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Biochar: A Key Player in Carbon Credits and Climate Mitigation

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Abstract: The creation of the carbon market came forth as a tool for managing, controlling, and reducing greenhouse gas emissions, combining environmental responsibility with financial incentives. Biochar has gained recognition as one of potential carbon offset solution. The practical and cost-effective establishment of biochar carbon credit standards is crucial for the integration of biochar into carbon trading systems, thus encouraging investments in the biochar industry while promoting sustainable carbon dioxide sequestration practices on a global scale. This communication focuses on the potential of biochar in carbon sequestration. Additionally, it spotlights case studies that highlight how biochar effectively generates carbon credits, as well as discussing the evolving carbon removal marketplace. Furthermore, we address knowledge gaps, areas of concern, and research priorities regarding biochar implementation in carbon credits, with the aim of enhancing our understanding of its role in climate change mitigation. This review positions biochar as a versatile and scalable technology with the potential to contribute significantly to carbon credits, aligning with sustainable development goals. It calls for continued research, transparency, and international cooperation to explore the full potential of biochar in climate change mitigation efforts.

Keywords: carbon credit; biochar; GHGs; sequestration; carbon removal marketplace; climate mitigation



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1. Introduction

Today, the global community faces an unprecedented challenge in the form of climate change, a phenomenon driven by the accumulation of greenhouse gases (GHGs) in the Earth's atmosphere [1]. Extreme weather events, rising sea levels, and ecosystem disruption underscore the urgent need for comprehensive strategies to reduce emissions and mitigate their impact [2]. Alongside carbon capture and storage (CCS) technologies, the carbon market has emerged as a pivotal tool in incentivizing and facilitating emissions reductions across various sectors [3]. The principle of the carbon market (Emission Trading System) is to assign price to each ton of CO₂ equivalent (CO₂e) emission, thus turning it into a trading commodity. This enables the exchange of both carbon emissions and carbon removals, commonly referred to as offsets [4]. This exchange is facilitated by an intermediate party, a platform called the marketplace. Carbon credit is a permission to generate and emit one ton of dioxide carbon (CO₂), and it can be bought through this marketplace. On the other hand, when a ton of CO₂ is removed from the atmosphere by applying any of the CCS technologies, it generates a carbon offset. The marketplace links the credits and the offsets to create the carbon market [5,6]. The revenues flow through this exchange to finance CCS projects and to sustain the management of the marketplace. Carbon credits have garnered significant attention as a practical mechanism to address this crisis [7]. These credits offer a unique economic approach to tackling climate change, aligning environmental responsibility with financial incentives [8]. By assigning a quantifiable value to each ton of CO₂e emissions, carbon credits motivate individuals, businesses, and governments to take measurable steps toward emission reduction [9]. This mitigates the environmental crisis, while also creating new market opportunities.

Within this landscape, a promising concept that has gained increasing recognition is the role of biochar in the carbon market. It offers a unique and sustainable approach to the carbon offset mechanism with the potential to revolutionize carbon sequestration and agriculture [10]. The Intergovernmental Panel on Climate Change (IPCC) (AR 6, WGIII, SPM, section D1.6) identified biochar as one of the carbon dioxide removal (CDR) methods to be applied in agriculture for storing carbon in the soil [11].

Biochar holds the promise of being a game-changer in the field of carbon credits and climate change mitigation [12]. Biochar, a form of charcoal, is the product of the conversion of organic materials, such as agricultural waste and forestry by-products, into a stable form of carbon that can be stored in soils for centuries [13]. By doing so, biochar not only removes CO₂ from the atmosphere, but also enhances soil quality and agricultural productivity [14].

While the carbon market, in its traditional forms, represents an exchange-based approach that assigns a monetary value to each ton of CO₂e emissions, biochar takes this concept a step further by addressing emissions reduction and sustainable land use in a single stroke [15]. By engaging in the creation of biochar, individuals, businesses, and governments have an opportunity to not only reduce their carbon footprint but also to foster healthier soils, promote sustainable agriculture, and mitigate the environmental challenges associated with land degradation [16].

The global conversation on climate change mitigation recognizes that a multifaceted approach is essential [17]. Transitioning to renewable energy sources, improving energy efficiency, and adopting sustainable practices are undeniably crucial elements in the battle against climate change [18]. On top of that, biochar represents an innovative and holistic approach that enhances the effectiveness of carbon exchange programs. Its significance extends beyond traditional carbon offset markets, resonating with agricultural and ecological goals [19].

The aim of this communication is to articulate the significance and potential of the carbon credit mechanism, particularly focusing on the role of biochar in carbon sequestration. The communication highlights the broader context of biochar carbon credits as an incentivized strategy to combat climate change through reducing emissions and engaging in carbon sequestration activities. It addresses the opportunities as well as the risks associated with the application of biochar in the carbon market. In doing so, it aspires to provide a comprehensive understanding of its strengths and limitations, thus informing the continued evolution of climate action strategies in an ever-changing global landscape.

2. Carbon Market Mechanism

The creation of carbon credits and carbon offsets represents a market-driven approach to combating climate change by providing financial incentives for the reduction in GHG emissions and the enhancement of carbon sequestration [20]. Participants, including businesses, governments, and individuals, engage in emissions reduction activities such as energy efficiency improvements, renewable energy projects, reforestation, and afforestation [21]. These initiatives result in a reduction in emissions, and their accuracy is ensured through third-party verification [22]. Upon successful verification, carbon credits are issued, each typically representing the reduction of one metric ton of CO₂ or its equivalent in other GHGs [23]. These credits are tradable commodities, and they can be purchased by entities seeking to offset their emissions [24]. The revenue generated from the sale of carbon credits provides a financial incentive for organizations to invest in carbon sequestration efforts, such as reforestation and conservation [25].

The combination of emission reduction activities and carbon offsetting through the issue of credits (Figure 1) allows the entity to claim carbon neutrality [26]. Achieving carbon neutrality is a crucial goal in the global effort to combat climate change [27]. The net effect is that the entity's overall impact on the climate is neutral, or in other words, it is not contributing to the increase in atmospheric GHG concentrations [28]. Carbon credits, therefore, serve as a tool to support carbon neutrality by providing a mechanism for financing emission reduction projects and activities [29].

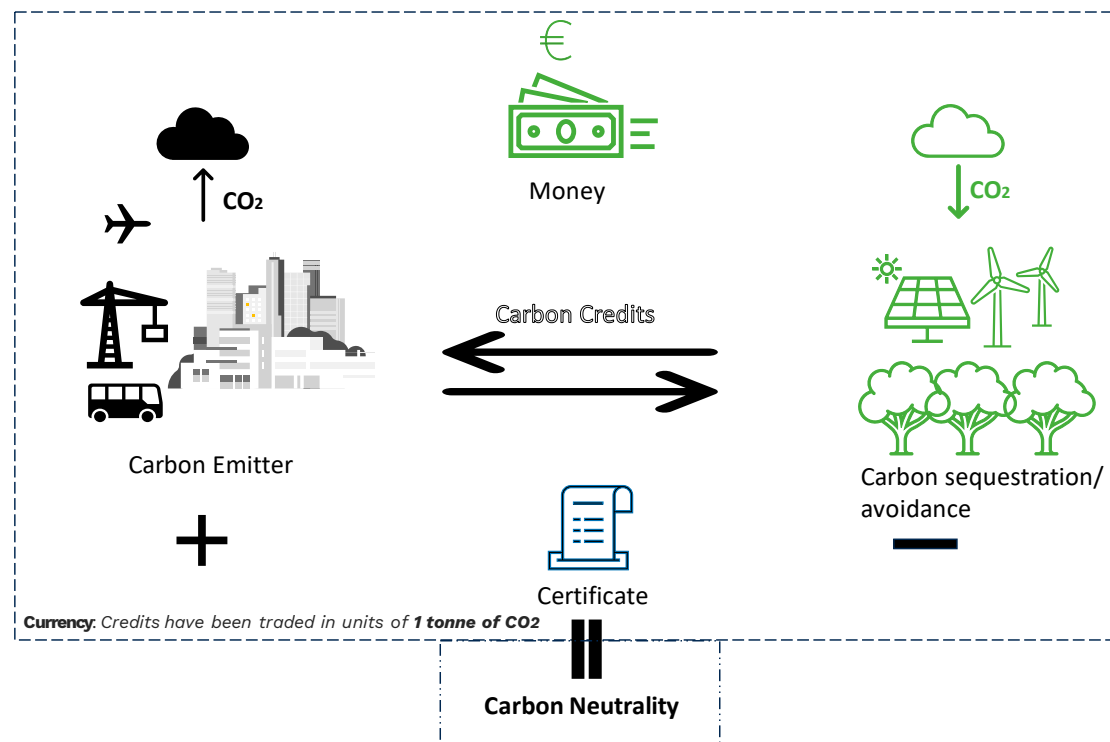


Figure 1. Simplified mechanism of carbon credit system.

According to the United Nations Environment Programme (UNEP): “there are two types of carbon markets: Compliance and voluntary. In compliance markets such as national or regional emissions trading schemes participants act in response to an obligation established by a regulatory body. In voluntary carbon markets, participants are under no formal obligation to achieve a specific target. Instead, non-state actors such as companies, cities or regions seek to voluntarily offset their emissions, for example, to achieve mitigation targets such as climate neutral, net zero emissions” [30].

The regulatory and market frameworks for carbon credits exhibit significant variation across regions, reflecting diverse approaches to addressing climate change and capitalizing on the potential environmental and economic benefits of carbon trading. The European Union stands out with the EU Emissions Trading System (EU ETS), a well-established and regulated carbon market. In contrast, the United States adopts a mixed approach with a combination of state-level initiatives and voluntary markets, showcasing a decentralized strategy [31]. China, a major global player in emissions, has initiated emissions trading schemes as part of its commitment to environmental sustainability [32].

International mechanisms such as the Clean Development Mechanism (CDM) and the Paris Agreement’s Article 6 play crucial roles in fostering global cooperation in emissions reduction and carbon trading [22,33]. These mechanisms provide a structured framework for countries to collaborate and contribute to the broader goal of mitigating climate change on a global scale.

Moreover, voluntary carbon markets have emerged worldwide, offering individuals and organizations the opportunity to voluntarily offset their emissions and support sustainability initiatives [34]. This voluntary participation underscores a growing awareness and commitment to environmental responsibility beyond regulatory requirements.

The existence of such diverse regulatory and market frameworks highlights the complexity of addressing climate change on a global scale. Each region tailors its approach based on its unique economic, political, and environmental context [35]. However, this diversity also poses challenges in terms of standardization and harmonization. Efforts are underway to standardize and globalize carbon markets, aiming to enhance their trans-

parency and accountability [36]. This standardization is essential for creating a more unified and effective global response to climate change [37].

The push for standardization is driven by the recognition that a coordinated and harmonized approach will maximize the efficiency and impact of carbon credit initiatives [38]. Through establishing common protocols and guidelines, the international community can ensure the credibility and integrity of carbon markets, fostering trust among participants [39]. This, in turn, can attract more players to the market, increasing its overall effectiveness in driving emissions reductions and promoting sustainable practices [6].

3. Biochar: A Negative Emissions Technology

3.1. Carbon Sequestration

The production of biochar follows nature's organic carbon pathways by removing CO₂ and permanently storing it in the soil. Through the application of controlled pyrolysis, wherein biomass undergoes carbonization to yield inert carbon, the production of biochar is a carbon dioxide removal (CDR) method, provided the biochar's permanence is ensured [40]. Carbon negative emissions refer to activities or technologies that remove more CO₂ from the atmosphere than they release [41].

Within the scope of pioneering negative emissions technologies, biochar serves as a focal point, directing the process of carbon sequestration and securely encapsulating it in a stable form, shielded from the transient nature of time [14]. This compelling product, examined within the context of emissions mitigation, emerges as a complex entity, elucidating remarkable potential in various dimensions. These facets include technical feasibility, scalability potential, cost-effectiveness, carbon stability, permanence, and rigorous verification and monitoring mechanisms [42]. Beyond these technical considerations, the appeal of biochar extends to encompass diverse application benefits, as demonstrated in various carbon reservoirs [43]. The achievement of carbon sequestration through biochar production emerges not only as a technological advancement but also as an economically feasible venture, especially in the context of the evolving carbon sink economy [16].

During the process of photosynthesis, plants capture atmospheric carbon and incorporate it into their structural components [44]. However, the natural decay process releases stored carbon back into the atmosphere in the form of CO₂ and CH₄, thereby concluding the carbon cycle at the end of the plant's life [19]. This phenomenon poses a challenge to the overarching goal of carbon sequestration. The introduction of biochar production disrupts this cycle by transforming part of the plant's carbon into a stable form of carbon resistant to decay, thereby preventing the return of part of the carbon back into the atmosphere [45]. The combination of the photosynthetic pathway with the pyrolytic conversion process creates an efficient system for carbon removal—a notable achievement in maintaining the balance of atmospheric carbon [46]. On a grand scale, biochar production emerges as a silent influencer, potentially impacting the carbon concentrations in our atmosphere [15]. To produce biochar resilient enough to withstand the temporal vicissitudes, a complex process unfolds—this process is characterized by the precise selection of feedstocks and the optimization of processing conditions, adhering to a protocol tailored to the specific requisites of carbon reservoirs [47]. This process demands execution with optimal sustainability, entailing a synergetic balance between technological expertise and ecological stewardship.

Kong et al. [48] reported that the conversion of biomass into biochar results in a stable form that resists decomposition. This finding holds significant promise for the development of an efficient carbon sequestration technology. Biochar is widely acknowledged for its exceptional chemical and microbial stability, attributed to the tightly structured aromatic rings and alkyl groups present in its composition [49]. This structural integrity gives biochar greater resistance to biological and chemical degradation compared to other forms of organic carbon.

Moreover, the organic components on the surface of biochar exhibit a propensity to form new agglomerate structures when interacting with the minerals and organic matter in carbonaceous materials. This interaction reduces the risk of microbial degradation through

providing a physical protective barrier [50]. Guo et al. [51] have emphasized that the stability of biochar relies not only on the degree of aromatic carbon aggregation but also on the integrity of the aggregated aromatic carbon and the silica–carbon complex, serving as a crucial protective mechanism.

In a comprehensive study, it was extrapolated through experimental evidence and modeling that the annual carbon loss from biochar due to mineralization and degradation, including dissolved organic matter (DOM), falls within the range of 3% to 26%. Further extrapolation suggested a substantial half-life of biochar, estimated to be between 10^2 and 10^7 years, affirming its remarkable stability [52].

Agricultural waste at the global scale, which has the capacity to produce 373 million tons of biochar annually, has the potential to sequester 0.55 petagrams of CO_2 [53]. The magnitude of carbon sequestration achievable with biochar surpasses that of biomass entering the soil directly, which undergoes complete degradation to CO_2 and returns to the atmosphere [54]. The stabilization of carbon in the form of biochar is thus considered a “carbon-negative” pathway, offering an effective strategy for reducing GHG emissions and sequestering biomass carbon [55].

While biomass rightfully claims attention for its potential in emission reduction and the promotion of circular economies, the significance of rapidly growing dedicated crops should not be understated, provided their cultivation adheres to the virtuous principles of sustainability [56]. In the cultivation of dedicated feedstocks, a conscientious coordination is implemented to ensure that valuable resources, such as land, water, and nutrients avoid direct competition with our essential food production systems [57]. The thermochemical conversion process must be executed with energy efficiency at its core [49]. The resulting pyrolytic gases and heat become integral players, contributing to the reduction in emissions within the process [58,59]. Fossil-based fuels, the outdated players, are systematically phased out from the production process; their minimal presence in cultivation and transportation is regarded as a positive contribution to sustainability [60]. The technical requirements governing biochar application demand meticulous attention. The impending application of biochar involves multifaceted considerations rooted in scientific methodology. The integration of biochar into this final phase requires a systematic evaluation of its carbon sequestration efficacy, acknowledging parameters such as surface area, porosity, and chemical composition. Through the synthesis of these elements, we can unlock the full potential of biochar as a tool in addressing carbon emissions and fostering sustainable environmental practices [61].

3.2. The Cascaded Use of Biochar Prior to Its Permanent Storage in the Soil's Carbon Reservoir

The impact of biochar application on agricultural and forest soils becomes a subject of extensive research [62]. Soil, as the largest terrestrial carbon reservoir, has attracted significant academic and commercial interest over the last few decades concerning the implications of introducing biochar. Researchers have concluded that under appropriate conditions that guarantee carbon stability during production, biochar can be securely retained in soils for an extended timeframe [63].

Various surveys have delved into the stability of biochar in soil, a noteworthy investigation was undertaken by Wang et al. [64], who conducted a meta-analysis of 24 studies to assess biochar stability. Their findings, based on 128 observations, revealed that biochar decomposition rates varied significantly depending on factors such as raw material variety, operational parameters, temporal aspects of experimentation, and clay content in the soil. The results demonstrated a mean residence time of 108 days for the labile carbon pool and an impressive 556 years for the stable carbon pool, representing 3% and 97% of the carbon, respectively. This indicates that only a small fraction of biochar is readily available, with a substantial portion contributing to long-term carbon sequestration [42]. This implies the potential of biochar to serve as a viable strategy for enhancing carbon storage in soil over extended periods.

Biochar, when applied to soils, undergoes exposure to biotic, abiotic, and indirect stresses, influencing the rate of mineralization [65]. The stability of carbon becomes crucial in withstanding such stresses, emphasizing the importance of feedstock type and processing conditions [49]. Besides its carbon sequestration potential, biochar has been recognized for providing numerous agronomic benefits. Biochar application significantly influences soil quality and fertility, yielding enhancements in nutrient cycling, increased water and nutrient retention, enhanced crop productivity, and efficiency in water and nutrient use [66]. Moreover, biochar has been reported to play a vital role in reducing GHG emissions such as CO₂, CH₄, and N₂O from soils, although mixed results have been reported [67].

The sorption capabilities of biochar present opportunities for soil remediation, with potential applications in mitigating pollutants [68]. The positive effects observed in soil properties, such as porosity, bulk density, water dynamics, acidification, interplay with soil organic matter, attenuation of priming effects, and induction of soil microbial activity, contribute to its overall positive impact [66]. However, it is essential to acknowledge that the outcomes reported in the literature are contingent on various factors, including biochar type, feedstock, production conditions, amount applied, soil type, specific cropping systems, and cultivation management practices [69]. Despite predominantly positive effects, some cases report negative outcomes [70]. Biochar can also be integrated into various applications before its final storage in soils, maximizing its value [71]. Additionally, biochar finds applications in water remediation [72], anaerobic digestion [73], silage production, litter additives, waste sludge processing, manure composting, and fish farm effluent treatment [74].

Despite the numerous advantages, the deployment of biochar on a large scale requires the consideration of potential risks. The reported albedo effect, stemming from a reduced surface reflectivity due to high biochar application rates, has the potential to increase soil temperature, consequently diminishing the benefits achieved through carbon sequestration [75]. Addressing this concern requires further investigation, with a focus on establishing application rate thresholds for optimal outcomes. The scientific community should continue exploring these nuances to ensure the responsible and effective utilization of biochar in agricultural and forest soil management.

4. Carbon Removal Marketplace

Voluntary carbon markets provide participants with the opportunity to address their emissions voluntarily [76]. This enables them to support carbon neutrality assertions, achieve reductions in net emissions, or contribute towards national climate targets. Voluntary carbon markets accommodate both emission reductions, where emissions are prevented elsewhere; and removals, involving the extraction of CO₂ from the atmosphere through direct capture or biomass growth, followed by permanent storage in a carbon pool [77]. Additionally, these initiatives must demonstrate measurable and additional impacts while aligning with the principles of sustainability.

Traditionally, the focus in voluntary markets has been on the avoidance of or reduction in emissions [34]. However, there is a growing emphasis on markets specifically dedicated to carbon removals, which have gained prominence over the last years. In existing carbon removal markets, there has been a notable emphasis on natural solutions.

The emerging landscape of voluntary carbon removal markets includes platforms and service providers with a specific focus on carbon dioxide removal (CDR) units. Noteworthy examples include *Puro Earth* (Finland), *Nori* (US), *MoorFutures* (Germany), and *max.moor* (Switzerland) [78]. *Puro Earth* stands out as the first business-to-business (B2B) marketplace, while *Nori* (US), *Compensate* (Finland), and *Carbon Engineering's BeZero* (Canada, Great Britain) cater to both business and individual consumers (B2B/C) [79]. For instance, *Puro Earth* currently offers biochar, bio-based construction materials, and carbonated building elements as carbon removal methods available for the purchase of carbon removal certificates (CORC).

Biochar and its production process certification are now indispensable prerequisites for biochar producers aiming to engage in the rapidly growing carbon removal marketplace [80]. As of now, only a select few marketplace providers facilitate carbon removal through biochar [15]. Notably, *Pacific Biochar* has achieved the distinction of securing the first carbon credits for biochar production in the United States [43]. Similarly, *Puro Earth* has endorsed biochar for carbon credits, with Carbo Culture emerging as one of its initial biochar companies available for carbon trading [81].

Participation in the *Carbonfuture* [82] marketplace requires that both the biochar and its production process adhere to the certification standards outlined by the European Biochar Certificate (EBC) or an equivalent certification body [39]. Similarly, *Puro Earth* also mandates that the production process be certified by the EBC or a comparable certification entity [83]. However, in cases where the production process lacks certification, an official life cycle assessment needs to be executed and presented [43]. Essentially, most of the prerequisites for participating in the Puro marketplace align with the requirements of the EBC. Additionally, an independent facility audit (Figure 2) may be required as an additional step.



Figure 2. Streamlined representation of pivotal actors within the voluntary BC value chain in market dynamics.

Each marketplace features its own specific carbon removal quantification protocol, which is based on their activity boundaries and uncertainty buffers prescribed by the respective marketplace providers. Detailed information about these protocols can be found in each platform’s comprehensive methodologies.

5. Case Studies and Projects

The successful generation of carbon credits through biochar initiatives highlights the growing recognition of biochar’s diverse benefits. Table 1 presents some examples of biochar projects and carbon credit generation. Nonetheless, it is crucial to stay updated with the latest developments and advancements in biochar projects to comprehensively assess their ongoing success in generating carbon credits. Continuous research and monitoring are essential to validate the long-term effectiveness and scalability of these biochar-based solutions within the broader context of carbon sequestration and climate change mitigation.

Table 1. Examples of biochar projects and carbon credit generation.

Case Study/Projects	Location	Key Benefits	Methodology and Achievements	Carbon Credit Generated from	Ref.
Cool Terra Carbon	United States	<ul style="list-style-type: none"> - Boosts soil health - Increases crop productivity - Sequesters carbon 	Demonstrated BC’s impact on soil health, crop productivity, and carbon sequestration. Quantified carbon stored in soil through improved agricultural practices, resulting in reduced GHG emissions and increased soil organic carbon.	Sequestration Project	[73]

Table 1. Cont.

Case Study/Projects	Location	Key Benefits	Methodology and Achievements	Carbon Credit Generated from	Ref.
Sonnenerde Pyreg 500	Austria	<ul style="list-style-type: none"> - improving the health of urban trees - increasing water storage capacity - preventing nutrient outflow into groundwater 	Use biogenic waste. Long-term carbon storage	Agricultural Residue Conversion and Soil Improvement project	[74]
Terra Preta	Africa and South America	<ul style="list-style-type: none"> - Improves sanitation - Enhances carbon sequestration 	Replaced traditional waste management with BC-based systems. Reduced GHG emissions from waste management, improved soil fertility, and generated carbon credits.	Sanitation Project	[75]
Carbon Gold's Sustainable Agriculture	UK and Africa	<ul style="list-style-type: none"> - Promotes sustainable agriculture - Enhances soil carbon sequestration and crop yields 	Measured and quantified increased soil carbon content and crop yields due to BC application. Generated carbon credits based on these measurements.	Sequestration Project	[76]
Husk BC Project	Southeast Asia	<ul style="list-style-type: none"> - Reduces methane emissions from rice paddies 	Demonstrated BC's effectiveness in reducing methane emissions while improving soil health. Generated carbon credits based on reduced methane emissions and carbon sequestration in soils.	Sequestration Project	[77]

6. Knowledge Gaps, Areas of Concern, and Research Priorities

Identifying deficiencies in the current body of research on biochar's utilization as a mechanism in the creation of carbon credits is imperative for advancing our understanding of this field and enhancing the efficacy of biochar in carbon sequestration endeavors. Several critical research gaps warrant thorough exploration. Firstly, the protracted carbon sequestration potential of biochar across various soil types and environmental conditions necessitates an in-depth analysis to ascertain its longevity. Quantification of the reduction in GHG emissions attributable to biochar application requires precise and standardized methodologies, encompassing its impact on nitrous oxide and methane emissions. Investigations into the optimal biomass feedstock and production techniques to maximize carbon sequestration are essential. Moreover, biochar's performance in diverse soil types and its implications for soil health and fertility demand a comprehensive examination. The influence of biochar on soil microbial communities and its ramifications for carbon sequestration and nutrient cycling necessitate extended study. In addition, the identification of the most effective application rates and frequencies while avoiding adverse effects, such as nutrient immobilization, is pivotal. When analyzing the production and use of biochar in response to market incentives, it is crucial to carefully examine its environmental impacts. This involves assessing changes in land use, effects on water quality, and the potential loss of biodiversity. A thorough evaluation is essential to anticipate and address any negative consequences. Meanwhile, existing policy and regulatory frameworks should be checked for potential shortcomings that could hinder its wider adoption. Public opinion, awareness, and outreach are crucial when integrating biochar into the carbon offset markets and mak-

ing it consistent with other climate mitigation strategies. Furthermore, an investigation of social aspects and equity when implementing biochar becomes necessary to ensure equity among diverse stakeholders in terms of distributing benefits.

The carbon removal marketplace underpins the key elements of the verification process through various considerations and concerns. There are several entities and mechanisms; however, concerns are raised about verifying biochar stability. Carbon offset standards and certification programs including Verra's Verified Carbon Standard (VCS) and Golden standard, are crucial for ensuring project adherence to criteria such as permanence, but they may be criticized for their lack of strictness and uniform application across diverse regions. Furthermore, independent third-party verifiers (certification bodies or field monitoring) are important in the verification process, but questions may arise with respect to their objectivity and resource limitations. In addition, carbon registry platforms play a vital role in tracking and proving emissions reductions; however, one must be very careful as there are issues surrounding data accuracy and access transparency. It is also worth noting that scientific and academic collaboration is necessary for continuous research, yet there have been concerns about conflicting research outcomes as well as industry influence. It is worth mentioning that insurance and buffer pools are very important in managing risk but may lead to inadequacy of coverage and moral hazard. On the contrary, there is a major benefit from the use of modern monitoring technologies such as satellite imaging, but they can also be expensive, inaccessible, or even invade one's privacy. Lastly, public reporting and disclosure mechanisms are critical to fostering transparency; however, these measures may be overshadowed by greenwashing and inadequate public understanding of complex information. To make sure that there is trust in the carbon removal market, this marketplace must have open discussions with stakeholders and implement adaptive management approaches, as well as practice transparent reporting. Interdisciplinary research collaborations and longitudinal monitoring are pivotal to address these gaps and further the maturation of biochar as a carbon credit mechanism for robust climate change mitigation efforts.

7. Conclusions

The production and use of biochar represents an essential potential for offsetting CO₂ emission, creating carbon credits through its unique ability to sequester carbon permanently. Biochar use contributes to reducing atmospheric GHG concentrations and, at the same time, enhances soil fertility, promotes sustainable agriculture, can replace less sustainable materials in horticulture substrates, and can partly substitute construction materials. Biochar utilization presents a promising avenue for carbon offset projects, providing a tangible means for businesses and individuals to actively participate in climate change mitigation efforts. By mitigating emissions and fostering soil health simultaneously, biochar aligns with the principles of sustainable development, offering a win-win solution for both the environmental and agricultural sectors. As governments, businesses, and individuals seek effective strategies to combat climate change, biochar stands out as a versatile and scalable technology that merits further exploration and implementation. The adoption of biochar as a key player in carbon credits not only underscores its economic viability but also underscores the urgency of transitioning towards more sustainable and regenerative practices.

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