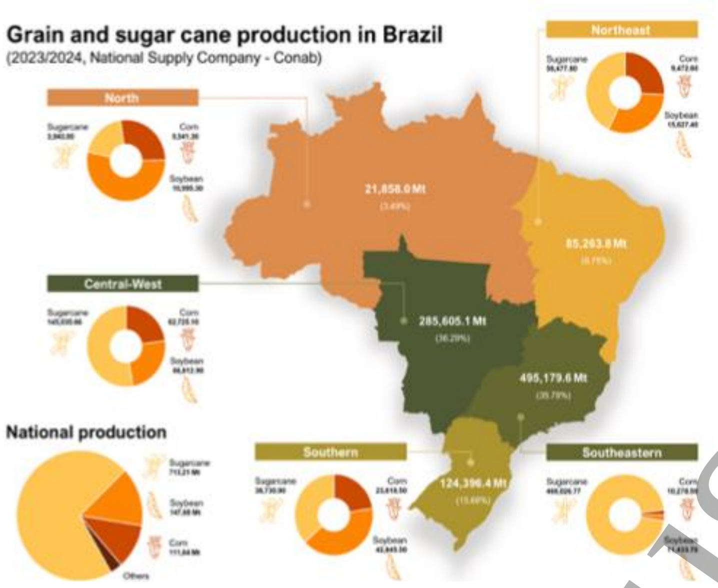

Figure 2. Distribution of grain and sugar cane production in Brazil.

Although much of the biomass generated by Brazilian agriculture is already allocated to established uses such as energy generation, this competition may limit its availability for biochar production. For instance, in sugarcane systems, bagasse and filter cake are widely utilized as boiler fuels, compost, and direct organic fertilizers. Similarly, in soybean and maize production, crop residues are essential for maintaining soil cover and sustaining no-tillage systems. These consolidated uses underscore the potential barriers in redirecting agricultural residues for new purposes. Despite this, Brazil's overall biomass production remains exceptionally high, offering substantial opportunities to develop biochar value chains without compromising existing agricultural and environmental functions.

Most interviewees identified the potential to generate and sell biochar credit (BCR) as a main opportunity. The BCR market holds a particular appeal for producers in South America and Africa, even though globally only 42% of producers earn revenue from selling carbon credit. In these regions, over half of all biochar production comes from companies that generate 90% or more of their income from BCR sales (Global Biochar Market Report, 2024). The dominance of the BCR market among South American and African producers appears to be driven by two key factors. First, the lower labor costs in these regions allow the production of biochar at a more competitive price. Second, the value of BCRs seems to be independent of the production location, creating a level-playing field for global producers.

This unique combination of advantages empowers biochar producers in South America and Africa to develop successful business models that depend heavily, if not entirely, on revenue generated from the BCR market (Global Biochar Market Report, 2024). At the global level, the Biochar Carbon Removal Market Snapshot 2025 reports that 3.04 million tonnes of biochar carbon removal credits were contracted between 2022 and the first half of 2025, with 683,000 tonnes delivered and market value increasing from 14.6 million to 181.5 million US dollars between 2022 and 2024, while biochar represented around 94% of long-term carbon removal credits delivered on the voluntary market in 2023 (CDR.fyi, 2024; CDR.fyi, 2025; Biochar Carbon Removal Manual, 2025).

Involvement of the local community was mostly categorized as an opportunity in Brazil. Strengthening community participation could play a critical role in scaling-up sustainable biochar adoption, particularly in smallholder and family farming systems. The Gaian Project offers a compelling example of how community-based approaches can be effectively mobilized to promote sustainable land management practices. By fostering a cooperative network among universities, public institutions, and agricultural cooperatives, the project successfully implemented Agroecological Agroforestry Systems (SAFs) while prioritizing local empowerment (Felipe et al., 2023). The inclusion of biochar as a soil amendment is instrumental in enhancing soil health and improving land productivity. This case reinforces the importance of coupling technological innovation with participatory frameworks to ensure long-term impacts and equitable benefits.

3.3 Current barriers

Sales to the end consumer represents a gap in the national market, categorized by most participants as a business opportunity. Threats were practically nonexistent, mainly because the Brazilian market is incipient, waste is plentiful, and waste is not adequately disposed of in the environment. Almost all participants classified the lack of public policies as a national weakness; the lack of technologies, specialized labor, and low availability of investments were also cited. We categorized these prospects into three main categories, as described in the following section and summarized in Figure 3.

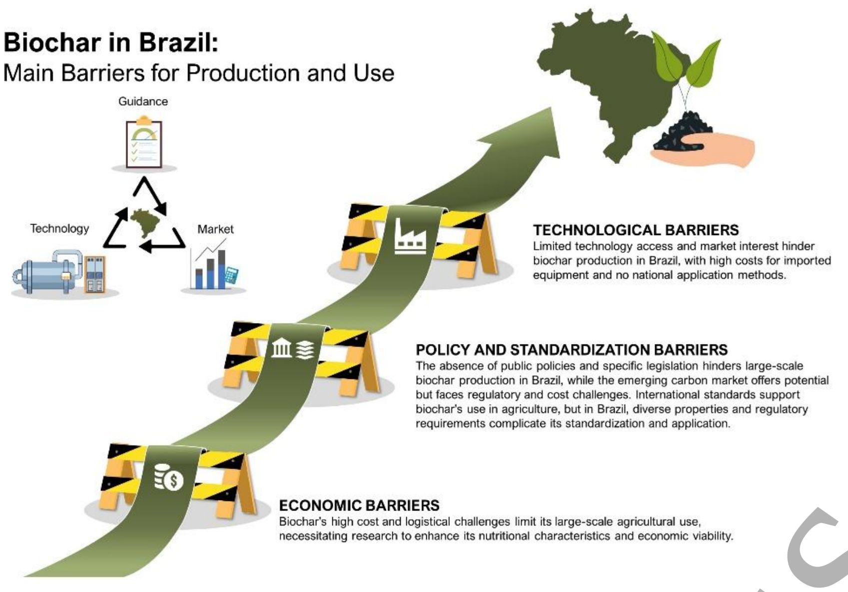

Figure 3. Main barriers to production and use biochar in Brazil.

3.3.1 Economic

Biochar itself, depending on the pyrolysis conditions and feedstock, is considered a low-reactive matrix, requiring high rates of modification of soil properties. This makes operational logistics difficult and often renders its use in the field unfeasible. Therefore, research efforts are crucial for enhancing the nutritional characteristics of biochar, enabling the effective utilisation of lower and more cost-effective application rates in agricultural settings. Regarding economic aspects, interviewees reported that the current costs of biochar for agricultural use are still relatively high, largely because production is small-scale and logistics are not yet optimised. Estimates of farm gate costs varied widely, reflecting differences in feedstock, technology, and distance to fields. Most participants agreed that larger and more integrated supply chains could significantly reduce the unit costs. However, they also highlighted the need to secure sustainable biomass supplies without competing with existing uses such as energy generation, animal bedding, and industrial processes. Recent techno-economic assessments have shown that there is no single "average cost" of biochar for agricultural use because production costs are highly sensitive to feedstock price, plant configuration, and the spatial scale of the biomass supply chain. For example, a detailed case study in Michigan estimated the minimum selling price of biochar under both stationary and portable production systems and found values on the order of US$ 1,340 to 1,606 per ton for stationary facilities (depending on region) and around US$ 2,350 per ton for portable units, with higher costs associated with more dispersed feedstock supply and longer transport distances (Ahmed et al., 2025). This analysis also demonstrated that expanding the geographic radius for biomass collection substantially increases the final cost of biochar, largely because of higher transportation and handling costs (Ahmed et al., 2025).

3.3.2 Politics and Legislations

In Brazil, there is no specific legislation on the agricultural or environmental use of biochar. The Ministry of Agriculture, Livestock, and Supply (MAPA) must include biochar in the category of products already foreseen as soil conditioners, organic fertilisers, or organomineral fertilisers (in the case of its combined use with mineral nutrient sources). It may also be considered a new product, in which case, a set of parameters for quality inspection covering efficiency, safety, and other criteria must be specified (Alberto et al., n.d.).

The lack of specific legislation for biochar creates difficulties in defining its classification and determining registration requirements. A key factor that contributes to the international acceptance of biochar for agricultural use is the existence of specific protocols. The International Biochar Initiative (IBI) has been working with researchers and industry professionals to guide and create standards and support good industrial practices, including a certification system designed to delineate a transparent and sustainable future for biochar (Thengane et al., 2021). In Brazil, for direct use in agriculture or commercialisation, biochar must satisfy the directives proposed within the series of normative instructions (NIs) issued by the MAPA. These normatives include soil conditioners, plant substrates, and organic fertilisers. Despite the great agricultural and economic potential of biochar, its unique physicochemical characteristics could preclude its adequacy in current legislation and, consequently, its commercialisation and safe use in various sectors of Brazilian agriculture (Carnier et al., 2021).

The wide variety of materials that can be obtained from the carbonisation of biomass, and hence the different responses resulting from its application in different crops, makes it difficult to obtain biochar standards. Therefore, further research and practical applications still should be conducted before a well-established legal protocol can be issued.

3.3.3 Technology

Limited access to technology is one of the difficulties associated with scaling up biochar production in Brazil. Currently, we are not aware of any Brazilian manufacturer that produces pyrolyzers specifically for biochar production. Low temperature (350–400 ºC) masonry reactors are used in batch processes in the steel industry to produce charcoal, but their permeability to oxygen during the reaction results in a material that cannot be considered biochar under the WBC or IBI standards. Although there is abundant academic research on continuous industrial reactors, only small machines have been implemented and tested, and none have achieved industrial-scale manufacturing or productivity. Currently, pyrolyzers are imported, which leads to high plant implementation and maintenance costs. Stakeholders have also reported low efficiency in the production process.

Machinery and equipment for applying biochar in the field remain a technological challenge, as there are still no national methodologies for its application to soil using machines and implements. Furthermore, there is a lack of studies evaluating the use, adaptation, and industrial production of other machines already consolidated in the agricultural and forestry sectors for the application of biochar (Cardoso Júnior et al., 2022). Technologies to stabilise and granulate biochar should also be developed.

3.4 Strategies to Scale Biochar in Brazil

Once the main barriers to biochar development in Brazil were identified, five key strategies were outlined for scaling production and use across Brazil (Figure 4). These strategies are defined based on expert consensus and are oriented toward overcoming technical, economic, regulatory, and social constraints. They provide a foundation for guiding coordinated actions among stakeholders and fostering an enabling environment for the sustainable expansion of biochar applications.

According to specialists, the implementation of effective public policies is essential for biochar to realize its full potential in Brazil. The establishment of a regulatory technical standard that defines production parameters and minimum physicochemical characteristics is critical not only to stimulate market development, but also to ensure product reliability for end-users. Within the scope of public policy, a desirable scenario for expanding the biochar industry involves the introduction of fiscal incentives that target both producers and users. The proposed measures include tax reductions or exemptions on biochar production and commercialisation, income tax credits for producers who apply for biochar, fees, and tax discounts for companies incorporating biochar into their operations, deduction of R&D expenditures from taxable income, and access to subsidised credit lines for producers. These initiatives can foster large-scale biochar production, increase biochar supply, and accelerate sectoral growth. As production costs decline, public support mechanisms can gradually be phased out (Pourhashem et al., 2019). The lack of coordination among civil society, the government, academia, and sector stakeholders limits the development and adoption of biochar. Therefore, promoting dialogue and collaboration between these sectors is the first step towards the promotion and inclusion of biochar in the national market.

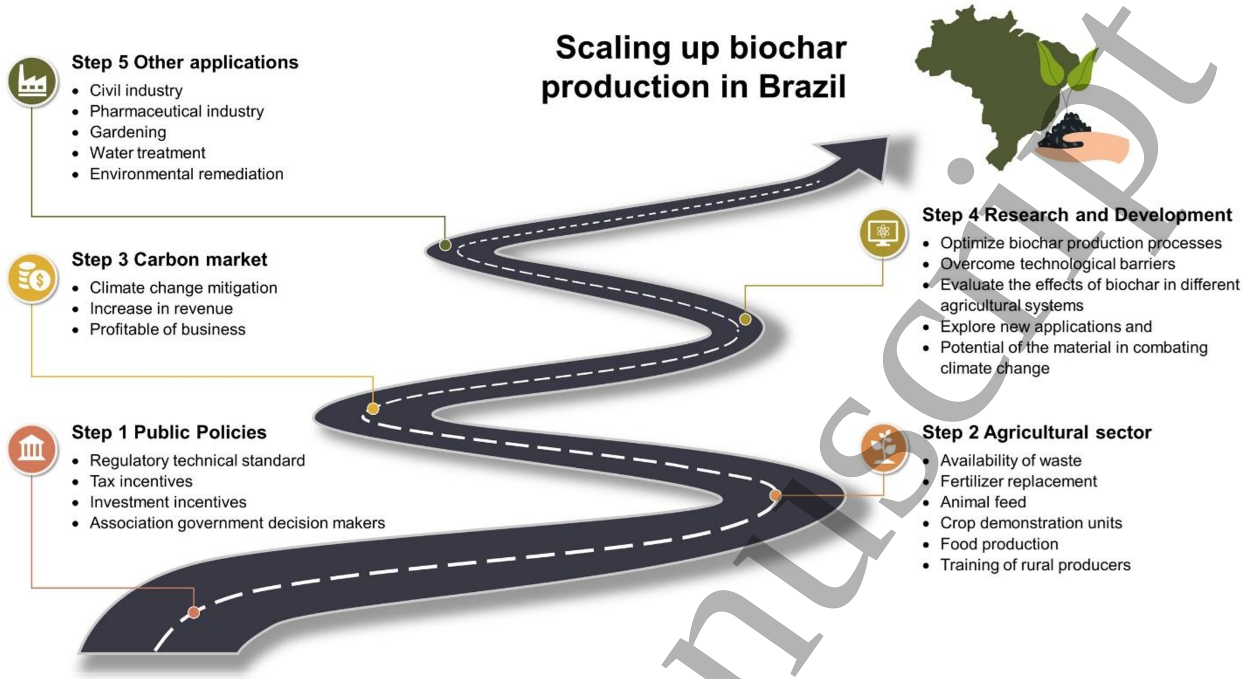

Figure 4. Strategies to overcome biochar barriers in Brazil.

The enormous agricultural potential of Brazil is the second step towards consolidating the national biochar industry. Brazil has an extensive agricultural production and is a prolific exporter of agricultural commodities. The country's extensive agricultural activities, characterised by high productivity and product diversity, play an important role in global food security and national socioeconomic development (Costa, et. al, 2022). Engaging agribusiness stakeholders through open and constructive dialogue requires a coordinated, multilevel approach, ranging from large agribusiness corporations to smallholder family farmers. A key component of this process is active listening, which aims to identify specific needs, knowledge gaps, and operational challenges faced by different groups. Evidence suggests that farmers are more likely to adopt innovations when they offer clear environmental benefits or direct improvements in agricultural productivity (Dumbrell, Kragt, & Gibson, 2016; Pourhashem et al., 2019). In this sense, demonstration units should be considered valuable tools for learning and disseminating knowledge regarding the use of biochar in different agricultural crops. Demonstration units are a complex method of rural extension carried out so that the researcher, extensionist, and rural producer, working in cooperation, can observe what happens and evaluate the results achieved in terms of production, productivity, and economy (Planejamento_UTD, n.d.).

Another alternative is the commercialisation of avoided emissions to replace chemical fertilisers. In addition to reducing negative emissions through carbon sequestration, biochar application has a greater impact on reducing total emissions. It avoids emissions roughly 1.5 times more than the amount removed through sequestration, suggesting that biochar could play a more significant role in climate change (Deng et al., 2024). Novais et al. (2017) measured CO_2, CH_4, and N_2O emissions from a tropical sandy soil in São Paulo state, Brazil, under laboratory-controlled conditions, that received poultry manure and sugarcane straw biochars. The addition of the two biochars significantly reduced the GHG emissions compared to the respective non-pyrolyzed materials. The highest GHG emissions were found for the application of 25 Mg ha^{-1} to the soil, compared to the doses of 12.5 and 50 Mg ha^{-1}.

The third step is to explore the carbon market for biochar. The adoption of biochar for carbon credits will provide a tangible means for companies and individuals to actively participate in climate change mitigation efforts, promote economic viability, and accelerate production scaling(Salma et al., 2024). Another way to encourage this market would be to generate carbon credits for farmers who adopt sustainable agricultural practices, such as reducing tillage or optimizing the use of fertilizers in combination with biochar. This approach addresses the critical concern of sustainably transforming agricultural systems while ensuring farmers' economic viability (Cariappa et al., 2024). Owing to the Brazilian carbon credit market's nascent stage, there is a significant gap in the availability of professionals who comprehend the topic and can guide biochar producers and users on its potential within the biochar carbon market.

In parallel with the actions mentioned above, there must be continuous investment in research and development (R&D). Only through research will it be possible to optimize biochar production processes, overcome technological barriers, evaluate the effects of biochar in different agricultural systems, and explore new applications and its potential in combating climate change. Based on robust data, R&D is crucial in supporting public policy and investment decisions. In addition, it allows for the training of agents who disseminate knowledge. Wu et al. (2023) conducted a bibliometric analysis to visualize the current research status and trends in biochar research. A total of 5,535 documents were collected from the Web of Science Core Collection and subjected to visualisation analysis for the development of the biochar field in 2021. According to the results, China contributed the most, accounting for 43.99% of the total publications, followed by the USA with 504 publications (9.11 %). Brazil occupied the 8th position with

159 publications in 2021 (2.87 %). These data reinforce the imminent need for growth in R&D on biochar in Brazil, so that we can consolidate our position as a global exponent on this topic.

Finally, the exploitation of co-products, such as bio-oil and syngas, can be considered a strategy for income generation, making biochar production economically viable. Furthermore, recent advancements in biochar functionalization have led to new applications in various fields, including energy conversion and storage, wastewater treatment, and environmental remediation (Yameen et al., 2024).

5. Conclusion

The results of this study help to clarify how policy design, investment decisions and technology development pathways for biochar can be oriented in the Brazilian context. Stakeholders consistently described a sector that is still emerging, with promising potential but constrained by regulatory uncertainty, fragmented markets, and logistical challenges. Building on these empirical insights and the existing literature, the elements that address the main barriers identified and organizes potential avenues for action. Priority directions include establishing a coherent regulatory framework for biochar, integrating biochar into climate and agricultural policy instruments, and supporting standards and certification schemes that provide credibility to biochar-based carbon removal. These insights offer concrete entry points for federal and state authorities when revising low-carbon agriculture programs, designing fiscal and credit incentives, and aligning biochar deployment with broader decarbonisation and soil restoration strategies. From an investment perspective, these same conditions also indicate that business models are more likely to be attractive when they combine agricultural benefits with carbon removal, co-products and long-term offtake contracts supported by credible certification, which can make biochar projects more bankable for domestic and international investors. Together, these elements synthesize stakeholder perceptions into a coherent pathway for future development of the Brazilian biochar sector.

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Ethical statement

Part of this study was based on voluntary interviews. Professionals specialised in social science surveying methods carried out this part of research which was conducted following the guidelines of the Research Ethics Committee of the Pontifical Catholic University of Rio de Janeiro (PUC-Rio) and the ethical principles of the Declaration of Helsinki. All participants were informed about the aims of the study and gave informed consent to take part in the interviews. No personal identifiers were collected or reported, and all data are presented in aggregated and anonymised form.

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