

Is biochar a Carbon Dioxide Removal?

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Photo 1.
Biochar blocks.
Photo K. Candelier.

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RÉSUMÉ

Le biocharbon peut-il servir à des fins de capture et de stockage du CO₂ ?

Le biocharbon (ou biochar, ou agrichar) est généralement présenté comme un moyen de capture et de stockage du dioxyde de carbone atmosphérique (en anglais *carbon dioxide removal* ou CDR), avec un fort potentiel de contribution à l'atténuation du changement climatique assorti des co-bénéfices de ses propriétés d'amendement des sols, entre autres. Nous examinons la pertinence d'une classification du biocharbon comme moyen de capture et de stockage du dioxyde de carbone, en avançant que, dans la plupart des cas, son utilisation permet de réduire les émissions de CO₂. En effet, le biocharbon est avant tout un moyen de transformer la biomasse en une matrice plus pérenne pour le stockage du carbone, indépendamment de toute capture de carbone ayant eu lieu précédemment dans différents types de biomasse. Il est donc trompeur d'attribuer des processus de capture du carbone au biocharbon, sauf dans certains cas très précis (plantations forestières dédiées par exemple). Il est important de faire la distinction entre capture/stockage et réduction des émissions afin d'éviter l'allocation inappropriée de ressources prévues pour les activités d'atténuation et d'apporter plus de certitude aux modèles de commercialisation du biocharbon, qui pourraient être faussés par des attentes irréalistes quant aux revenus associés aux marchés du carbone. Comme le biocharbon peut jouer un rôle important non seulement dans l'atténuation mais aussi dans l'adaptation au changement climatique, en améliorant la résilience de l'agriculture et de la sylviculture, nous estimons que ces atouts combinés du biocharbon doivent être pleinement reconnus dans les politiques publiques pour permettre son déploiement à grande échelle, comme par exemple en soutenant son utilisation en remplacement des engrais chimiques.

Mots-clés : biocharbon, élimination des émissions de CO₂, CDR, changement climatique, crédits carbone, adaptation.

ABSTRACT

Is biochar a carbon dioxide removal?

Biochar is commonly presented as a carbon dioxide removal (CDR) technology with great potential to contribute to climate change mitigation and co-benefits thanks to its soil conditioning properties, among others. We discuss the relevance of classifying biochar as a carbon dioxide removal and argue that in most cases its use will rather reduce CO₂ emissions. The reason is that biochar is mostly a way of processing biomass into a more permanent matrix for carbon storage, independently of carbon removals that may have occurred previously into various types of biomass. It is therefore misleading to attribute carbon removal processes to biochar except in some very specific cases (e.g., purpose-grown tree plantations). Making a distinction between CDR and emission reductions is important to prevent the misallocation of resources available for mitigation activities and provides more certainty to biochar business models that could be misled by unrealistic expectations over (inflated) carbon-related revenues. As biochar has the potential to play a significant role, not only for mitigation but also for adaptation to climate change with increasing resilience of agriculture and forestry, we argue that policies should fully recognise the combined adaptation and mitigation benefits of biochar and act accordingly to create the right conditions for deploying it at scale (e.g., by supporting its use as a replacement for chemical fertilisers).

Keywords: biochar, carbon dioxide removal, CDR, climate change, carbon credits, adaptation.

RESUMEN

¿Puede considerarse el biocarbón un extractor de dióxido de carbono (CDR)?

El biocarbón (*biochar*) se presenta a menudo como extractor del dióxido de carbono de la atmósfera (CDR por sus siglas en inglés) con gran potencial para contribuir a la mitigación del cambio climático y con beneficios colaterales debidos a sus propiedades como enmienda del suelo, entre otros. Debatisimos la relevancia de clasificar el biocarbón como medio para extraer dióxido de carbono y argumentamos que en la mayoría de los casos su uso, más que eliminar, reduce las emisiones de CO₂. La razón es que el biocarbón es ante todo un método para procesar biomasa en una matriz más permanente de almacenaje de carbono, independientemente de la extracción de carbono que puede haber tenido lugar previamente en varios tipos de biomasa. Por lo tanto, es erróneo atribuir al biocarbón procesos de extracción de carbono, excepto en algunos casos muy específicos (e.g. plantaciones de árboles destinadas a este fin). Es importante distinguir entre CDR y reducción de emisiones para evitar asignaciones inapropiadas de recursos disponibles para actividades de mitigación de cambio climático, y para proporcionar mayor certeza en los modelos de negocio del biocarbón, a los que podrían atribuirse expectativas no realistas de ingresos provenientes del mercado del carbono. Como el biocarbón tiene el potencial de desempeñar un papel significativo no solo en la mitigación, sino también en la adaptación al cambio climático, con una creciente resiliencia de la agricultura y la silvicultura, consideramos que las políticas deberían reconocer la superposición entre los beneficios de adaptación y mitigación del biocarbón y favorecer la creación de las condiciones adecuadas para su despliegue a escala (e.g. apoyando su uso como sustituto de fertilizantes químicos).

Palabras clave: biocarbón, extracción de dióxido de carbono, CDR, cambio climático, créditos de carbono, adaptación.

The quest for Carbon Dioxide Removals (CDR) to limit global warming

Projects and policies for climate change mitigation must reach higher levels of ambition to “*limit the increase in the global average temperature to well below 2°C above pre-industrial levels*” according to the Paris Agreement (UNFCCC 2015). While the priority is to reduce emissions in all sectors, the CDR activities are becoming increasingly important not only to accelerate and diversify efforts to limit climate change but also to compensate for the share of emissions (residual emissions) that will prove extremely difficult and/or costly to abate (IPCC 2022a). It thus becomes clear that action must be taken on both sides (Warszawski et al. 2018): reducing emissions and removing carbon from the atmosphere.

CDR can take various forms, and technologies are being intensively researched to find ways to upscale removals at an affordable cost. Many options have been proposed and tried with varying levels of technological sophistication and reliance on ecosystems but also contrasted costs and associated risks and co-benefits. For instance, while Direct Air Carbon Capture and Storage (DACCS) or Bioenergy with Carbon Capture and Storage (BECCS) are very technology-intensive and may not be cost-effective at scale yet (Smith et al. 2023), afforestation and reforestation (A/R) is a proven way to sequester carbon in trees, but may be detrimental to other objectives such as biodiversity conservation or food security due to competitive land uses (Deprez et al. 2024). Oceans are also a very active field for CDR, but most of the proposed technologies and activities remain poorly known both in terms of potential and risks (Gattuso et al. 2018).

Biochar is praised as a promising CDR

In this rapidly evolving field, biochar is an option that is increasingly praised for both its potential (Lefebvre et al. 2023) and variety of uses and co-benefits (Schmidt and Wilson 2014). It is produced out of organic material (generally waste biomass) with a pyrolysis process (heating at high temperatures in the absence of oxygen), or alternatively gasification, and can then be used productively while storing the carbon for very long periods, up to a thousand years. Among the application types are water filtration, additives to construction materials, animal feed or food supplements, and most prominently, fertiliser for agriculture.

As organic waste and residues of all kinds (agricultural and forestry residues, manure, garden refuse, etc.) are a source of greenhouse gas emissions, their proces-

sing into biochar with further long-term carbon storage in a matrix (either soils, construction material, filtration systems, etc.) contributes to climate change mitigation. This idea emerged in the mid-2000s and the establishment of the International Biochar Initiative (IBI) in 2006 has been instrumental in making it consensual in major climate discussions. As described in the scientometric review by Wu et al. (2019), which spans 20 years of biochar research, this product has been praised for its mitigation potential since at least 1998 but with increased intensity over the 2011-2015 period with a higher level of generalisation.

In the related forums and literature (e.g., Lehmann et al. 2021), including the reports by the Intergovernmental Panel on Climate Change (IPCC 2022a), biochar is usually presented as a CDR specifically and has generated lots of expectations. The IBI speaks of a “carbon negative” technology and simultaneously suggests that “biomass residuals” are prioritised as feedstock: this might be contradictory according to the main argument in our paper. The excitement around biochar for mitigation is also stimulated by the quest by the private sector, and to a lower extent by governments, for CDR carbon credits that will allow them to offset their residual emissions and achieve their net zero commitments (Trouwloon et al. 2023). This is translated in the prices of CDR/ biochar carbon credits that reach much higher levels than other carbon credits associated with “reduced emissions,” up to ten times more, with reported prices of about USD 200/tCO₂-eq (e.g., <https://puro.earth>) compared to USD 5-20/tCO₂-eq (Forest Trends' Ecosystem Marketplace 2023).

Mistaking biochar for CDR has consequences

But is biochar really a CDR? Considering the state of knowledge and research that we mentioned above, as well as the spectacular spread between prices for CDR or reduced emissions credits, a thorough examination of the relevance of classifying biochar as a CDR seems to be lacking. This question matters for at least three reasons.

First, climate change mitigation and the net-zero transition require such high levels of investments that only an optimal allocation of financial resources would enable humanity to limit global warming at the targeted levels (Krishnan et al. 2022). As a significant share of these investments is expected to be provided through carbon markets (Kreibich and Obergassel 2019), which are assumed to orient investments towards the most cost-effective measures, it matters if biochar-based mitigation is remunerated at very high CDR levels rather than at “emissions reductions” levels. Indeed, this would lead to an eviction effect where a given investment into biochar-based mitigation would displace a similar level of investment in another activity that would have many times more mitigation impact due to the difference in value between both types of carbon credits.

Inset 1.

Drivers for carbon market prices.

In this paper, we discuss the status of biochar from a climate change mitigation perspective with implications on the carbon markets. We assume that credits associated with biochar are wrongly valued due to their carbon dioxide removal (CDR) status as opposed to reduced emissions. While this assumption is useful for our demonstration and to justify the necessity to assess biochar for what it essentially is, it can also be nuanced and put into perspective without undermining the whole argument.

Activities leading to the issuance of carbon credits are of many different types and come with their own characteristics. These do not only relate to the mitigation impacts (e.g., permanence of sequestration) but also to co-benefits or risks associated with the implementation of activities. Their production costs vary as well as the probability that they generate real impacts (e.g., additionality criterion). Besides, transactions take place in different ways, and over-the-counter purchases coexist with more fluid and transparent markets.

In other words, buyers of carbon credits can have various motivations and criteria to decide which activities should be favoured and what prices would be justified. While carbon markets have initially been conceived as a place to exchange a commodity because the tCO₂-eq metric assumes similar mitigation impacts whatever their origin, in reality, they are complex and multidimensional.

This complexity and the many criteria leading to a price for carbon credits may be in favour of biochar. While we emphasised the CDR/reduced emissions divide, biochar holds characteristics that may push the value of associated carbon credits upward. Indeed, permanence of storage is assumed to be very long-term, application to soils could increase productivity and adaptation of agriculture to climate change, and production costs are so substantial that only high prices for credits would compensate for the relative lack of willingness by farmers to pay decent prices for the product itself.

Inset 2.

Defining terms to avoid confusion: removal, capture, storage, sequestration, and emissions reductions.

Capture: It refers to the action of preventing emissions at processing sites such as plants and factories, by capturing greenhouse gases at the emission stage with subsequent storage. A prominent example is bioenergy with carbon capture and storage (BECCS), where crops are cultivated to produce energy and carbon emissions are captured at the energy generation site. In turn this leads to a case of negative emissions because carbon is first removed from the atmosphere with crop cultivation and then energy is produced without emitting emissions back into the atmosphere.

Emissions reductions: It refers to the avoidance of emissions when an activity is either prevented (e.g., not driving a car or not clear-cutting a forest) or substituted (e.g., shifting from conventional to electric vehicles) so that the actual situation generates fewer emissions than the baseline situation (when the course of action is not altered).

Removal: it refers to the action of removing carbon dioxide from the atmosphere with subsequent storage in biological (e.g., in trees or plants with photosynthesis), geological (e.g., oil and gas depleted reservoirs), or ocean matrices (e.g., in kelp or plankton). This action can be with or without human intervention, for instance with tree/crop planting (intervention) and natural forests or natural ocean sinks (no intervention). Note that a first and important confusion, which is at the core of our analysis, is that the role of human interventions (or absence thereof) in such removals is often neglected. Another important source of confusion, which is more subtle yet critical, is that the human interventions in removals can be motivated either by the removal itself or by an economic activity that triggers removals as a side-effect (e.g., farming or sustainable forestry).

Sequestration: This is an ambiguous term that involves the notions of removal and storage. It usually refers to Afforestation/Reforestation activities and beyond, to the role of living organisms in removing carbon from the atmosphere with photosynthesis.

Storage/matrix: For carbon to be removed from the atmosphere, it must be stored in a matrix either in solid or liquid form. These matrices can be living organisms, geological reservoirs such as saline aquifers, or products. But carbon storage in a matrix does not imply a case of removal, and storage can change forms and matrices as exemplified by woody biomass processing into biochar. Fossil fuels are also a good example because they represent a carbon storage matrix with removal dating millions of years ago in plants and animals and before fossilisation processes. Pushing the reasoning to its end, one could thus argue that conserving fossil fuels in a safe place would be a case of CDR.

To be very concrete, if an investor pays USD 200/tCO₂-eq for a credit generated with a biochar project rather than USD 20/tCO₂-eq for a credit generated from other types of projects (e.g., renewable energy), this investment is 10 times less effective in terms of global warming effect. Admittedly, the drivers for carbon credits prices are many, and the situation is more complex than just comparing CDR and reduced emissions, which we discuss in inset 1 to put our reasoning into perspective.

Second, biochar remains an uncertain venture because the market is not mature and the specific role of carbon credits revenues in business models remains unclear (Pirard et al. 2024). In this context, investors face a difficult choice because, on one hand, while biochar is presented as a high-potential product in terms of marketing (Wang et al. 2020), sales and associated revenues remain unclear, and on the other hand, expectations are high that carbon-related revenues will provide a decisive contribution (interviews with biochar producers, South Africa). There is thus a risk that investors who rely on high carbon credit prices face a drastic decline in revenues if and when market actors realise that it is actually a case of emissions reductions with associated (and orders of magnitude lower) prices.

Third, confusing emissions reductions and CDR would misinform global policies on climate change mitigation. As humanity needs to act on both sides to achieve ambitious targets, but the types of activities differ and require targeted incentives, classifying activities in the wrong category would only lead to deceiving policies and investments overall.

Why is the rationale for biochar as a Carbon Dioxide Removal misleading?

The reason why biochar is presented as a CDR is that it is associated with the removal of carbon through the photosynthesis process and subsequent permanent storage into biochar. There is indeed a carbon cycle with a two-stage storage that starts with removal by plants and then storage in biochar.

The key question is whether the production of biochar is associated with the first removal stage (photosynthesis) or only with the biomass processing activity to create a new matrix (see inset 2 for terminology). In the former case, one can argue that biochar is a CDR. In the latter case, such a claim can be dismissed because biochar can only be credited for its contribution to greater permanence of storage. As we will argue, such greater permanence is another word for “emissions reductions.”

In order to understand the reasoning, we need to discuss the feedstock options for biochar production and introduce the concept of additionality. Feedstock options are many, and they differ mainly on one dimension that matters here: were they cultivated for the purpose of biochar production («purpose-grown»), or for any other reason? Suppose we simplify the analysis by focusing on the main sustainable feedstocks (table I) available to biochar producers that pose limited risks to food security and biodiversity, namely agricultural residues, forestry residues, animal manure and wastewater biosolids (Lefebvre et al. 2023),

Table I.

Status of biochar as carbon dioxide removal (CDR) or reduced emissions for the main feedstock options.

Feedstock option	Status of biochar from a climate change mitigation perspective	Likelihood
Agricultural residues: e.g., corn stover, rice straw, sugarcane bagasse, wheat straw, cotton stalk	Reduced emissions compared to a situation where residues are burnt or left to decay	Very common
Forestry residues: e.g., tree branches and twigs, bark, sawdust	Reduced emissions compared to a situation where residues are burnt or left to decay	Common
Purpose-grown tree plantations/crop farming (exclusively established for biochar production)	CDR	Uncommon/non-existent
Land restoration with clear-cutting of invasive trees	Reduced emissions compared to a situation where woody biomass is burnt or left to decay	Uncommon
Dedicated sustainable management of areas invaded by trees with the application of a rotation system in woodlots	CDR	Uncommon/non-existent
Sustainable natural forest management with enhanced carbon removals after harvesting	CDR	Uncommon/non-existent

Note: we do not address cases where feedstock would have been used for bioenergy in the absence of biochar production; it should be assessed on a case-by-case basis, e.g., because it could lead to fossil fuel substitution

while also including the underestimated waste biomass resulting from land restoration (Pirard et al. 2024). In that case, it is straightforward that the biomass was not cultivated for the purpose of biochar production. But the situation is different for purpose-grown woodlots and forestry management that lead to wood extraction while stimulating regrowth. In these particular cases, which remain poorly documented as a source of feedstock for biochar, we argue that removals as well as the long-term storage must be attributed to its production (figure 1).

Additionality refers to the fact that the observed situation, either investments into processing facilities, use of residues, or plant cultivation, would not have taken place without a climate change mitigation objective. The absence of additionality means that a given activity would take place whatever the revenues associated with mitigation, and as such does not need to be supported: it has or will happen anyway.

Figure 1 summarises the interactions between the types of feedstocks and additionality at various stages and shows that biochar can only be considered a CDR in very specific, and rarely seen, situations. These situations correspond to the scenarios that contain green-circled boxes above the dotted horizontal line. Indeed, they indicate scenarios where the removal of carbon dioxide from the atmosphere can be attributed to biochar production, i.e., situations where removals would not have happened without such a use. Yet, what happens most of the time is that agriculture and forestry residues are used as feedstock

so that the biochar producer is not the cause of carbon removals in the first place and only changes the course of action at the end of the chain (under the dotted horizontal line) when the biomass management (or lack thereof) is about to lead to greenhouse gas emissions. In other words, biochar production only changes the ultimate form of biomass by processing it into biochar before it decomposes and releases greenhouse gases. As such, it prevents emissions and ensures long-term storage with enhanced permanence of the carbon storage compared to biomass.

How to make the most of biochar by combining adaptation and mitigation benefits?

Our clarification on the role that biochar can play for climate change mitigation, which in most documented cases leads to reducing emissions rather than removing carbon dioxide from the atmosphere, should not be misinterpreted. Indeed, such a contribution is in itself welcome and should be supported, yet such support should be proportional to its contribution to ensure the better allocation of resources that remain largely insufficient in the face of the challenge. But while all mitigation actions may be equivalent from a purely mitigation perspective worldwide, as one

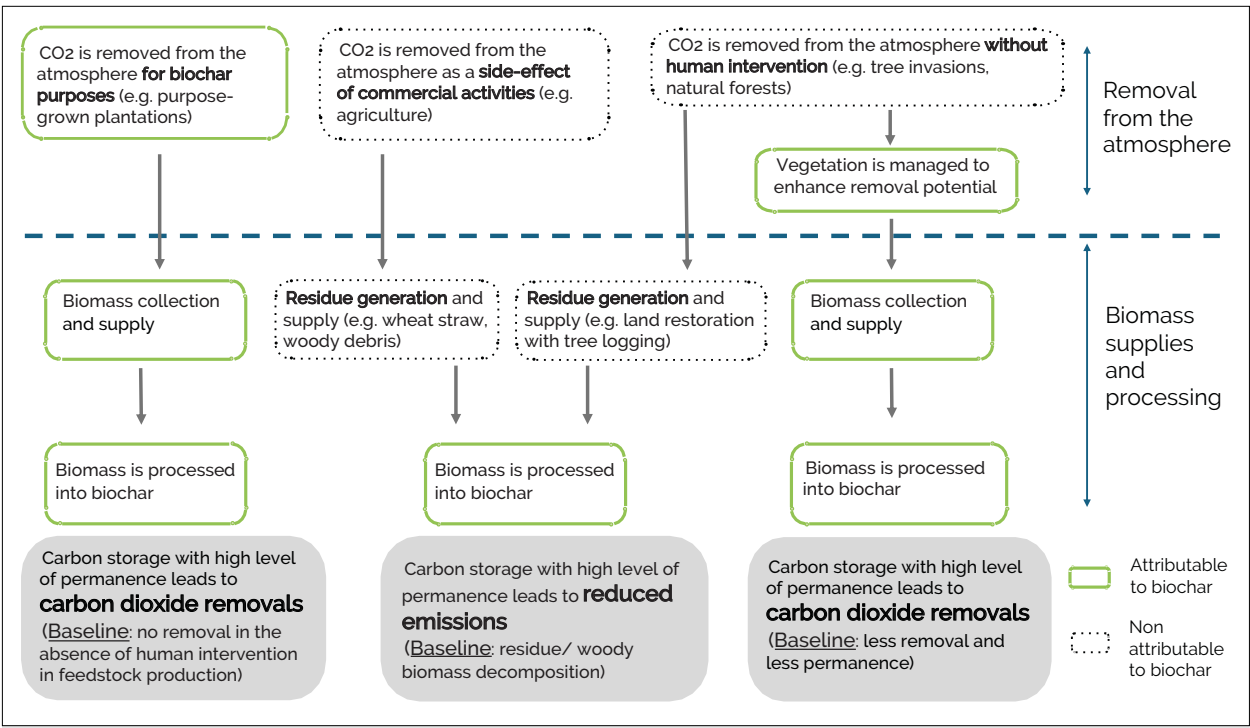


Figure 1. Situations leading to biochar as a case of carbon dioxide removal (CDR) or emissions reductions.

ton of CO₂ emission avoided has a similar impact whatever the sector or geography, such actions differ with respect to their other impacts. For instance, avoiding emissions from the conversion of a tropical forest may have benefits for biodiversity, while reducing emissions from transportation systems may have benefits for health locally. These differences are acknowledged and factored in the carbon credit markets with differences in their prices depending on the nature of the projects (inset 1 and Forest Trends' Ecosystem Marketplace 2023).

In the case of biochar, this distinction is highly relevant for one of its most promising end uses (Schmidt and Wilson 2014), namely as a non-chemical fertiliser for agriculture and forestry. This rapidly evolving field remains contested on its margins, but the consensus rather points to biochar application to soils as a means to improve soil health and plant growth. A thorough and recent review of the literature indicates that such positive impacts are empirically observed in most cases even though mixed or opposite results were also reported (Wang et al. 2020). The authors conclude that the reasons for either positive or negative impacts may depend on the type of feedstock and quality of biochar, but also the rates of application, soil and climate conditions, and other factors.

While more insights are thus needed to understand how exactly to enhance the benefits of biochar application to soils, the state of knowledge backs the assumption that it would generally contribute to an increased resilience for agriculture and forestry in the context of climate change. As indicated in the latest report by the IPCC on impacts, adaptation and vulnerability (IPCC 2022b), any means to address resilience in these sectors is required due to the worrying impacts according to most scenarios. There is thus an appealing combination of mitigation and adaptation benefits derived from biochar application to soils. Moreover, these cumulated benefits would be particularly useful to justify investments and public policies that would create a market for the end product, hereby reducing the need for artificially inflated values for carbon credits as CDR.

Conclusive remarks

We have attempted to clarify the situations where biochar should be considered a CDR and those where it should rather be viewed as a driver of emissions reduction. We argued that the common assumption that it is a case of CDR stems from the erroneous analysis that it is responsible for the carbon removal processes that take place at the beginning of the chain with plants photosynthesis. In fact, in most cases biochar results from the processing of residues generated as a side-product of other commercial or restoration activities. As such, it only contributes to reducing emissions compared to the baseline situation where such residues decompose or are burnt and emit greenhouse gases. It does so by extending the permanence of the carbon storage matrix by many orders of magnitude, possibly from days (when residues are burnt) to a thousand years (if

biochar meets the most optimistic expectations in the best conditions). The confusion also stems from the misuse of various related but different concepts of removal, storage, sequestration, and others (inset 2), and which one should be attributed to what activity.

This distinction refers to the concept of additionality, which enables the attribution of removals to biochar whenever justified. This is important from an economic perspective because it leads to the identification of what resorts to either CDR or emissions reduction and which activities should be supported based on their specific role in the mitigation space. Only such distinctions can lead to an optimal allocation of the scarce financial resources available to limit global warming due to their contrasting costs, hence their needs for financial support. They also prevent unrealistic expectations in terms of carbon credit prices that convey the risk of a bubble that would eventually burst and slow down investments due to unsustainable business models.

As biochar holds the potential to play a significant role not only in climate change mitigation but also in adaptation with an increased resilience of agriculture and forestry in the face of worsening conditions, it would be counterproductive to assign it a function that it cannot endorse. Rather, we argue that markets should only consider the substantial yet specific services it can provide, and that policies should fully recognise its combined adaptation and mitigation benefits and act accordingly to create the conditions of its deployment at scale. This could translate into public policies that promote the use of biochar by farmers (either through incentives or constraints) to stimulate demand and generate solid revenues on top of carbon credits (possibly in substitution to chemical fertilisers), policies that increase availability and/or lower supply costs of biomass feedstocks (e.g., no-burning policies for residues), publicly-funded research to assess benefits and support higher prices for biochar, or subsidies to biochar producers to account for adaptation benefits.

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