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Biochar carbon markets: A mitigation deterrence threat

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ABSTRACT

This article aims to add to the emerging empirical mitigation deterrence literature by drawing on ongoing research into a particular form of greenhouse gas removal technology – biochar – and associated biochar carbon markets. As such, the aim of this paper is to explore whether the UK carbon market for biochar, *in practice* is likely to contribute to delays in emissions reduction. In other words, we explore whether UK biochar carbon markets are (likely to be) as much of a problem for mitigation deterrence as imagined or envisaged within the mitigation deterrence literature. We draw from original data collected in 2022 from 33 semi-structured interviews with mostly UK based experts who have an interest or potential interest in biochar, supplemented with a document analysis. Conceptual approaches from the social studies of finance have guided the analysis, an approach that enables systematic investigation of experts' understandings of the biochar carbon market landscape in the UK. Although biochar proponents forwarded narratives – or fictional expectations – about how the future trading of carbon credits in carbon markets could lower the cost of producing biochar on a large scale, other experts doubted the credibility of these narratives. Whilst the construction and sustainable functioning of a UK-based biochar carbon market remains a speculative, rather than credible proposition, it nevertheless constitutes a threat of mitigation deterrence because of the assumption that a UK biochar carbon market will become a reality. There is the promise of future removals even if this is only imagined.

1. Introduction

While the relationship between human economic activities and atmospheric concentrations of greenhouse gases was outlined in the first IPCC report in 1990, the policy drive to reduce greenhouse gas emissions gained significant impetus following the 2015 Paris Agreement. This international treaty was signed by member states of the United Nations Framework Convention on Climate Change (UNFCCC) and aims to maintain the increase in global average temperature to below 2°C and attempts to limit the increase to 1.5°C (UNFCCC, 2015). To meet the temperature targets of 2°C and 1.5°C, the IPCC mitigation scenarios rely not only on the reduction of greenhouse gas emissions but also on their removal from the atmosphere through the deployment of greenhouse gas removal (GGR) technologies (Anderson and Peters, 2016; Carton, 2019; Peters and Geden, 2017).

GGR technologies are viewed as key for the hard to decarbonise sectors of transport (shipping and aviation) and agriculture (Buck, 2021; Markusson et al., 2020; Waller et al., 2020). Any overshoot in emissions could be compensated for by GGR technologies (Markusson et al., 2020; Waller et al., 2020). However, only two large scale GGR approaches have been included in Integrated Assessment Models (IAMs) which underpin scenarios used in the Paris Agreement, and these are afforestation and biomass energy with carbon capture and storage (BECCS) (Anderson and Peters, 2016; Bellamy et al., 2021; Waller, 2020). Other GGR technologies include biochar, peatland restoration, enhanced rock weathering, ocean fertilisation, and direct air capture (Bellamy and Osaka, 2020; Buck, 2019). GGR technologies are being imagined at scales that will assist in reaching net zero targets, but many of these technologies have not moved beyond theoretical studies or small-scale demonstrations.

It is claimed that the focus on removing carbon from the atmosphere undermines ambitious decarbonisation strategies and results in 'mitigation deterrence'. Markusson et al. (2018: 1) define mitigation deterrence as 'the prospect of reduced or delayed mitigation resulting from

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the introduction or consideration of another climate intervention'.

An emerging literature on mitigation deterrence argues that the impact of delays is systemically catastrophic, because for every year the world fails to decarbonise, as well as every year greenhouse gas emissions are stable or increasing, global warming extends into the future (Malm, 2018). For this mitigation deterrence literature, socio-technical devices such as climate change scenarios and carbon markets are a means for maintaining business as usual for carbon emitting industries (Lohmann, 2008; Markusson et al., 2018).

While much of the mitigation deterrence literature is theoretical, recent years have seen the publication of related empirical case studies which have expanded the understanding of how carbon offset markets are brought into being through socio-material assemblages (Carton, 2020; Lyons and Westoby, 2014; Osborne and Shapiro-Garza, 2018; Watt, 2021). This article aims to add to the emerging empirical mitigation deterrence literature by drawing on ongoing research into a particular form of greenhouse gas removal (GGR) technology – biochar – and associated biochar carbon markets. As such, the aim of this paper is to explore whether the UK carbon market for biochar, *in practice* is likely to contribute to delays in emissions reduction. In other words, we explore whether UK biochar carbon markets are (likely to be) as much of a problem for mitigation deterrence as imagined or envisaged within the mitigation deterrence literature. The investigation draws on insights from the social studies of finance (SFF) because this literature is interested in market making as a socio-material process (i.e. one that simultaneously weaves together discursive promissory narratives and active nonhuman technical devices). Our focus is a particular type of market – carbon markets for biochar – and so SFF gives us useful conceptual tools to enable us to explore both the narratives and materialities of biochar carbon markets. Through this analysis, an assessment can be made of the implications of biochar carbon markets for mitigation deterrence.

Biochar is of interest as it is one of five GGR approaches currently part of a £30 million GGR demonstrator programme in the UK, funded by UK Research and Innovation (UKRI). The Biochar Demonstrator includes field trials with farmers in England, with biochar being applied to both arable and pastureland. In addition, biochar is attracting attention from scientists, policymakers and industrial sectors in the UK as a scalable GGR technology (IPCC, 2022; Royal Society and Royal Academy of Engineering, 2018; BEIS, 2021). Biochar is a carbon-rich substance, and alongside its ability to sequester carbon, when deployed to agricultural land, has a wide range of agricultural co-benefits including improving soil health by increasing the water and nutrient holding capacities of soil. However, mass production and deployment of biochar is currently not viable because it is prohibitively expensive to produce. Creating a market in biochar carbon credits has been proposed as a means of reducing costs for biochar producers by catalysing investment in biochar projects from financiers and banks.

The rest of this article is organized as follows. The next section discusses the literature concerning GGR technologies as a potential mitigation deterrence and discusses the manners in which mitigation deterrence may occur. The GGR technology of interest in this article is biochar, and further background on biochar is provided next. The article's conceptual approach is grounded in the social studies of finance and further detail on this is provided along with a description of our methods in the Concepts and Methods section. This is followed by our analysis of the enablers and constraints of biochar carbon markets in the UK. Finally, we draw conclusions as to how this study adds to the mitigation deterrence debate and make recommendations to UK policymakers.

2. GGR technologies and mitigation deterrence

GGR technologies are increasingly included in international policy discussions as a mitigation alternative for countries with carbon intensive economies. However, a growing literature on 'mitigation deterrence' has criticized the assumption that the continued use of fossil fuels can be offset through carbon removal and carbon sinks (Carton et al., 2020). This literature correctly identifies that such mitigation strategies could allow 'business as usual' because a consideration of these potential climate interventions 'reduces or delays' radical but necessary changes in the global economy such as far-reaching decarbonisation (Markusson et al., 2018: 1). This literature argues that there is more than one form of mitigation deterrence, to the extent that McLaren (2020) has developed a typology of three different forms of mitigation deterrence. Firstly, there are instances of 'substitution' and 'failure'. In the substitution scenario, actual or future greenhouse gas removal may be traded on carbon markets. With failure, the long-term removal of greenhouse gases is not achieved. Secondly, attempts at mitigation may lead to 'rebounds.' In such cases, any unintended consequences associated with GGR technologies may result in additional greenhouse gas emissions. Thirdly and most pertinent for this article, are instances of 'mitigation foregone'. This facet of the typology captures instances where a reliance on unproven or uncertain GGR technologies may result in delays or deter action to reduce emissions in the present / near term (McLaren., 2020). Fundamentally, what this typology draws attention to is a failure to reduce emissions due to the imagined offsets promised by GGR technologies. Instead of reducing emissions, the use of such GGR technologies has the potential to maintain or encourage continued fossil fuel use (Anderson and Peters, 2016; McLaren et al., 2019).

Currently, the mitigation deterrence literature tends to treat GGR technologies as a blank canvass for political interests and the exercise of socio-economic power. This scholarship often applies a 'cultural political economic' (CPE) lens to GGR technologies (see Markusson et al., 2018; Asayama and Hulme, 2019; Carton, 2019; Markusson et al., 2022). For CPE, representations, texts, and social imaginaries are deployed by powerful entities to promote their interests (Sum and Jessop, 2013). When applied to mitigation deterrence, socio-technical devices, such as climate change scenarios, are viewed as a means to maintain business as usual for neoliberal modes of resource exploitation and carbon emissions (Asayama and Hulme, 2019; Carton, 2019). For example, climate scenarios that employ somewhat heroic assumptions about the contribution that carbon capture technologies make to negative emissions allow firms to delay present action and mitigate the rate of fixed capital devaluation that would occur if alternative business strategies or forms of divestment were pursued (Carton, 2019). In such a way, a techno-optimism is likely to create delays around addressing greenhouse gas emissions and potentially draws attention away from more effective actions and measures (Lamb et al., 2020; McLaren et al., 2021). Therefore, it is critical to understand how GGR technologies may contribute to mitigation deterrence. In the section that follows we provide further detail about biochar, the GGR technology of interest in this article.

3. Biochar as a GGR technology

Land-based GGR approaches include growing trees or perennial biomass crops, restoring peatland, and applying biochar. These GGR approaches require large areas of rural and semi-natural land for their deployment. Biochar stores the carbon from its original biomass source material in a stable form (Shackley et al., 2016) and can be produced from virgin wood, agricultural and forestry residues, food, animal, and human waste, and fibres (Hansson et al., 2021; Otte and Vik, 2017; Pourhashem et al., 2019; Rittl et al., 2015). It is created by a thermochemical process called pyrolysis, the thermal decomposition of biomass which occurs at a very high temperature and under oxygen-deprived conditions. Biomass that is not turned into biochar and is instead left to decay and decompose, is rapidly broken down by micro-organisms, enabling carbon to be released back into the atmosphere as carbon dioxide (Clare et al., 2014; Hansson et al., 2021; Shackley et al., 2016). When applied to soils, the length of time biochar carbon remains ranges

from decades to millennia (International Biochar Initiative, 2023), although this is largely dependent on the type of feedstock used, the type of pyrolysis, and the settings used during pyrolysis (Bruun et al., 2016; Hansson et al., 2021; Lopez-Capel et al., 2016).

Biochar has begun to capture the imagination of policy makers and industry due to its versatility and therefore potential scalability. In the UK, the estimated potential of greenhouse gas removal for biochar is 6–41 $MtCO_2$ per year, although globally, it is projected to be between 1.9 and 4.8 $GtCO_2$ per year (Royal Society and Royal Academy of Engineering, 2018). In agricultural settings, biochar sequesters carbon, whilst its co-benefits include increasing soil fertility, acting as a soil conditioner, and increasing the water holding capacity of soil (Otte and Vik, 2017; Pourhashem et al., 2019; Rittl et al., 2015). The National Farmers Union (NFU) has identified biochar as one of several GGR approaches that may help the UK agricultural sector achieve net zero by 2040 (NFU, 2021). Other uses include the application of biochar to quarries, embankments, and mines for land remediation, soil restoration, and carbon sequestration (TerrAffix, 2022). Biochar can also be added to road construction materials or aggregates in cement and concrete production, as well as in textiles, in paper production, and in ceramics (Buck, 2019; Schmidt and Shackley, 2016). The use of biochar as a peat substitute is promoted by the horticultural industry (Carbon Gold, 2023). Further, there is the potential for carbon removal with bioenergy with biochar capture and storage (Buck, 2019). Whilst there are numerous uses for biochar, the focus of this article is the application of biochar to agricultural land.

At present, biochar is a commodity with carbon sink properties, but expensive to produce. Carbon trading allows greenhouse gas removal to offset carbon dioxide emissions elsewhere. This is because carbon credits representing greenhouse gas removals can be purchased on carbon exchanges by organisations that produce carbon emissions. Trading is facilitated by a range of actors and technical components, including carbon brokers, exchange platforms, emissions auditors, offset project developers, news services and law firms (Bryant, 2019). Carbon markets are thought to be critical for the scaling up of biochar as a form of carbon capture because the ability to develop forward contracts is a means to secure investment for biochar projects from financiers and banks (Luckhurst, 2022; O'Toole et al., 2016; Shackley, 2016). The prospect of being able to trade carbon credits relating to biochar is therefore viewed as a potential means to transform this commodity into a scalable form of carbon capture.

This background provides an initial insight into the way GGR technologies may contribute to mitigation deterrence, along with the characteristics of biochar as a GGR technology. In the next section we outline our conceptual approach of the social studies of finance (SSF) along with a description of our methods. This conceptual approach and the empirical data enable us to provide an account of the factors that enable or constrain biochar carbon markets, and the implications for mitigation deterrence. This is provided in the subsequent analysis.

4. Concepts and methods

4.1. Social studies of finance

This article grounds its conceptual approach in the social studies of finance (SSF), to provide a fuller account of the active role that socio-technical practices and tools themselves play in the construction of biochar markets. While not a 'coherent research program with a singular objective or politics' (de Goede, 2005: 25), SSF can be understood as an interdisciplinary approach preoccupied with the active role that socio-technical devices play in the construction of markets and the outcomes that arise from market activities. Scholarship within this research agenda attends to the entangled nature of economic, cultural, and social relations in the creation and reproduction of financial markets (Callon, 2007). For this analytical approach, any functioning market is historically contingent on a combination of material and technical devices, texts, algorithms, rules, and human beings, that shape agency and bring economic phenomena into being (Berndt and Boeckler, 2009). The component objects and practices of markets thus allow 'coordinated market actions' -such as exchange- to be achieved (Langley, 2010: 398). This approach holds an expansive conception of the economic agency of equipment and technical devices working together in hybrid collectives with humans. This should be contrasted with the CPE approach for which political agency and the exercise of power is the purview of people and social institutions/organizations. For example, in a CPE analysis of transition scenarios used by fossil fuel company Shell, it is wider 'hegemonic political regimes' that facilitate the inclusion of 'highly improbable' assumptions that future technologies will be able to compensate for Shell fully exploiting its oil reserves in the future (Markusson et al., 2018: 6; Carton, 2019: 761). Models are thus docile tools in the hands of fossil fuel corporations. Alternatively, prominent scholarship in SSF holds agency to be distributed and often non-human, with the materiality of equipment playing an important role in determining market outcomes (Callon and Muniesa, 2005; Callon et al., 2002; Hardie and MacKenzie, 2007; MacKenzie, 2009; MacKenzie et al., 2012). This conceptual approach allows us to draw out the factors which enable or constrain biochar carbon markets and the potential implications for mitigation deterrence. Attention now turns to our methods of data collection and analysis.

4.2. Methods

The work reported here forms one element of a broader research project which is interested in the application of biochar to agricultural land. The methods described are for one aspect of the social science research of which this article forms one part. This research was interested in individuals and organisations who already had a specified, explicit interest (positive, negative and neutral) in biochar and had made statements about biochar in one way or another. These individuals and organisations were considered experts in biochar. The knowledge

Table 1
Types and the number of experts with an interest or potential interest in biochar.

Type	Number of Experts with an Actual Interest in Biochar	Number of Experts with a Potential Interest in Biochar
Farmer Focused		
Science / R & D	3	0
Representation / Advocacy	4	0
Provision of Goods and Services	0	2
Environmental		
Advocacy	1	1
Government (National and Local)		
National Government	4	0
Local Authorities	2	0
Biochar Producers		
Commercial	4	0
Farmer led	3	0
Community	1	0
Pyrolysis Machine Manufacturer	1	0
Forest Focused		
Tree and Woodland Management	2	0
Biochar Industry Representatives		
Representation / Advocacy	3	0
Carbon Trading		
Carbon Trading Companies	2	0
TOTAL	30	3

base was diverse, and as Table 1 illustrates, expertise was drawn from various sectors. Experts include those from organisations undertaking research and development within the agricultural sector, farming industry representatives, environmental advocacy groups, UK government departments and local authorities, biochar producers (commercial, farmer-led, and community based) and a biochar pyrolysis machine manufacturer, forestry organisations, biochar industry representatives, and carbon trading companies (with knowledge of biochar carbon trading).

The research was also interested in engaging with individuals and organisations who did not currently have a specific interest in biochar, but who may have a potential interest in the future (e.g. owners of potential biochar 'storage' sites). Experts were also included who may not have specific knowledge of biochar but do have knowledge from an allied area, e.g. those with knowledge and expertise of other land based GGR approaches such as increasing soil carbon. Experts include organisations providing goods and services to the agricultural sector in relation to soil carbon, and environmental advocacy groups. Effort was made to ensure that all sectors with a knowledge of biochar were included to ensure a full range of opinions and understandings were considered.

4.2.1. Data collection and selection

Individuals and organisations were identified in a number of ways, and these are outlined below.

1. A Google search was conducted on 29 September 2021. The search terms used were: biochar and UK agriculture; and biochar and UK. As the project is specifically focusing on carbon sequestration in a UK context, the UK was used as a search term to ensure we initially identified UK based individuals and organisations.
2. Twitter announcements of the publication of reports relating to net zero or climate change. These reports were checked to ensure biochar was included.
3. Reports relating to net zero or climate change obtained from a website or identified through Twitter. These reports were checked to ensure biochar was included.
4. Review of the social science literature around biochar.
5. Individuals and organisations who directly contacted the project following national and local media coverage.
6. Individuals and organisations who were suggested to us by other experts (snowballing).

In total, we identified 94 individuals and organisations with an interest or potential interest in biochar, and of these 33 agreed to take part in a semi-structured interview. A semi-structured approach was used as this enabled specific points around biochar to be addressed whilst also ensuring flexibility to meet the needs of the expert (Clark et al., 2021).

The majority of experts were UK based, although we also included 7 international experts who were willing to take part. Due to the links with the UK, these international experts could still play a role in the UK biochar landscape. Interviews were conducted online via Teams and lasted for up to one and half hours.

The interviews were conducted to gain an understanding of the claims and arguments being made about biochar, specifically asking experts about their knowledge of biochar; the potential uses of biochar; their views on the benefits and risks of biochar; the opportunities and risks associated with biochar feedstocks; and their views on the incentivisation and regulation of biochar. These wider questions do not form part of the analysis here but are noted to provide context to our study. The question we asked our experts which is relevant here is: Do you think biochar can play a role in carbon trading? In responding to this question, experts reflected on the possibility of biochar carbon markets and biochar carbon trading contributing to mitigation deterrence. We did not specifically ask experts about the possibility of biochar carbon markets or biochar carbon trading being a form of mitigation deterrence. However, our broad range of interviewees answered in ways which speak to the claims of the mitigation deterrence literature (see also Brad and Schneider, 2023).

To supplement our expert interviews, we also conducted a document analysis. Once experts were identified, individual websites were checked for any documents or reports relating to biochar that had been released by the individual or organisation. Individual websites were searched using the term biochar. Any document or report mentioning biochar in relation to the UK was included. Any documents relating to net zero produced by key agricultural stakeholders such as the NFU were also included. This was to ensure we picked up the key arguments surrounding other potential land-based approaches to reducing carbon emissions which are recommended to biochar stakeholders. Our study is interested in the application of biochar to agricultural land, however, there are a number of other allied land-based GGR approaches which can be used in agricultural settings. These include afforestation, peatland restoration, enhanced rock weathering, and increasing soil carbon. In total, 36 items were identified (see Appendix 1).

4.2.2. Data analysis

To examine the interview data and documents in detail, a thematic analysis was employed drawing on conceptual concerns of the social studies of finance. While there are many types of thematic analysis (Clark et al., 2021; Ryan and Bernard, 2003), the approach used in this study is the six-stage process developed by Braun and Clarke (2006).

The biochar carbon markets theme was a key starting point for the analysis presented here. Within this biochar carbon markets theme, the two sub-themes of techno-optimism towards biochar carbon markets; and monitoring, reporting and verification and credibility uncertainties were identified. This analysis is outlined in the next section.

A point to note: data from the interviews is presented here as anonymous with a generic respondent number (e.g. R6 for respondent 6), although the type of expert they are (e.g. Government Department) is indicated. The biochar industry in the UK is small and emerging so experts were guaranteed anonymity.

5. Biochar carbon markets: enablers and constraints

Our analysis of the data from the expert interviews and the document analysis reveals enablers and constraints around biochar carbon market making. It is organised under two themes: the presentation of fictional expectations about biochar carbon markets and expressions of techno-optimism about its feasibility; and the scepticism based on the lack of monitoring, reporting and verification (MRV) for the carbon sequestration properties of biochar. Without MRV, the amount of carbon sequestered by GGR technologies such as biochar cannot be verified. This is crucial if biochar carbon markets are to be credible.

5.1. Techno-optimism towards biochar carbon markets

A small portion of the data did reflect optimism towards the prospect of biochar carbon markets. One Biochar Industry Representative reiterated the transformational potential that carbon trading could have for the price of biochar:

> "What has changed and what is new since the IPCC report are the carbon markets. So now you can get €120.00 per ton of carbon dioxide equivalent, which means the producer may ultimately get something in the order of €90 to €100. … That lowers the cost to the consumer and increases the volume. … The other thing is that we now have a dozen or more companies in North America that will lend money based on future carbon credits" (R26).

According to this causal narrative, biochar carbon trading would offset biochar production costs, thereby lowering the cost of biochar for consumers. This ties in with the idea of mitigation foregone as biochar may appear cheaper than actions required to reduce emissions.

Therefore, mitigation becomes vulnerable to deterrence.

Industry proponents of biochar also appealed to robust accountancy methods being developed by private companies that would allow carbon to be mapped and measured in a precise manner. They argued that the company, Carbon Future, has "implemented the methodology that you can really track and trace all the carbon and where it comes from. It includes the LCA that you can see really how much carbon is actually stored" (R21). These findings resonate with observations in SSF scholarship about the way that market life involves operationalizing and manipulating an uncertain future. For example, influential work from Beckert (2016: 8) argues that capitalist economies are underpinned by 'fictional expectations' through which narratives and images about future states of the world trace out causal relations and provide a sense of how present actions might or will influence outcomes. Such future oriented accounts need to be viewed as plausible or credible by their intended audience. When applied to the notion of the management of inflationary expectations, central bank speeches and publications are thought to coordinate the expectations of the public around the future rate of expectations and the actions central banks will take to achieve their target rate of inflation (Wansleben, 2018). Such fictional expectations need to be rendered credible. The credibility of such central bank pronouncements derives from perceptions of a central bank's willingness and ability to take actions to deliver a set level of inflation (Hall, 2008). This is often a result of past historical performance, the perceived effectiveness of policy tools and plausibility of the causal story being forwarded by the central bank (Morris and Collins, 2023). In the case of biochar carbon markets, fictional expectations refer to the causal account of how a developed market for carbon will garner investment and lending to produce biochar at a viable cost, and in doing so support the upscaling of biochar production. Like any future oriented account of the economy, they need to be viewed as credible by the audience and this credibility is by no means inevitable.

Alongside such appeals to technical innovation in climate finance and accountancy, a notable feature of this techno-optimism is the attempt to imbue these fictional expectations with credibility through appeals to the materiality of biochar. This invocation of a currently unrealised future by a biochar industry representative and a commercial biochar producer was in terms of biochar's durability and materiality. In doing so, these respondents claimed that biochar was one of the only durable forms of carbon storage that could be effectively traded on carbon markets. A Biochar Industry Representative contrasted the potential for biochar to provide "100–1000 year durability…in the right situation" (R20) with less durable 'tree planting.'.

Moreover, the materiality of biochar was also touted by a commercially facing biochar producer as an alternative to more speculative sources of carbon credits:

> "I think biochar is the most secure and durable form of carbon storage because you can literally pick it up and hold it. It's not like buying carbon credit of a tree that may or may not have been planted 10 times and then cut down a year later. There's a risk in the fraudulent kind of trading of carbon credits and I think biochar can mitigate that risk and provide a more verifiable solution. It's immediate, which is pretty impressive. When you plant a tree, you've got a carbon debt of about roughly on average 80 years until that tree reaches maturity. I can produce a ton of biochar today and you can hold that carbon and it is there and we're all very happy and we know it exists. So, I think it will provide the foundations for a movement towards carbon trading which is far more secure and trusted" (R17).

In such a way, the materiality and temporal immediacy of biochar provides an anchor for expectations around carbon credits. These properties of biochar are deployed to reduce uncertainty about longer term carbon credits connected to the planting of trees as carbon sinks, which may or may not actually come to fruition.

The coalescence of fictional expectations and imagined offsets can be seen when McLaren's (2020) typology is considered alongside the dynamics revealed by applying the SSF lens to the data. Mitigation deterrence as mitigation foregone is likely to occur because although the UK biochar carbon market is not functioning and remains speculative, it is underpinned by the idea that offsets will occur by imagined future removals following biochar application. The imagined offsets from GGR technologies such as biochar may exceed potential deployment rates or be limited by resources. This results in a failure to reduce emissions because fossil fuels continue to be used as it is assumed that offsets will occur elsewhere. Just by considering an alternative such as biochar application with its associated imagined offsets leads to reduced attempts to decrease emissions (McLaren, 2020).

5.2. *Monitoring, reporting and verification (MRV) and credibility uncertainties*

Optimism around the deliverability of biochar carbon markets and the associated imagined offsets were outliers within our wider data set. Various experts described uncertainties around the very practices needed to propagate and sustain coordinated market activities, particularly around monitoring, reporting, and verification (MRV). In such a way, these uncertainties cause these actors to doubt that carbon markets, and biochar as a mitigation technology, will work (Joly and Le Renard, 2021).

Insights from existing work in SSF indicates that technical devices and market making practices are needed to construct markets and coordinate market activities. SSF scholarship tells us that standardization is needed for most markets, because it allows different entities to be organized according to pre-identified characteristics (Preda, 2006). Before emissions credits can be allocated to market participants and rendered transferable and tradable, they must first be 'defined legally and technically' (MacKenzie, 2009: 443). This involves socio-technical processes of standardization, which allows entities to be organized, and classification so that commodities with observed similarities can be meaningfully compared (Callon et al., 2002).

At present, there are considerable uncertainties around the ability to develop such standards for biochar. For example, the Committee on Climate Change (2020), the UK Government's statutory advisor on climate policy, did not recommend soil carbon sequestration in its *Land Use: Policies for a Net Zero UK* report, nor did they recommend biochar as this was considered speculative. If biochar is not actually adding additional carbon to the soil, then carbon emissions are not being offset. As a Farmer Focused - Representation/Advocacy expert confessed:

> "I think carbon trading is in its infancy at the moment. I'm not sure that we entirely understand how much carbon we are actually removing from the atmosphere and that's hopefully the end game, but…whether that is actually the case at the moment I don't know and I don't think anybody really knows" (R3).

In such a way, the credibility of carbon markets for biochar hinges on the ability to verify that biochar does actually store carbon (Buck, 2019). This is a crucial issue for the making of carbon markets, because it allows credits to be derived from quantifiable emissions reductions, as well as allowing the carbon market industry to compare biochar sinks with other sources of emissions reduction (Callon et al., 2002: 201).

Once applied to agricultural land, the stability of biochar determines how long biochar carbon will remain sequestered in the soil. For biochar carbon trading, evidence is required that increases to soil carbon have been sustained over the finance period and will continue to remain in place. This evidence is captured by monitoring, reporting, and verification (MRV) (Price et al., 2023). There are no universal standards for MRV (Price et al., 2023), although the Core Carbon Principles (CCPs) developed by the Integrity Council for the Voluntary Carbon Market (ICVCM) can be used to determine the credibility and dependability of MRV approaches (ICVCM, 2023).

The importance of verification for the credibility of carbon markets

relating to biochar was emphasized by a Government Department expert, when they discussed prospects for monitoring, reporting and verification of soil carbon sequestration:

> "A lot of investors talk about it [biochar carbon trading] already … So, I think it's got huge interest already. It doesn't have a carbon code, so the MRV would be a barrier for that. But once that's established, it's almost worrying how quickly it could take off" (R24).

This expert thus underlined the importance of fictional expectations around the impact of a carbon code and the potential impact of such a code to lend credibility to these unrealized markets and catalyze investment. However, this expert simultaneously voiced concerns about the present lack of MRV for biochar.

In any carbon trading scheme, carbon sequestration must occur which would otherwise not have happened without the incentive of carbon credits (O'Toole et al., 2016). The application of biochar to land would be an *additional* effort to sequester carbon. The stability of biochar carbon ensures that carbon remains in soil for vastly longer periods of time than is otherwise possible with carbon derived from the addition of straw or compost to soil (O'Toole et al., 2016). However, the permanence of biochar also has to be measured by collecting soil samples throughout the duration of the biochar carbon trading contract (Black et al., 2022). This can only occur if there is credible MRV.

The uncertainties around MRV were also present in a response from a Farmer Focused – Science/R&D expert:

> "And then we get to that verification question. What was it before you did it? What was it afterwards? What have you been paid to do? What you get paid to do becomes a really important question in terms of this carbon trading. … I'm concerned about the long-term damage that could be done by this carbon trading on farms who commit to it and then can't prove it. And so would using an input like biochar falsify those figures slightly?" (R4).

Whether through traditional soil core sampling, or by remote sensing technologies, soil sampling must take place before any participation in biochar carbon trading begins. This is a requirement because initial soil carbon levels provide the baseline for the assessment and value of any changes (Black et al., 2022; Price et al., 2023). It has to be proven that management changes to land *increases* levels of carbon in soil (Black et al., 2022). This underlines the importance of MRV for biochar carbon markets.

The questions raised by these experts demonstrate the uncertainties around biochar carbon markets, biochar carbon trading and MRV. There is often a discursive struggle around carbon trading because proponents mobilise knowledge claims which suggest carbon credits are scientifically valid and legitimate (Watt, 2021). This is achieved through the accumulation of scientific and technical knowledge used to justify the use of greenhouse gas removal technologies (including biochar), and this knowledge is in turn, used to justify carbon trading (Lohmann, 2009). Many of the socio-technical anxieties relating to the fictional expectations of biochar carbon markets borne out in these interview materials indicates that the credibility needed for carbon sequestration to work is currently lacking due to the ambiguities around MRV.

Quantifying carbon removal following biochar application to agricultural land is beset with uncertainty. The amount of carbon sequestration that occurs in practice may be considerably less than that which is imagined and is a further example of mitigation foregone. The lack of credible MRV means that any additional carbon associated with biochar application cannot be effectively measured and is currently assumed. There is the potential for less urgency around reducing present and future emissions because of the assumption that biochar carbon markets will be able to be used for offsetting.

6. Conclusion and recommendations

This article has aimed to add to the emerging empirical mitigation deterrence literature by drawing on ongoing research into a particular form of greenhouse gas removal technology – biochar – and associated biochar carbon markets. The article has explored whether the UK carbon market for biochar, *in practice* is likely to contribute to delays in emissions reduction. We have investigated whether UK biochar carbon markets are (likely to be) as much of a problem for mitigation deterrence as imagined or envisaged within the mitigation deterrence literature.

Conceptual approaches from SSF have illustrated how 'promoters' of biochar carbon markets attempt to legitimize them by framing them as a feasible solution to a hugely significant societal problem (Joly and Le Renard, 2021: 900). However, at present, the market for biochar carbon credits is in a nascent form. For carbon markets, the trading platform or exchange must certify or verify a carbon sink so that credits can be derived from this. To date, only a small number of exchanges have verified carbon credits linked to biochar. The acceptance of biochar as a techno-scientific promise thus hinges on experts and stakeholders viewing biochar as a credible technology that 'will work' (Joly and Le Renard, 2021: 906).

As we have shown, biochar carbon markets are currently resisted by the majority of experts. This is due to them being a potential form of mitigation deterrence, a finding that supports the idea that GGR technologies such as biochar may contribute to mitigation deterrence (Carton, 2019; Carton et al., 2023; Markusson et al., 2018). While the mitigation deterrence literature views the socio-technical devices of carbon markets, and associated narratives around these solutions as a way of maintaining intensive carbon emissions through offsetting mechanisms, our results show how and why fictional expectations around future biochar carbon markets currently lack credibility. Although some proponents of the mass production of biochar were optimistic about the scalability of biochar, many more of our experts doubted the credibility of this vision. Techno-optimism about the future widespread production of biochar was based on fictional expectations about a future in which the trading of carbon credits in carbon markets will lower the cost of producing biochar on a large scale. Such proponents of biochar appealed to the durability and tangibility of biochar as a way of rendering this causal story about the future credible. However, a greater number of experts tempered the optimism by expressing doubts about the socio-technical practices needed to construct a functioning biochar carbon market. Experts acknowledged that currently the amount of carbon biochar is sequestering is unable to be verified.

Mitigation foregone (McLaren, 2020) was evident throughout the analysis. This was due to the imagined viability of biochar carbon markets offsetting emissions whilst there was continued fossil fuel use. In addition, the lack of credible MRV meant that any additional carbon associated with biochar application could not be effectively measured and was currently assumed. The SSF concepts revealed the fictional expectations evident in the data around biochar carbon markets, whilst the mitigation deterrence literature helped explain how these fictional expectations can lead to mitigation foregone due to imagined offsets.

Given that the current UK Government is committed to private investment in nature markets alongside public funding (UK Government, 2023), biochar carbon markets may become legitimate in the UK. The UK Government (2023) is considering how carbon can be measured on agricultural land and are likely to be supporting farmers to undertake carbon audits by 2024. However, they acknowledge that 'there is currently no pathway for successful methodologies to be recognised as sufficiently robust to underpin high integrity nature markets' (UK Government, 2023: 23) To counter this, the British Standards Institution (BSI) is engaging with market players and other stakeholders to identify and develop standards for market needs, a task that is to continue until 2026 (UK Government, 2023). It appears that systems are being put in place by the UK Government to enable nature markets such as biochar carbon trading to occur. Ultimately, how successful biochar carbon

markets are in the UK will depend in large part, on the UK Government. It is possible that biochar delivers large amounts of verified GGR whilst becoming a type one mitigation deterrence (substitution) according to McLaren's (2020) typology. Further research will be needed in the future to ascertain how these developments impact biochar carbon markets, biochar carbon trading and mitigation deterrence.

Carbon trading appears to be playing a role in various forms of climate policy, a further example being the European Union's Carbon Removal Certification Framework (Brad and Schneider, 2023). Therefore, further research could compare and contrast the climate policies of different countries to establish if these policies are contributing to mitigation deterrence.

Our findings have two wider implications for the mitigation deterrence literature. Firstly, they suggest that land-based carbon sinks may be particularly harmful forms of mitigation deterrence, precisely because they allow promoters of new forms of carbon capture to anchor their future oriented narratives in material and already existing entities, which gives them greater temporal proximity and therefore credibility claims.

Secondly, these findings establish the value of rigorous qualitative research for the interrogation of claims made about GGR technologies such as biochar. By combining concepts from SSF and mitigation deterrence to qualitative empirical data, this article has scrutinized the plausibility of claims being made about fictional expectations using various forms of expert testimony. This qualitative data suggests that whilst the construction and sustainable functioning of a UK-based biochar carbon market remains a speculative, rather than credible proposition, it is a threat of mitigation deterrence because of the assumption that a UK biochar carbon market will become a reality. There is the promise of future removals even though these are currently only imagined.

These empirical results may also help address an issue raised by Carton et al. (2023). In their review of the literature on the moral hazard and mitigation deterrence of GGR technologies, they noted there was a divergence in how individuals do or do not support the moral hazard/mitigation deterrence hypothesis. They suggested this could be because individuals underreport it when asked by researchers. We did not specifically ask our interviewees if biochar carbon trading could be a form of mitigation deterrence. Nevertheless, the analysis shows that our broad range of interviewees answered in ways which speak to the claims of the mitigation deterrence literature. The imagined offsets promised by GGR technologies could lead to a failure to reduce emissions. As mitigation deterrence can be ambiguous as a concept (Carton et al., 2023), a simple, but potentially more powerful term to use would be *failure to reduce emissions*.

Our findings also lead us to make a recommendation to UK policymakers. Currently, the UK biochar carbon market is a speculative rather than a credible proposition. However, it is possible that in the future, biochar can deliver large amounts of verified GGR which can be subsequently traded on biochar carbon markets. At the same time, biochar carbon trading could contribute to a reduction in the urgency of wider mitigation actions. Policymakers need to address the robustness of MRV for biochar, and additionally, the ways in which biochar markets interact with wider climate mitigation activities and agendas at the national level, in specific sectors of the economy, and in the net zero strategies of specific private organisations. The very real threat of mitigation deterrence from biochar carbon markets makes this imperative for policymakers to address.

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CRediT authorship contribution statement

John Morris: Conceptualization, Writing – original draft, Writing – review & editing. **Catherine Price:** Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Data curation. **Carol Morris:** Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix 1

Table A1
The 36 items identified in the document analysis: the stakeholder, document details, the document link, and where the documents were obtained from are all shown.

Name of stakeholder	Document and date published	Document link	Document Obtained From
Innovative Farmers	Field lab: BioRich (February 2020)	https://innovativefarmers.org/media/dvdhpub1/biochar-if-final-report-biorich-february-2020-pdf-1.pdf	Website
CIEL	Net Zero Carbon and UK Livestock (October 2020)	https://cielivestock.co.uk/expertise/net-zero-carbon-uk-livestock/report-october-2020/	Website
Innovation for Agriculture	Reducing Greenhouse Gas Emissions at Farm Level (January 2022)	https://vm-01-crm02.altido.com/clients/innovationforagriculture-d3eb0808ff1c2b63/uploads/documents/website-resource/the-go-to-guide-for-reducing-on-farm-ghg-emissions-resource-145.pdf	Website
NFU	Achieving Net Zero: Farming's 2040 Goal (September 2019)	https://www.nfuonline.com/archive?treeid=138313	Website
NFU	Our Journey to Net Zero: Farming's 2040 Goal (October 2021)	https://www.nfuonline.com/archive?treeid=152885	Twitter

(*continued on next page*)

Table A1 (*continued*)

Name of stakeholder	Document and date published	Document link	Document Obtained From
NFU	Net Zero Carbon and Agriculture: A Guide for Local Authorities (February 2021)	https://www.nfuonline.com/archive?treeid=149034	Website
AHDB	A high-level scoping review. Farming, greenhouse gas emissions and carbon storage: cereals and oilseeds (November 2020).	https://projectblue.blob.core.windows.net/media/Default/Research%20Papers/Cereals%20and%20Oilseed/2020/RR94%20-%20final%20report.pdf	Website
Nature Friendly Farming Network	Rethink Farming: A Practical Guide for Farming, Nature and Climate (October 2021)	https://www.nffn.org.uk/assets/farm_practices_reports/nffn-rethink-farming-report_digital-final-release-2.pdf	Twitter
Nature Friendly Farming Network	Net Zero Carbon in the UK Farming Sector: A Practical Guide (October 2019).	https://www.nffn.org.uk/net-zero-a-practical-guide/	Website
Biofuelwatch	What we have learned about biochar since Biofuelwatch 2011 report was published (January 2020).	https://www.biofuelwatch.org.uk/wp-content/uploads/biochar-briefing-2020.pdf	Website
Biofuelwatch	Biochar: A cause for concern? (23 Joly 2013)	https://www.biofuelwatch.org.uk/2013/biochar-ecologist-article-2013/	Website
Biofuelwatch	Biochar: Black Gold or Just Another Snake Oil Scheme (18 September 2013)	https://www.biofuelwatch.org.uk/2013/biochar-earthislandjournal-article/	Website
Biofuelwatch	Biochar: A Critical Review of Science and Policy (November 2011)	http://www.biofuelwatch.org.uk/files/Biochar-Report3.pdf	Website
Green Alliance	Cutting the Climate Impact of Land Use (April 2019)	https://green-alliance.org.uk/resources/Cutting_climate_impact_of_land_use.pdf	Website
Green Alliance	The opportunities of agri-carbon markets: policy and practice (January 2022)	https://green-alliance.org.uk/resources/The_opportunities_of_agri-carbon_markets.pdf	Website
WWF	Keeping it cool: How the UK can end its contribution to climate change (November 2018)	https://www.wwf.org.uk/sites/default/files/2018–11/NetZeroReportART.pdf	Website
Farming Connect	Biochar for climate change: Is it a viable strategy? (27 August 2020)	https://businesswales.gov.wales/farmingconnect/news-and-events/technical-articles/biochar-climate-change-it-viable-strategy	Website
Committee on Climate Change	Land use: Policies for a net zero UK (January 2020)	https://www.theccc.org.uk/publication/land-use-policies-for-a-net-zero-uk/	Website
Houses of Parliament Parliamentary Office of Science and Technology	Biochar POSTNote (Joly 2010)	https://researchbriefings.files.parliament.uk/documents/POST-PN-358/POST-PN-358.pdf	Website
The James Hutton Institute	Climate-positive farming reviews: A review of pyrolysis and biochar as climate-positive biomass technologies for the Scottish Uplands (December 2020)	https://www.hutton.ac.uk/sites/default/files/files/publications/ClimPosReview-Biochar-Msika2020.pdf	Website
UCL	Towards Net Zero in UK Agriculture (April 2021)	https://www.sustainablefinance.hsbc.com/carbon-transition/towards-net-zero-in-uk-agriculture	Website
The Royal Society	Geoengineering the climate: Science, governance and uncertainty (September 2009)	https://royalsociety.org/topics-policy/publications/2009/geoengineering-climate/	Website
The Royal Society	Greenhouse gas removal (September 2018)	https://royalsociety.org/topics-policy/projects/greenhouse-gas-removal/	Website
UK Biochar Research Centre	An assessment of the benefits and issues associated with the application of biochar to soil (February 2011)	https://www.research.ed.ac.uk/en/publications/an-assessment-of-the-benefits-and-issues-associated-with-the-appl	Website
UK Biochar Research Centre	Biochar in growing media: A sustainability and feasibility assessment (May 2013)	https://www.biochar.ac.uk/abstract.php?id=68	Website
British Society of Soil Science	Science Note: Soil Carbon (October 2021)	https://soils.org.uk/wp-content/uploads/2021/11/Long_BSSS_Science-Note_FOR-DIGITAL.pdf	Twitter
IPCC	Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (2019)	https://www.ipcc.ch/srccl/	Website
European Academies Science Advisory Council	Negative emission technologies: What role in meeting Paris Agreement targets? (February 2018)	https://easac.eu/fileadmin/PDF_s/reports_statements/Negative_Carbon/EASAC_Report_on_Negative_Emission_Technologies.pdf	Website
Royal Horticultural Society (RHS)	Biochar (2021)	https://www.rhs.org.uk/soil-composts-mulches/biochar	Website
SoilFixer	SoilFixer website (accessed January 2022)	https://www.soilfixer.co.uk/	Website
Carbon Gold	Carbon Gold website (accessed January 2022)	https://www.carbongold.com/	Website
TerrAffix	TerrAffix website (accessed January 2022)	https://terraffix.co.uk/	Website
Welsh Biochar Project	Welsh Biochar Report (December 2017)	https://businesswales.gov.wales/walesruralnetwork/sites/walesruralnetwork/files/documents/Welsh_Biochar_Report%20%282%29.pdf	Website
Biochar Wales	Biochar Wales (January 2022)	https://www.biochar.wales/	Website
The Future Forest Company	The Future Forest Company (Website biochar section - January 2022)	https://thefutureforestcompany.com/biochar/	Website
Bartlett Tree Experts	Biochar Soil Amendment: Frequently Asked Questions (Accessed January 2022)	https://www.bartlett.com/resources/biocharfaqs.pdf	Website

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References

Anderson, K., Peters, G., 2016. The trouble with negative emissions. Science vol. 354 (6309), 182–183. https://doi.org/10.1126/science.aah4567.

Asayama, S., Hulme, M., 2019. Engineering climate debt: temperature overshoot and peak-shaving as risky subprime mortgage lending. Clim. Policy vol. *19* (8), 937–946. https://doi.org/10.1080/14693062.2019.1623165.

Beckert, J., 2016. Imagined Futures: Fictional Expectations and Capitalist Dynamics. Harvard University Press.

BEIS (2021) *Greenhouse gas removal methods and their potential UK deployment* [Online]. Available at ⟨https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1026988/ggr-methods-potential-deployment.pdf⟩ (Accessed 10 August 2023).

Bellamy, R., Osaka, S., 2020. Unnatural climate solutions? Nat. Clim. Change vol. 10 (2), 98–99. https://doi.org/10.1038/s41558-019-0661-z.

Bellamy, R., Fridahl, M., Lezaun, J., Palmer, J., Rodriguez, E., Lefvert, A., Hansson, A., Grönkvist, S., Haikola, S., 2021. Incentivising bioenergy with carbon capture and storage (BECCS) responsibly: comparing stakeholder policy preferences in the United Kingdom and Sweden. Environ. Sci. Policy vol. 116, 47–55. https://doi.org/10.1016/j.envsci.2020.09.022.

Berndt, C., Boeckler, M., 2009. Geographies of circulation and exchange: constructions of markets. Prog. Hum. Geogr. vol. *33* (2), 535–551. https://doi.org/10.1177/0309132509104805.

Black, H.I.J., Reed, M.S., Kendall, H., Parkhurst, R., Cannon, N., Chapman, P.J., Orman, M., Phelps, J., Rudman, H., Whalley, S., Yeluripati, J., Ziv, G., 2022. What makes an operational farm soil carbon code? Insights from a global comparison of existing soil carbon codes using a structured analytical framework. Carbon Manag. vol. 13 (1), 554–580. https://doi.org/10.1080/17583004.2022.2135459.

Brad, A., Schneider, E., 2023. Carbon dioxide removal and mitigation deterrence in EU climate policy: towards a research approach. Environ. Sci. Policy vol. 150, 1–9. https://doi.org/10.1016/j.envsci.2023.103591.

Braun, V., Clarke, V., 2006. 'Using thematic analysis in psychology'. Qual. Res. Psychol. vol. 3 (2), 77–101. https://doi.org/10.1057/978-1-137-35913-1.

Bruun, E., Cross, A., Hammond, J., Nelissen, V., Rasse, D., Hauggaard-Nielsen, H., 2016. 'Biochar carbon stability and effect of greenhouse gas emissions'. In: Shackley, S., Ruysschaert, G., Zwart, K., Glaser, B. (Eds.), Biochar in European Soils and Agriculture: Science and Practice. Routledge, Abingdon, pp. 165–183.

Bryant, G., 2019. Carbon markets in a climate-changing capitalism. Cambridge University Press.

Buck, H.J., 2019. After geoengineering: climate tragedy. Repair, and Restoration. Verso, London.

Buck, H.J., 2021. Ending Fossil Fuels: Why Net Zero is not Enough. Verso, London.

Callon, M., 2007. What does it mean to say that economics is performative? Do Econ. Make Mark. ? performativity Econ. 311–357.

Callon, M., Muniesa, F., 2005. Peripheral vision: Economic markets as calculative collective devices. Organ. Stud. Vol *26* (*no.* (8)), 1229–1250. https://doi.org/10.1177/0170840605056393.

Callon, M., Méadel, C., Rabeharisoa, V., 2002. The economy of qualities. Econ. Soc. vol. 31 (2), 194–217. https://doi.org/10.1080/03085140220123126.

Carbon Gold (2023) *How to use biochar* [Online]. Available at ⟨https://www.carbongold.com/how-to-use-biochar/⟩ (Accessed 4 January 2023).

Carton, W., 2019. Fixing" climate change by mortgaging the future: negative emissions, spatiotemporal fixes, and the political economy of delay. Antipode vol. 51 (3), 750–769. https://doi.org/10.1111/anti.12532.

Carton, W., 2020. Rendering local: the politics of differential knowledge in carbon offset governance. Ann. Am. Assoc. Geogr. vol. 110 (5), 1353–1368. https://doi.org/10.1080/24694452.2019.1707642.

Carton, W., Hougaard, I.-M., Markusson, N., Lund, J.F., 2023. Is carbon removal delaying emission reductions? WIREs Clim. Change 1–18. https://doi.org/10.1002/wcc.826.

Carton, W., Asiyanbi, A., Beck, S., Buck, H.J., Lund, J.F., 2020. Negative emissions and the long history of carbon removal. WIREs Clim. Change vol. 11 (6), 1–25. https://doi.org/10.1002/wcc.671.

Clare, A., Barnes, A., McDonagh, J., Shackley, S., 2014. From rhetoric to reality: farmer perspectives on the economic potential of biochar in China. Int. J. Agric. Sustain. vol. 12 (4), 440–458. https://doi.org/10.1080/14735903.2014.927711.

Clark, T., Foster, L., Sloan, L., Bryman, A., 2021. Bryman's Social Research Methods, Sixth edn. Oxford, Oxford University Press.

Committee on Climate Change (2020) *Land Use: Policies for a Net Zero UK* [Online]. Available at ⟨https://www.theccc.org.uk/publication/land-use-policies-for-a-net-zero-uk/⟩(Accessed⟩ 10 August 2023).

de Goede, M. (2005). Resocialising and repoliticising financial markets: contours of social studies of finance. *Economic sociology: European electronic newsletter*, *6*(3), 19-28. Available at: ⟨https://www.econstor.eu/bitstream/10419/155851/1/vol06-no03-a4.pdf⟩ (Accessed 12 March 2023).

Hall, R.B., 2008. Central Banking as Global Governance: Constructing Financial Credibility (No. 109. Cambridge University Press.

Hansson, A., Haikola, S., Fridahl, M., Yanda, P., Mabhuye, E., Pauline, N., 2021. Biochar as multi-purpose sustainable technology: experiences from projects in Tanzania. Environ., Dev. Sustain. vol. 23, 5182–5214. https://doi.org/10.1007/s10668-020-00809-8.

Hardie, I., MacKenzie, D., 2007. Assembling an economic actor: the agencement of a Hedge Fund. Sociol. Rev. Vol. *55* (1), 57–80. https://doi.org/10.1111/j.1467-954X.2007.00682.x.

ICVCM (2023) *The Core Carbon Principles Assessment Framework* [Online]. Available at ⟨https://icvcm.org/assessment-framework/⟩ (Accessed 9 August 2023).

International Biochar Initiative (2023) *FAQs* [Online]. Available at ⟨https://biochar-international.org/faqs/⟩ (Accessed 14 January 2023).

IPCC (2022) *Climate Change 2022: Mitigation of Climate Change* [Online]. Available at: ⟨https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_FullReport.pdf⟩ (Accessed 4 January 2023).

Joly, P.B., Le Renard, C., 2021. The past futures of techno-scientific promises. Sci. Public Policy Vol. *48* (No. (6)), 900–910. https://doi.org/10.1093/scipol/scab054.

Lamb, W.F., Mattioli, G., Levi, S., Timmons Roberts, J., Capstick, S., Creutzig, F., Minx, J. C., Müller-Hansen, F., Culhane, T., Steinberger, J.K., 2020. Discourses of climate delay. Glob. Sustain. vol. 3, 1–5. https://doi.org/10.1017/sus.2020.13.

Langley, P., 2010. Review essay: on the materiality of markets. J. Cult. Econ. Vol. *3* (3), 395–402. https://doi.org/10.1080/17530350.2010.506327.

Lohmann, L., 2008. Carbon trading, Climate justice and the production of ignorance: ten examples. Development vol. 51, 359–365. https://doi.org/10.1057/dev.2008.27.

Lohmann, L., 2009. Climate as Investment. Dev. Change vol. 40 (6), 1063–1083. https://doi.org/10.1111/j.1467-7660.2009.01612.x.

Lopez-Capel, E., Zwart, K., Shackley, S., Postma, R., Stenstrom, J., Rasse, D., Budai, A., Glaser, B., 2016. 'Biochar properties'. In: Shackley, S., Ruysschaert, G., Zwart, K., Glaser, B. (Eds.), Biochar in European Soils and Agriculture: Science and Practice. Routledge, Abingdon, pp. 41–72.

Luckhurst, K. (2022). *Biochar: the 'black gold' for soils that is getting big bets on offset markets* [Online]. Available at ⟨https://www.reutersevents.com/sustainability/biochar-black-gold-soils-getting-big-bets-offset-markets⟩ (Accessed 30 January 2022).

Lyons, K., Westoby, P., 2014. Carbon markets and the new "Carbon Violence": a Ugandan study. Int. J. Afr. Renaiss. Stud. - Multi- Inter- Transdiscipl. vol. 9 (2), 77–94. https://doi.org/10.1080/18186874.2014.987956.

MacKenzie, D., 2009. Making things the same: gases, emission rights and the politics of carbon markets. Account., Organ. Soc. Vol. *34* (nos.3-4), 440–455. https://doi.org/10.1016/j.aos.2008.02.004.

MacKenzie, D., Beunza, D., Millo, Y., Pardo-Guerra, J.P., 2012. Drilling through the Allegheny Mountains: liquidity, materiality and high-frequency trading. J. Cult. Econ. Vol *5* (3), 279–296. https://doi.org/10.1080/17530350.2012.674963.

Malm, A., 2018. The Progress of This Storm: Nature and Society in a Warming World. Verso, London.

Markusson, N., McLaren, D., Tyfield, D., 2018. Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs). Glob. Sustain. vol. 1, 1–9. https://doi.org/10.1017/sus.2018.10.

Markusson, N., McLaren, D., Szerszynski, B., Tyfield, D., Willis, R., 2022. Life in the hole: practices and emotions in the cultural political economy of mitigation deterrence. Eur. J. Futures Res. vol. 10 (2), 1–14. https://doi.org/10.1186/s40309-021-00186-z.

Markusson, N., Balta-Ozkan, N., Chilvers, J., Healey, P., Reiner, D., McLaren, D., 2020. Social science sequestered. Front. Clim. vol. 2, 1–6. https://doi.org/10.3389/fclim.2020.00002.

McLaren, D., 2020. Quantifying the potential scale of mitigation deterrence from greenhouse gas removal techniques. Clim. Change vol. 162, 2411–2428. https://doi.org/10.1007/s10584-020-02732-3.

McLaren, D., Willis, R., Szerszynski, B., Tyfield, D., Markusson, N., 2021. Attractions of delay: using deliberative engagement to investigate the political and strategic impacts of greenhouse gas removal technologies. Environ. Plan. E Nat. Space 1–22. https://doi.org/10.1177/25148486211066238.

McLaren, D.P., Tyfield, D.P., Willis, R., Szerszynski, B., Markusson, N.O., 2019. Beyond "Net-Zero": a case for separate targets for emissions reduction and negative emissions. Front. Clim. vol. 1 (August), 1–5. https://doi.org/10.3389/fclim.2019.00004.

Morris, J.H., Collins, H., 2023. (Mis)managing Macroprudential Expectations: How Central Banks Govern Financial and Climate Tail Risks. Edward Elgar Publishing, Cheltenham.

NFU (2021) *Our Journey to Net Zero: Farming's 2040 Goal* [Online]. Available at ⟨https://www.nfuonline.com/media/rwzkb3fc/our-journey-to-net-zero-2021.pdf⟩ (Accessed 2 December 2022).

O'Toole, A., Andersson, D., Gerlach, A., Glaser, B., Kammann, C., Kern, J., Kuoppamäki, K., Mumme, J., Schmidt, H.-P., Schulze, M., Srocke, F., Stenrød, M., Stenström, J., 2016. 'Current and future applications for biochar'. In: Shackley, S., Ruysschaert, G., Zwart, K., Glaser, B. (Eds.), Biochar in European Soils and Agriculture: Science and Practice. Routledge, Abingdon, pp. 253–280.

Osborne, T., Shapiro-Garza, E., 2018. Embedding carbon markets: complicating commodification of ecosystem services in Mexico's forests. Ann. Am. Assoc. Geogr. vol. 108 (1), 88–105. https://doi.org/10.1080/24694452.2017.1343657.

Otte, P.P., Vik, J., 2017. Biochar systems: developing a socio-technical system framework for biochar production in Norway. Technol. Soc. vol. 51, 34–45. https://doi.org/10.1016/j.techsoc.2017.07.004.

Peters, G.P., Geden, O., 2017. Catalysing a political shift from low to negative carbon. In: Nature Climate Change, vol. 7. Nature Publishing Group, pp. 619–621. https://doi.org/10.1038/nclimate3369.

Pourhashem, G., Hung, S.Y., Medlock, K.B., Masiello, C.A., 2019. Policy support for biochar: review and recommendations. GCB Bioenergy vol. 11, 364–380. https://doi.org/10.1111/gcbb.12582.

Preda, A., 2006. Socio-technical agency in financial markets: the case of the stock ticker. Soc. Stud. Sci. Vol. *36* (5), 753–782. https://doi.org/10.1177/0306312706059543.

Price, P., Black, H., Cantle, C., Dawson, L., Tomkins, D. (2023) *Guidance Note for Land Managers. Soil Carbon: What are carbon stocks and how can they be measured?* [Online]. Available at ⟨https://soils.org.uk/wp-content/uploads/2023/06/BSSS_Science-Note_June-23_Soil-Carbon-Stocks_FINAL-DIGITAL_300623.pdf⟩ (Accessed 10 August 2023).

Rittl, T.F., Arts, B., Kuyper, T.W., 2015. Biochar: an emerging policy arrangement in Brazil? Environ. Sci. Policy vol. 51, 45–55. https://doi.org/10.1016/j.envsci.2015.03.010.

Royal Society and Royal Academy of Engineering (2018) *Greenhouse Gas Removal* [Online]. Available at ⟨https://royalsociety.org/-/media/policy/projects/greenhouse-gas-removal/royal-society-greenhouse-gas-removal-report-2018.pdf⟩ (Accessed 2 December 2022).

Ryan, G.W., Bernard, H.R., 2003. Techniques to identify themes. Field Methods vol. 15 (1), 85–109. https://doi.org/10.1177/1525822×02239569.

Schmidt, H.-P., Shackley, S., 2016. Biochar horizon 2025'. In: Shackley, S., Ruysschaert, G., Zwart, K., Glaser, B. (Eds.), Biochar in European Soils and Agriculture: Science and Practice. Abingdon, Routledge, pp. 281–289.
Shackley, S., Schmidt, H.-P., Glaser, B., 2016. 'Introduction'. In: Shackley, S., Ruysschaert, G., Zwart, K., Glaser, B. (Eds.), Biochar in European Soils and Agriculture: Science and Practice. Routledge, Abingdon, pp. 1–16.
Sum, N.-L., Jessop, B., 2013. Towards a Cultural Political Economy: Putting Culture in its Place in Political Economy. Edward Elgar Publishing Limited, Cheltenham.
TerrAffix (2022) *TerrAffix: Soil-Habitat-Carbon* [Online]. Available at ⟨https://terraffix.co.uk/⟩ (Accessed 6 December 2022).
UK Government (2023) *Nature markets: A framework for scaling up private investment in nature recovery and sustainable farming* [Online]. Available at ⟨https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1147397/nature-markets.pdf⟩ (Accessed 1 August 2023).
UNFCCC (2015) *Paris Agreement* [Online]. Available at ⟨https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf⟩ (Accessed 14 January 2023).
Waller, L., Rayner, T., Chilvers, J., Gough, C.A., Lorenzoni, I., Jordan, A., Vaughan, N., 2020. Contested framings of greenhouse gas removal and its feasibility: social and political dimensions. WIREs Clim. Change vol. 11 (4), 1–17. https://doi.org/10.1002/wcc.649.
Wansleben, L., 2018. How expectations became governable: institutional change and the performative power of central banks. Theory Soc. vol *47* (*no* 6), 773–803. https://doi.org/10.1007/s11186-018-09334-0.
Watt, R., 2021. The fantasy of carbon offsetting. Environ. Polit. vol. 30 (7), 1069–1088. https://doi.org/10.1080/09644016.2021.1877063.

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