ECONOMICALLY EFFICIENT ECONOMIC INSTRUMENTS FOR INCREASED USE OF BIOCHAR ON AGRICULTURAL LAND

Scientific Report from DCE – Danish Centre for Environment and Energy No. 600 2024

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Abstract: The purpose of this study is to investigate the cost-effectiveness of alternative economic instruments targeting increased use of biochar on agricultural land with the aim of enhancing carbon sequestration and storage in the soil. The report outlines the advantages and disadvantages of applying input and output-based subsidies for biochar use, using biochar as an offset measure, and integrating biochar in a cap-and-trade emission market. The analysis suggests that it is important to provide consistent economic incentives for biochar and alternative carbon sequestration measures.

Keywords: Biochar, carbon offsets, carbon sequestration, cost effectiveness, subsidies.

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Preface

This report was commissioned by the Ministry of Food, Agriculture and Fisheries. The purpose of the report is to investigate the economic efficiency of alternative economic instruments targeting increased use of biochar on agricultural land, and the potential implications in the Danish context. Economic efficiency depends on the ability of the instruments to achieve increased carbon sequestration at least cost, while considering the ability of biochar to sequester carbon in the longer term as well as the time horizon of climate policies.

Increased use of biochar on agricultural land can be achieved through economic instruments encouraging farmers to adopt biochar practices, such as agri-environmental support targeting biochar use or its carbon sequestration effect. Also, biochar could potentially be used as a carbon offsetting measure, where firms subject to carbon dioxide emission regulations, such as the EU ETS, and firms that voluntarily want to buy offsets, can purchase credits from farmers applying biochar. Finally, biochar use could even become directly integrated into cap-and-trade systems for greenhouse gas emissions, where farmers that are allocated individual carbon emission allowances could use biochar as a tool to comply with their own allowance or sell credits to other farmers. The report is based on a literature review and economic analysis.

The report has been subject to internal and external review. Comments obtained have been addressed in the final version of the report.

Sammenfatning

Anvendelse af biokul på landbrugsjord er en potentiel strategi til at reducere udledningen af drivhusgasser, og det fremhæves, at biokul er et kulstofdræn, der er meget permanent sammenlignet med andre bindingstiltag. Formålet med dette studie er at undersøge omkostningseffektiviteten af alternative økonomiske instrumenter rettet mod øget brug af biochar på landbrugsjord med det formål at forbedre kulstofbinding og -lagring i jorden. Rapporten skitserer fordele og ulemper ved at anvende input- og output-baserede subsidier til brug af biochar, ved at bruge biochar som en kompensationsforanstaltning og ved at integrere biochar i et cap-and-trade-emissionsmarked. Omkostningseffektiviteten af disse foranstaltninger afhænger af instrumenternes evne til at opnå langsigtet og pålidelig kulstofbinding. Analysen er baseret på en litteraturgennemgang og en økonomisk analyse.

Et input-baseret tilskud til biochar kunne være baseret på antallet af involverede hektar, mængden af biochar, der bruges, eller mængden af kulstof i det anvendte biochar. Omkostningseffektiviteten af sådanne subsidier afhænger af sammenhængen mellem disse foranstaltninger og den endelige mængde kulstofbinding. Den endelige mængde kulstofbinding afhænger af nedbrydningshastigheden af lageret af biochar-C i landbrugsjorden. For at evaluere betydningen af nedbrydningen af biochar-C-lageret i en politisk sammenhæng, er det nødvendigt at overveje længden af den relevante politiske periode.

Usikkerhed om effekten af kulstofbindingstiltag ses generelt som en udfordring, når man udvikler politikker og politiske instrumenter til formålet. Dette er også relevant i forbindelse med biochar, da nettoeffekten på kulstofbinding på kort og lang sigt afhænger af valget af det råmateriale, der bruges til at producere biochar. Valget af råmateriale kan påvirke både biokullets varighed og den opnåede nettokulstofbinding. Det sidste er vigtigt, da den biomasse, der bruges til at producere råstoffet, i mange tilfælde kan bidrage til kulstofbinding ved den oprindelige anvendelse. For eksempel fører halm, skovrester og spildevandsslam til kulstofbinding, når det efterlades (eller anvendes) på landbrugs- og skovjord. En omkostningseffektiv tilgang ville kræve, at man tilskynder til alle kulstofbindingstiltag ved hjælp af en konsekvent tilgang, såsom at give økonomiske incitamenter, hvor niveauet af miljøstøtter beregnes konsekvent. Konsistens kræver, at varighed og usikkerhed håndteres på samme måde for alle foranstaltninger. Et alternativ ville være at anvende differentieret miljøstøtte afhængigt af det råmateriale, der bruges til at producere biokul. Dette kan blive administrativt kompliceret, da den voksende leverandørindustri af biochar kan have omkostningsfordele forbundet med et fleksibelt valg af råmaterialer og råmaterialeblandinger.

For empirisk at bestemme det omkostningseffektive niveau for økonomisk støtte til brug af biochar i landbrugssektoren, er der behov for en empirisk analyse. Denne analyse skal helst have en bredere tilgang til kulstofbinding i arealanvendelsessektoren i betragtning af de stærke forbindelser mellem brug af biochar og andre anvendelser af biomasse, som kan påvirke nettodrivhusgasemissionerne gennem enten binding eller fortrængning af fossile brændstoffer.

Summary

Biochar application on agricultural land is a potential greenhouse gas emission mitigation strategy and is advocated for the high permanence of biochar as a carbon sink compared to other sequestration measures. The purpose of this study is to investigate the cost-effectiveness of alternative economic instruments targeting increased use of biochar on agricultural land with the aim of enhancing carbon sequestration and storage in the soil. The report outlines the advantages and disadvantages of applying input and output-based subsidies for biochar use, using biochar as an offset measure, and integrating biochar in a cap-and-trade emission market. The cost-effectiveness of these measures depends on the ability of the instruments to achieve long-term and reliable carbon sequestration. The analysis is based on a literature review and economic analysis.

An input-based subsidy to biochar could be based on the number of hectares involved, the amount of biochar used, or the amount of carbon in the biochar used. The cost-effectiveness of such subsidies depends on the correlation between these measures and the final amount of carbon sequestration. The final amount of carbon sequestration depends on the decay rate of the stock of biochar-C in agricultural soils. To evaluate the importance of the decay of the biochar-C stock in a policy context, it is necessary to consider the length of the relevant policy period.

Uncertainty about the effect of carbon sequestration measures is generally seen as a challenge when developing policies and policy instruments for the purpose. This is also relevant in the case of biochar, given that the net effect on carbon sequestration in the short and long term depends on the choice of feedstock used to produce the biochar. The feedstock choice can affect both the permanence of the biochar and the net carbon sequestration achieved. The latter is important as the biomass used to produce the feedstock could, in many cases, contribute to carbon sequestration in its original use. For example, straw, forest residues, and sewage sludge lead to carbon sequestration when left (or applied) on agricultural and forest land. A cost-effective approach would require encouraging all carbon sequestration activities using a consistent approach, such as providing economic incentives where the level of environmental support is calculated consistently. Consistency requires that permanence and uncertainty be dealt with in the same way for all measures. An alternative would be to apply differentiated environmental support depending on the feedstock used to produce biochar. This can become administratively complex as the growing biochar supply industry may have cost advantages associated with a flexible choice of feedstock and feedstock mixes.

To empirically determine the cost-effective level of financial support for biochar use in the agricultural sector, empirical analysis is needed. This analysis should preferably take a broader approach to carbon sequestration in the land use sector, given the strong linkages between biochar use and other uses of biomass, which can affect net greenhouse gas emissions through either sequestration or displacement of fossil fuels.

1 Introduction

Biochar application on agricultural land is a potential greenhouse gas emission mitigation strategy and is advocated for the high permanence of biochar as a carbon sink compared to other sequestration measures (Lehmann et al., 2021; Verde and Chiaramonti, 2021). Biochar sequestration creates benefits to society as it contributes to mitigation of climate change. Hence, the biochar carbon sequestration is a public good. In contrast, biochar carbon sequestration does not directly benefit Danish farmers who apply the biochar on their agricultural land. In line with that, the current use of biochar in the Danish agricultural sector is relatively small. Hence, there can be reasons to introduce economic policy instruments that incentivize the use of biochar.

In addition to carbon sequestration, biochar can also improve soil structure, water retention capacity of soils, and nutrient availability, thereby contributing to increased crop yields. However, there is no strong evidence for such positive yield effects in the Danish context (Elsgaard et al. 2022). Positive yield alone would not be a clear motive for the Danish government to encourage increased use of biochar, because such yield effects would be considered by the farmers when they decide on production given that biochar use would then affect farm profits. Hence, yield improvements are a so called private good, which does not call for public intervention.

Economic instruments that can be relevant for encouraging carbon sequestration using biochar are financial incentives and market mechanisms to encourage farmers to adopt biochar practices. For example, the government can provide subsidies to farmers that cover a portion or all the costs associated with biochar purchase, equipment, and management. Alternatively, subsidies to biochar use could be output based, i.e. be proportional to the carbon sequestration achieved. Also, biochar could potentially be used as a carbon offsetting measure, where firms subject to carbon dioxide emission regulations or firms that voluntarily want to buy offsets to strengthen their trademark can purchase credits from farmers applying biochar on their land. Finally, biochar use could be directly integrated into cap-and-trade systems for greenhouse gas emissions, for example if greenhouse gas emissions from the agricultural sector would become regulated at the farm level such that farmers are allocated individual carbon emission allowances. They could then use biochar as a tool to comply with their own allowance or sell credits to other farmers or regulated entities.

Carbon sequestration in land use can often mitigate greenhouse gas emissions at low costs (Gren et al., 2012; Mason & Plantinga, 2013). Despite that, there has been a slow introduction of policy instruments for carbon sequestration in EU and internationally. This is argued to be linked to policymakers' concerns regarding the non-permanence (Feng et al., 2002; Kim et al., 2008; Maréchal & Hecq, 2006), additionality (Horowitz & Just, 2013; Mason & Plantinga, 2013; Pates & Hendricks, 2020), and leakage (Gan & McCarl, 2007; Murray et al., 2004) that can potentially be associated with carbon sequestration. The use of biochar for carbon sequestration in agricultural soils is regarded as a promising remedy for these problems. Biochar exhibits greater biological stability over extended durations, enabling enhanced long-term carbon sequestration (Lehmann et al., 2021). Moreover, the inherent stability of biochar mitigates the necessity for regular monitoring of soil carbon fluctuations, hence diminishing transaction costs (Kim et al., 2008). It is also argued that biochar satisfies the additionality requirement, as biochar carbon sequestration leads to emissions reductions that would not otherwise have occurred (Chiroleu-Assouline et al., 2018). This argument is only valid if the estimated carbon sequestration effect of biochar takes into account that the biomass used to produce biochar could have also led to carbon sequestration in its original use, albeit of a less permanent nature. This can for example be the case if the feedstock used is agricultural and crop residues that would otherwise be left on the ground. Last, it is argued that the emissions reductions achieved through biochar carbon sequestration in agricultural soils are improbable to lead to corresponding increases in emissions in other locations (Eory et al., 2018; McCarl et al., 2012; Murray et al., 2004). Again, this argument might not be valid if biochar is produced and used on large scale, because the demand for biomass for the purpose of biochar production could then compete with the demand for biomass for other uses, implying that market prices of these other goods could be affected. These other uses could also matter for climate policy, for example biomass used to produce biofuel can replace fossil fuels. However, we can conclude that there are several reasons to think that policy instruments for increased biochar use could be easier to design in a suitable manner than for other carbon sequestration measures, because the carbon sequestration effect is more reliable. Still, the cost effectiveness of the policy instruments will depend on its design.

The purpose of this study is to investigate the cost effectiveness of alternative economic instruments targeting increased use of biochar on agricultural land with the aim of enhancing carbon sequestration and storage in the soil. The report outlines the advantages and disadvantages of applying input and output-based subsidies for biochar use, using biochar as an offset measure, and integrating biochar in a cap-and-trade emission market. The cost effectiveness of these measures depends on the ability of the instruments to achieve long term and reliable carbon sequestration. The analysis is made based on a literature review and economic analysis.

The remainder of the report is organized as follows: Section 2 briefly describes biochar production and the biochar market. Section 3 describes the concept of cost effectiveness and its implications for policy instrument choice. Section 4 and 5 describe input and output-based subsidies, respectively. Section 6 describes the potential for using biochar as an offset measure in a cap-and-trade emission market. Section 7 discusses the potential implications in the Danish context and provides conclusions.

2 Background

In this section, we first briefly describe biochar production, biochar supply markets, and the status of biochar in relation to carbon sequestration policy.

2.1 Biochar production

Biochar has gained attention as a potential tool for increasing carbon sequestration in agricultural land. The benefits of this include the ability of biochar to sequester carbon over long time compared to soil organic carbon pools built up from crop residues, potentially enhance soil fertility, and enhanced water retention. On the negative side, the production of biochar can be cost and energy-intensive and involves costly transports of feedstock and is thus dependent on feedstock availability. Moreover, there is limited knowledge about the long-term effects on soil properties and ecosystems.

Biochar is produced through thermal conversion, so called pyrolysis, of biomass materials. It can be a main product or a co-product from several diverse technologies ranging in scale and complexity (Lehmann and Joseph, 2015). The relative proportions of biochar and its by-products vary depending on the specific conditions of the biomass conversion process: fast pyrolysis is performed at higher heating rates and yields more by-products in terms of bio-oil and syngas which can be used as substitutes for fossil fuels, while slow pyrolysis produces greater quantities of biochar (Bruun et al., 2011). To maximize the yields of stable biochar carbon and achieve economic viability, slow pyrolysis is widely used (Pratt and Moran, 2010; Teichmann, 2014). In this report, we consider biochar produced via slow pyrolysis, consistent with the approach in Elsgaard et al. (2022).

Potential feedstocks for biochar production include agricultural residues, forestry residues, livestock manure, and municipal organic waste. The selection of biochar feedstock often depends on local availability and sustainability factors (Lehmann and Joseph, 2015). Agricultural crop residues are considered one of the best feedstocks for biochar production for carbon sequestration because they are readily available and abundant, contain relatively low ash and toxic gases, and have a lower moisture content making them suitable for transportation and storage. Moreover, their use can contribute to the reduction of agricultural waste and the prevention of methane emissions from residue decomposition (EBC, 2022; Li et al., 2023). In this report, the focus is on policy instruments incentivizing biochar use, while the choice of feedstock to produce biochar is not considered. With efficient economic incentives for biochar use, farmers will be willing to pay for biochar. This demand for biochar will serve as a motive for producers to supply the biochar product.

2.2 The biochar supply market

In Europe the total biochar production was about 33 500 tons in 2022. This was produced at 28 different plants (EBI, 2023). The biochar producer organisation expected 50 000 tonnes to be produced in 2023 (EBI, 2023). This means that the average plant produces 1 196 tons biochar per year. Most of the production facilities can be found in Germany, Austria, and the Nordic countries (EBI, 2023). The producer organisation foresees a continued rapid growth of biochar production.

Biochar production is most likely to be adopted in locations with low-cost feedstock sources (Zilberman et al., 2023), given the high transportation costs for feedstock (Teichmann, 2015). The biochar producers may benefit from horizontal integration, i.e. economies of scope, implying that differentiated pyrolysis products (fuels, pyrolytic sugar, asphalts, and biochar) could be produced at the same location at little additional cost of diversification just by varying feedstock, temperature, and processing technology (Zilberman et al., 2023). Moreover, there are economies of scale in production, favouring large pyrolysis plants (Shackley, 2011; Teichmann, 2015). In contrast with feedstock, costs for transporting the final product, i.e., biochar, is low. This supports the choice made in this report to study the economic incentives for biochar use: the specific location of the production facility is comparatively less important when the main purpose is to achieve increased carbon sequestration.

2.3 Carbon sequestration policy and biochar

The EUs Land Use, Land-Use Change, and Forestry (LULUCF) regulation seeks to incorporate greenhouse gas (GHG) emissions and removals from land use into the EU 2030 climate framework (EU, 2018a). Moreover, the newly proposed effort-sharing legislation for the non-ETS sectors between 2021 and 2030 aims to incentivize Member States to augment soil carbon sequestration (EU, 2018b; Roelfsema et al., 2020). However, despite the increased ambitions for incorporating carbon sequestration in climate policy, there is slow progress in the development of policy instruments that provide incentives for landowners to enhance carbon sequestration on their land.

In the Danish context, biochar is included as an intervention in the agricultural sector within the Danish Climate Program (MCEU, 2020). Biochar sequestration is considered consistent with current agricultural methods and is expected to potentially cut the sector's emissions by 50 % (Hougaard, 2024). Biochar is even envisioned to be the single most important climate measure in the agricultural sector in terms of contributing to reaching the 2030 goal (DK Government, 2021). Given the concerns among farmers over the plans to introduce a CO2e tax on agriculture, the adoption of biochar carbon sequestration could potentially help to reduce the costs of complying with this tax (Hougaard, 2024). In a recent report on the Danish CO2e tax reform for the agricultural sector (EGS, 2024), it is suggested that biochar could play an important role in bringing down the greenhouse gas emissions from the sector, contributing with up to 0.8 million tons of CO2e until 2030. The report suggest that this could be achieved through a subsidy to Danish production of biochar, with the level of the subsidy being determined by biochar's emission factor, considering variations in the carbon content that depends on, e.g., the biomass used to produce biochar. It is acknowledged in the report that the precise design of a possible support scheme needs further investigation, and if support is directed towards production of biochar this can require approvement in accordance with the EU's state aid regulations.

3 Policy instruments and cost-effectiveness

Environmental policy instruments are often evaluated based on the reliability of the environmental effect, cost-effectiveness, distributional impacts (including fairness), and institutional feasibility (Goulder and Parry, 2008; Gupta et al., 2005). Reliability of the environmental effect refers to the degree to which a policy achieves its intended environmental goal or produces favourable environmental results. Cost-effectiveness implies that a targeted emissions reduction is achieved at least cost. To achieve that, all agents should face the same price on emissions and/or sequestration. For example, if biochar use should be subsidized, this rule implies that all farmers should receive the same support for biochar use per unit of carbon sequestered. This condition can be further strengthened, requiring that the support to biochar sequestration should equal the carbon price that faces all other agents in society, i.e., the subsidy should equal the level of a carbon tax applied for fossil fuel consumption and/or the price of emission permits within the EU Emission Trading Scheme (EU ETS), potentially with an adjustment for the reliability of the measure in achieving the intended environmental effect. Distributional issues primarily encompass elements such as justice and equity. Institutional feasibility refers to the degree to which a policy instrument is perceived as acceptable by the citizens and can be effectively put into practice. One can note that climate policy development typically places a strong focus on cost effectiveness (Aldy et al., 2003), which is also the focus of this report. Market-based instruments are widely recognized as the most efficient policies for achieving reductions in greenhouse gas emissions (Baumol and Oates, 1988), but different types of market-based instrument can differ in terms of cost effectiveness (OECD, 2019).

The remainder of this report investigates how economic instruments including input and output-based subsidies, offset markets, and integration of biochar in a cap-and-trade emission market, could be applied to biochar use, considering the long-term but not permanent carbon sequestration achieved by the measure and the associated uncertainty about the magnitude of carbon sequestration achieved. The non-permanence is of importance because the gradual decay of the biochar stock occurs over long time periods, while simultaneously the carbon price is expected to increase significantly over time implying that release of carbon to the atmosphere becomes successively more costly to society. Moreover, policy targets require defined carbon emission reductions within one or a few decades, implying that the climate impact of measures is given comparatively more attention in the debate. In addition, landowners typically sign contracts for undertaking environmentally motivated land use changes on their land for a limited number of years. The report will therefore explore how this affects the efficiency and design of the abovementioned instruments.

4 Subsidies to farmers for biochar use

Agri-environmental subsidies are financial incentives provided to farmers for adopting environmentally friendly farming practices. These subsidies are one of several instruments to implement a market-based solution: subsidies are typically argued to be more cost-effective than direct regulation of farm inputs and farm management practices when farmers have varying costs for providing environmental benefits.

Within EU, agri-environmental subsidies are offered within the framework of the Rural Development Programmes and CAP Strategic Plans. These subsidies are jointly funded by the EU and the national governments. The subsidies are typically designed as fixed per-hectare payments for stipulated agri-environmental practices. This is in many cases not cost effective because the environmental benefits generated can vary depending on the location (Hasler et al., 2022). Another drawback of the input-based subsidies is that they provide little incentives for innovation. The reason is that they typically focus on a single technology or practice, giving the farmer limited flexibility with respect to the choice of method for producing the targeted environmental good. Finally, one can note that uniform subsidies, based on either inputs or outputs, will encourage all farmers whose costs for implementation are lower or equal to the subsidy to adopt the scheme. This increases farmers' overall profits compared to the situation with no subsidy because for most farmers that adopt a scheme the compensation will exceed their costs. Depending on the variation in farmers' costs, the costs for taxpayers can be high in relation to the environmental effect.

Subsidies to farmers for biochar use could be designed similarly as other subsidies within the Rural Development Programmes and CAP Strategic Plans. There could for example be a per hectare subsidy for applying a given amount of biochar, or a subsidy per ton of biochar or biochar carbon. As a rule, subsidies that are more closely linked to the intended outcome are more cost effective than subsidies targeting practices that are less correlated with the outcome. In the following we will discuss the mentioned three possible subsidies, starting with the one least correlated with the achieved carbon sequestration (a per hectare subsidy for applying a given amount of biochar), proceeding with subsidies with successively higher correlation with the intended outcome (a subsidy per ton of biochar, a subsidy per ton of biochar carbon).

If there is *a subsidy per hectare for applying a given amount of biochar*, farmers' costs for implementation could vary because application costs per hectare might differ depending on the machinery available, storage capacity, land consolidation, and farmers' opportunity cost of time (Teichmann, 2015). For example, spreading biochar as a powder can generate huge emission of dust (Elsgaard et al., 2022), implying that new equipment could be needed for dust mitigation. Such new equipment could require a minimum application area to be economically viable. This could discourage farmers that would be willing to apply the same amount of biochar but on a smaller area. Also, some farmers could be unwilling to apply biochar in the required per-hectare amount, e.g., if they are concerned about potential harmful environmental impacts on soil or ground and surface water (cf., e.g., Xiang et al., 2021). They might then decide not to adopt the practice even though they might be willing to spread the same amount over a larger area for the same compensation.

Thus, a per hectare subsidy would be disadvantageous if biochar-C storage, i.e. the stock of biochar carbon in the soil, and biochar carbon sequestration, i.e. the annual net increase in biochar-C, are independent of the size of the area where the biochar is applied.

We next turn to a subsidy design that could avoid the above-described problem. With a *subsidy per ton of biochar*, farmers with low application costs would be more likely to adopt the scheme than farmers with higher cost. This would be beneficial from a cost-effectiveness point of view. On the other hand, the carbon content of biochar could vary considerably depending on the feedstock used and pyrolysis conditions (Elsgaard et al. 2022) and may range between 60 % and 90 % (McGlashan et al., 2012). Suppose that the subsidy is based on farmers' average costs for applying one tonne of biochar. If biochar with low carbon content is cheaper to produce and therefore also cheaper to buy, farmers are more likely to use the cheapest product which can lead to less carbon sequestration and biochar-C storage than expected. Also, biochar producers would have incentives to produce more cheap biochar with low carbon content which could lower the average carbon content in biochar offered on the market.

A remedy to this could be to instead decide on *a subsidy based on the carbon content of the biochar used*. This subsidy would more closely target the carbon sequestration and biochar-C storage achieved than either of the two previous alternatives, which is advantageous from a cost-effectiveness point of view. The use of such a subsidy would require that the carbon content of the biochar product used is easy to determine when approving the subsidy. This could entail additional administrative costs for the responsible agency, that must be considered when choosing the design of the subsidy.

Independently of the choice of design for an input-based subsidy to biochar use in agriculture, input based subsidies have a shortcoming in that they do not account for variations in the carbon sequestration and biochar-C storage effect across different biochar products and across different land types. This is further discussed in the following section.

5 Subsidies to farmers based on sequestration output

Instead of input-based subsidies as described above, different types of output-based subsidies can be considered as an alternative. Those differ from the input-based subsidies by being more strongly related to the intended environmental outcome, i.e. the carbon sequestration. The output-based subsidies could be determined either *ex ante*, based on the future expected sequestration achieved, or *ex post*, based on measurements of the actual sequestration achieved. The latter would require monitoring and testing biochar-C storage over very long time periods, which could become expensive to implement on the enrolled land. The follow-up process could also be complicated by the limited time duration of agri-environmental contracts typically found within the framework of Rural Development Programmes and CAP Strategic Plans.

In the literature there are methods suggested for determining the optimal size of a subsidy to a carbon sequestration measure, given the uncertainty and non-permanence of the sequestration achieved. These methods are briefly described in the following.

5.1 Uncertainty discounting

Kim and McCarl (2008) outline methods for comparing a measure with an uncertain environmental effect to that of a measure with a certain. They note that the effect of carbon sequestration measures such as changes in land-use, crop mix, tillage systems, and residue management is typically uncertain. This makes it necessary to compare these measures with more certain ones, such as reductions in fossil fuels. The aim of the comparison is to identify a suitable balance between the level of economic instruments targeting more and less certain measures, where more certain measures should be more strongly incentivized than more uncertain measures[1]. The sources of uncertainty can be, for example, climate and biologically induced variability in the quantity of carbon sequestered at a given location; aggregation induced sampling error at a regional scale; carbon pool measurement errors; and intertemporal variation in the permanence of carbon pools.

Kim and McCarl (2008) suggest that uncertainty could be considered using uncertainty discounting. The certainty equivalent, Q, of an uncertain amount of carbon sequestration can be calculated as:

$$Q = \bar{Q} - z_{\alpha}\sigma, \quad (1)$$

where $\bar{Q}$ is the expected (mean) carbon sequestration, σ is the standard deviation of carbon sequestration, and z_{α} is a multiplier which is determined by the desired level of confidence. For example, if carbon sequestration can be thought of as being normally distributed, a required level of confidence equal to 95 %, implies that z_{α} equals 1.64. This implies that carbon sequestration will be equal to or exceed the mean in 95 times out of 100. This could be for

[1] Although their study discusses the topic in terms of comparable credits for carbon offsets, the approach is equally valid for subsidies.

example in 95 out of 100 locations where biochar is applied, or 95 out of 100 years at a given location.

To obtain an uncertainty discount factor, one can first note that the coefficient of variation, CV, can be expressed as $CV = \sigma/\bar{Q}$, i.e. it is the ratio of the standard deviation and the mean. Equation (1) can then be rewritten as:

$$Q = \bar{Q}(1 - z_\alpha CV),$$

where $z_\alpha CV$ is the uncertainty discount factor. To apply this approach in practice, it is necessary to determine α, z_α, and CV.

The level of confidence must be subjectively determined by policy makers. Policy makers that are concerned with uncertainty will always chose a higher level of confidence than 50 %, i.e., prefer that the sequestration is at least equal to the mean in more than 50 % of the cases (i.e., locations or years)[2]. If a normal distribution can be assumed[3], z_α will equal zero for a confidence level of 50 % and will be higher for higher confidence levels.

The CV is determined by the mean and standard deviation of carbon sequestration. Those can be calculated using data from field experiments or simulation models. Typically, many studies report the variation in the annual sequestration for a single site, and therefore do not fully reflect spatial and temporal variation in carbon sequestration across multiple sites and multiple years. To be consistent with the likely multisite, multiyear nature of biochar sequestration contracts, the CV should be based on data from multiple sites across multiple years.

Kim and McCarl (2008) show that the uncertainty discount factor $z_\alpha CV$ could be the neighbourhood of 15–20 % when carbon sequestration is proxied by agricultural crop yield[4], and a confidence level of 90-95 % is applied. They do not apply their method to biochar or other measures such as catch crops or afforestation that can be relevant in the European policy context. One can note that a similar approach is applied to European forest carbon sequestration in the study by Gren et al. (2009). To study policy relevant measures in the agricultural sector, including biochar, in Europe and Denmark further research is needed.

5.2 Permanence discounting

The carbon sequestration achieved with the help of biochar depends on the stability of the carbon. Studies have come up with quite different estimates of biochar permanence, suggesting that between 18 % and 60 % of the stable fraction becomes mineralized within a century (Elsgaard et al., 2021, pp. 27-28). Thus, even if biochar carbon is more stable than carbon stocks generated through the decay of crop residues, it can be relevant to consider non-permanence when designing policy instruments.

[2] 50 % confidence implies that $z_\alpha = 0$ under a normal distribution.
[3] This is often done with reference to the Central Limit Theorem. One can note that it is straightforward to calculate z_α also for other distributional assumptions such as a lognormal, and there are also possibilities to calculate z_α without placing any à priori assumptions on the distribution, see e.g. Gren et al. (2009).
[4] Hence, assuming that crop yields are correlated with crop residue amounts.

A study by Kim et al. (2008) focusses specifically on methods for comparing different non-permanent carbon sequestration measures with a perfectly permanent sequestration option. They focus on the role of non-permanence for the level of the compensation that should be paid to the landowner. The level of the compensation for a non-permanent carbon sequestration option should be lower than for a permanent one, everything else equal.

The focus on non-permanence is motivated by that fact that in general carbon sequestration does not last forever: either the carbon is eventually released back to the atmosphere or there are expenditures to maintain the carbon sequestered. Kim et al. (2008) show that the permanence discount should be a function of the future needs to replace carbon sequestration measures (either because the contract with the landowner ends or because sequestration is impacted by fire, pests, or flooding), and the magnitude of maintenance costs necessary to keep the carbon sequestered. The permanence discount, $PDisc$, is determined by the following formula:

$$PDisc = \frac{\sum_{t=0}^{T}[B_t(1+g)^t + M_t/P_0](1+r)^{-t}}{\sum_{t=0}^{T} Q_t(1+g)^t(1+r)^{-t}}, \tag{2}$$

where Q_t is the amount of sequestration at time t, B_t is the "buyback" of sequestration necessary (e.g., because contracts with landowners have expired), M_t is the maintenance cost at time t for keeping the carbon sequestered (i.e., costs that accrue at a time when there is no further sequestration achieved), P_0 is the initial carbon price, g is the rate of increase in carbon price, and r is the social discount rate.

Kim et al. (2008) empirically examines the magnitude of the discounts for alternative agricultural tillage and forest management cases, finding that permanence discounts in the range of 50 % are not uncommon. This means that impermanent sequestration measures may only receive payments amounting to 50 % of the market carbon price. They provide a couple of stylized examples. For agricultural soil carbon, the permanence discount under rising carbon prices becomes about 28 % when maintenance costs are necessary after project year 25, and about 100 % if the contract with the landowner expires after 25 years. Forest conservation implies a less than 1 % discount under rising carbon prices, while if a forest is harvested after 85 years and 77 % thereof is used as timber, the carbon in the remaining biomass is immediately released, and the biomass can be used for fossil fuel replacement, the permanence discount becomes about 50 %.

Corresponding calculations are not available for biochar, but the examples reveal that rising carbon prices imply that carbon sequestration options require a high permanence discounting even when projects are comparatively long term. This is because the replacement of projects that have expired becomes expensive at high carbon prices. Hence, it cannot be excluded that permanence discounting could be relevant also for biochar use in the agricultural sector.

Furthermore, Kim et al. (2008) show that under rapidly increasing carbon prices, and hence rapidly increasing subsidies to carbon sequestration, landowners might postpone the adoption of carbon sequestration measures, or never even undertake these measures. The reason is that for many carbon sequestration measures the carbon pool can only be increased up to a given level, thereafter the sequestration becomes zero. Hence, the sequestration benefits can only be obtained over a limited time span. For such measures, the activities will always pay off better at a later point in time, explaining the postponement. In line with this, it can be necessary to find out how much biochar can be applied to a field in the longer term and how frequent applications are possible. This can matter for both the timing of a policy, and farmers willingness to adopt a subsidy scheme.

6 Biochar as a carbon offsetting measure

Instead of providing subsidies, economic incentives for biochar could be created by having biochar as a carbon offset measure. There are mainly two ways to achieve that; either by permitting companies with regulated carbon emissions to offset some of their obligations through purchases of carbon credits associated with biochar use, or by encouraging voluntary carbon offset markets to increasingly include biochar as an option.

6.1 Offsetting emissions from regulated firms

At present, biochar is not an eligible measure in the context of regulated emission markets such as the EU ETS, but Verde and Chiaramonti (2021) argue that recent developments at the EU level, such as the inclusion of biochar in the Fertilising Products Regulation, the increased support for soil carbon sequestration in the Common Agricultural Policy (CAP) for the period 2021-2027, the new EU certification system for carbon removals, and the new binding targets for net greenhouse gas emissions from the LULUCF sector, can imply a higher likelihood that biochar use will become considered.

Participation in offset markets connected to regulated emissions is voluntary for landowners as well as for the regulated firms. The regulated sector can buy carbon sequestration offsets from the unregulated sector as compensation for its own emissions. This will result in lower costs to society since low-cost carbon sequestration options become available. On the other hand, it can imply a risk of introducing non-additional carbon sequestration projects (Gren and Aklilu, 2016). It is suggested that this is threat is mitigated through additionality tests of offset credits, increased monitoring and verification, and/or trading ratios between the regulated sector and offset sector emissions reductions where more than one kilo of carbon sequestration is required in exchange for one kilo of carbon emissions (Gren and Aklilu, 2016).

An alternative to such a side-market for carbon sequestration offsets could be to fully integrate the LULUCF sector in an emission and/or sequestration trading market. This could for example imply that a cap is set on LULUCF emissions separately, or on both fossil fuel and LULUCF emissions together, with emission and offset trading being allowed. Such a fully integrated market would then imply that each landowner would obtain an emission allowance, similar to that for firms within the EU ETS.

If biochar offsets can be purchased by regulated firms while the LULUCF sector is otherwise not regulated, this raises the question of whether biochar use on agricultural land is additional or not. The answer to this question hinges on whether other carbon sequestration measures than biochar are simultaneously made eligible as offset measures. If this is not the case, agricultural and forest residues might be used for biochar production to a considerable extent, implying that the soil carbon sequestration otherwise obtained from the residues left on the land is lost. This is a problem if sequestration of residues is significant: even though biochar sequestration is more permanent it is also more expensive. The policy could thus become cost inefficient if only biochar is available as an offset.

6.2 Designing policy instruments for carbon sequestration offsets

Independently of whether there is a side-market for sequestration offsets or whether the land use sector would be allocated net emission allowances, the non-permanence of biochar and other sequestration must be considered. Feng et al. (2002) show that this can be achieved in an economically optimal manner by applying one of the three following approaches: Pay-As-You-Go, Variable-Length-Contracts, and Carbon Annuity Accounts (CAA).

The Pay-As-You-Go approach implies that landowners sell and repurchase emission credits based on the permanent reduction of carbon at the going rate. Hence, if already sequestered carbon is released back to the atmosphere, the landowner must pay an amount equal to that release times the carbon price at the time when it is released.

Under the Variable-Length-Contracts approach, there are brokers that offer sellers of carbon sequestration (i.e., landowners) a menu of prices for differently long contracts. The brokers can then offer the buyers permanent contracts by combining a mix of contracts with sellers. The landowners then receive a price that considers the difference in carbon price between sequestering and releasing periods.

Finally, there could be set up Carbon Annuity Accounts. Landowners then get an initial payment for their carbon sequestration activities. This payment is placed in an annuity account, from which the landowner receives a rent on an annual basis. The landowner is encouraged to keep the money, including the rent, in the account as its value increases over time with offset carbon prices. However, the landowner is also free to end the contract and can then buyback offsets (i.e., pay for the resulting carbon release) using the account. Out of the three described options, the last one seems to be the one that is more easy to implement in practice.

6.3 Voluntary purchases of biochar offsets

There is a relatively small market for voluntary purchases of biochar offsets, where the biochar can be used in multiple different settings including the construction and infrastructure sector (Michaelowa et al., 2023). Firms or local municipalities that buy offsets in these markets are likely to do that to pursue own goals for greenhouse gas emissions reduction, not directly related to regulations. Firms could choose to have such goals if they believe that the goals help to avoid future stringent regulation or if environment friendliness can be communicated to consumers who are willing to pay extra for the company's environmental efforts. There is almost no research on voluntary biochar offset markets, but brokers that offer such offsets are available and apply their own rules for biochar offset eligibility (Basilevac, 2023). One can note that carbon sequestration offsets on voluntary markets are generally paid a lower price than offsets used to comply with mandatory emissions reductions (Gren and Aklilu, 2016).

7 Concluding remarks

For a policy instrument to be cost effective, it should directly target the intended outcome. When the intention is to reduce carbon dioxide emissions from fossil fuels, this rule is straightforward to apply as the emissions are directly proportional to the carbon content in the fuel used. In the case of carbon sequestration measures, including biochar application on agricultural land, afforestation, and cultivation of catch crops, the rule is somewhat more difficult to implement. The reason is that the carbon removal effect is more uncertain and that the sequestered carbon could over time be released back to the atmosphere.

The ease of implementation is also important for the choice of policy instruments. Economic policy instruments for carbon sequestration measures, including biochar, could be easier to implement if they are designed in a similar manner as existing policy instruments and hence do not require extensive changes in legislations and markets. Implementing carbon sequestration measures in the agricultural sector may be facilitated by designing policy instruments similarly to existing agri-environmental policies, which typically offer subsidies directed towards specific technologies or management practices. However, other policy instruments could be more cost-effective, i.e. lead to more sequestration per euro spent. Economic instruments that achieve the same carbon price across measures and sector are typically more cost effective than agri-environmental subsidies. Hence there can be a trade-off between rapid implementation on one hand and cost-effectiveness once the policy instrument is established on the other.

Based on the above review of alternative policy instrument designs for biochar use in the agricultural sector, one can thus conclude that a subsidy to biochar use could be easier to implement within a near future because of the similarity with existing agri-environmental support schemes. If that approach is chosen, the subsidy would be more cost-effective if the compensation level is calculated taking uncertainty and non-permanence into account. A rapid implementation of economic instruments for biochar is more motivated if the measure is cheap in terms of CO2e-mitigation per euro spent compared to other measures. If this is not the case, it could be better to aim for the implementation of a more general policy instrument design, where biochar is integrated within other carbon sequestration measures and/or emission reduction measures such that all measures are incentivized by the same carbon price, adjusted for uncertainty and non-permanence of the different measures. This requires either a generally applied carbon tax-subsidy scheme or a broader market for carbon sequestration and emission trading. To date, there are no cases of biochar being integrated in such broader emission/sequestration markets or tax schemes.

If a subsidy to biochar is implemented, motivated by the higher feasibility and the need for rapid environmental results, it should be considered whether it can be implemented simultaneously with corresponding subsidies for other carbon sequestration measures in the land use sector. Even though other measures may result in sequestration that is less permanent than that of biochar, these measures can still be of importance. The reason is that a sole subsidy to biochar use will provide incentives for using agricultural and forest residues, and sewage sludge, for the purpose of comparatively costly biochar use at the expense of the carbon sequestration achieved when the residues are left in the field or forest, or sewage sludge is spread on agricultural land. This can be inefficient from a cost effectiveness perspective because it can potentially be better to implement a larger amount of less permanent but cheaper sequestration measures, suitably allocated across time, than to implement costly biochar use. Thus, a preferrable approach would be to introduce similar subsidies to all carbon sequestration measures, taking the uncertainty and non-permanence of each type of measure into account when setting the compensation level.

To determine the appropriate level of a subsidy for biochar and for other sequestration measures that take uncertainty and non-permanence into account in line with the above-described methods, further research is necessary. Moreover, the issues of additionality and leakage are understudied for biochar, in particular many studies apply technical assumptions and constraints that are reasonable only when considering small scale use of biochar but seem implausible if biochar should be used at large scale. Investigation of large-scale use requires further knowledge on trade-off between alternative uses of biomass, as well as biochar trade between regions and countries. Further research on these aspects should therefore be valuable.

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ECONOMICALLY EFFICIENT ECONOMIC INSTRUMENTS FOR INCREASED USE OF BIOCHAR ON AGRICULTURAL LAND

The purpose of this study is to investigate the cost-effectiveness of alternative economic instruments targeting increased use of biochar on agricultural land with the aim of enhancing carbon sequestration and storage in the soil. The report outlines the advantages and disadvantages of applying input and output-based subsidies for biochar use, using biochar as an offset measure, and integrating biochar in a cap-and-trade emission market. The analysis suggests that it is important to provide consistent economic incentives for biochar and alternative carbon sequestration measures.

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