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Enabling small-scale production of biochar in carbon markets

A multi-actor governance approach

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Abstract

Climate change is increasing the temperature rise, which damages nature and people. Increasing and using carbon dioxide removal (CDR) techniques are crucial to limit global warming to staying under 2 °C and fulfilling the Paris Agreement. There are several different CDR techniques, and biochar is one. Biochar is estimated to be able to contribute significantly as a carbon sink, and using biochar in agriculture can have several additional benefits, such as increasing crop yields. Most farmers in low- and lower-middle-income countries are smallholder farmers who cultivate two hectares of land or less. This can present an opportunity for them to explore the use of biochar. Carbon credits are sold and traded on carbon markets and can broadly be divided between compliance such as EU ETS and voluntary, for example, companies wanting to fulfil climate targets. One credit is equivalent to one tonne of carbon dioxide being sequestered. The aim of the study is to provide knowledge about the enablement of small-scale biochar as a technology in carbon markets, focusing on low- and lower-middle-income countries using a multi-actor governance approach. The study combines a literature review and qualitative interviews. Carbon markets are signified by several attributes of multi-actor governance, including public and private cooperation and cooperation on several scales. The main drivers and barriers for biochar in carbon markets concern sustainability aspects, training and education, expenses and income, small-scale production, and technological maturity. The income from carbon credits can facilitate several barriers to applying and using biochar. Still, it also has challenges such as measuring, verifying, reporting and fulfilling the requirements of high-quality carbon credits, which can be extra demanding for smallholder farmers. Small-scale biochar production potentially has better conditions for voluntary markets due to more variations in the demand for credits. In compliance markets, buying countries often want to buy large amounts of credits, and a majority of countries do not recognise biochar as a carbon sink for countries' own target fulfilment. Small-scale biochar production has potential for carbon markets. Still, more research is needed on the carbon credit-specific aspects and the threshold for cooperatives of smallholder farmers, and what will happen when the central market mechanism under Article 6 in the Paris Agreement is final.

Sammanfattning

Klimatförändringarna bidrar till temperaturökningen, vilket skapar skador för natur och människor. Att öka användningen av tekniker för koldioxidupptagning är avgörande för att begränsa den globala uppvärmningen och hålla sig under 2 °C samt uppfylla Parisavtalet. Det finns flera olika tekniker koldioxidupptagning, varav biokol är en. Biokol bedöms kunna bidra väsentligt som kolsänka och att använda biokol i jordbruket kan ha flera fördelar, som att öka skörden. Småbrukare som odlar två hektar mark eller mindre är majoriteten av bönderna i låginkomstländer, vilket innebär att de kan ha möjlighet att använda biokol på sin mark. Koldioxidkrediter säljs och handlas på koldioxidmarknader och kan i stora drag delas upp mellan frivillig och reglerad marknad. En kredit motsvarar ett ton koldioxid som binds. Syftet med studien är att ge kunskap om möjligheterna kring småskalig biokol som en teknik på koldioxidmarknader, med fokus på låginkomstländer genom ett flernivåstyrnings-perspektiv. atudien kombinerar en litteraturöversikt och kvalitativa intervjuer. Koldioxidmarknader kännetecknas av flera attribut för flernivåstyrning till exempel offentliga och privata samarbeten på flera nivåer. De främsta drivkrafterna och hindren för biokol på koldioxidmarknader rör hållbarhetsaspekter, utbildning, utgifter och inkomster, småskalig produktion och teknisk utveckling. Intäkterna från koldioxidkrediter kan minska flera barriärer för tillämpning och användning av biokol. Trots det finns det också utmaningar kopplade till exempel till att mäta, verifiera och rapportera och uppfylla kraven för högkvalitativa koldioxidkrediter, vilket kan vara extra krävande för småbrukare. Småskalig biokol har potentiellt de bästa förutsättningarna på frivilliga marknader på grund av fler variationer i efterfrågan på krediter. På de reglerade koldioxidmarknaderna, vill köparländer oftast köpa större mängder krediter och biokol är inte erkänt av en majoritet av länder att använda som kolsänka inom ländernas måluppfyllnad. Småskalig produktion av biokol har potential för koldioxidmarknader, men det behövs mer forskning om de kolkreditspecifika aspekterna samt och tröskeln för gruppering av småbrukare, och vad som kommer att hända när den centrala marknadsmekanismen enligt artikel 6 i Parisavtalet är färdigförhandlad.

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Abbreviations

CDM	Clean Development Mechanism
CDR	Carbon Dioxide Removal
CSR	Corporate Social Responsibility
ETS	Emissions Trading System
ICVCM	Integrity Council for the Voluntary Carbon Market
ITMO	Internationally Transferred Mitigation Outcomes
LM Countries	Low-income and Lower-middle-income countries
LULUCF	Land Use, Land-Use Change and Forestry
MAG	Multi Actor Governance
MRV	Measuring Reporting Verification
NDCs	Nationally Determined Contributions
NGO	Non-profit organisation
NSA	Non-State Actor
VCM	Voluntary Carbon Markets
VCMI	Voluntary Carbon Markets Integrity Initiative

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1. Introduction

Climate change leads to more frequent and intense extreme events, causing severe impacts, losses, and damage to nature and people (IPCC, 2022). The most vulnerable people and systems spanning sectors and regions are disproportionately affected. Irreversible effects are seen as the weather and climate extremes have impacted natural and human systems no longer being able to adapt. Adaptation and mitigation efforts will be crucial to minimise the harmful effects of climate change and ensure future climate-resilient development. An important mitigation tool to reduce the amount of CO2 in the atmosphere and slow the effects of climate change is to strengthen and increase carbon stocks and sinks to compensate for unavoidable emissions (IPCC, 2022).

Carbon Dioxide Removal (CDR) is critical in limiting global warming to staying under 2 °C and fulfilling the Paris Agreement. Article 5.1 in the Paris Agreement states, “Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases [...]” (UNFCCC, 2020). There are several different CDR options discussed in the literature, such as biochar, soil carbon sequestration, direct air capture (DAC), enhanced weathering (EW), bioenergy with carbon capture and storage (BECCS) and afforestation and reforestation (Fridahl, Hansson & Haikola, 2020).

Carbon markets where carbon credits are sold and bought are rapidly emerging and have quickly become a billion-dollar industry. Carbon markets are changing with new directives and higher interest from the private and public sectors to use CDR technologies (Green, 2022). Adding to the shifts in implementing the Paris Agreement on a national and global level, there is a need to investigate further the possibility of upscaling CDR technologies such as biochar. There are limitations to all CDR technologies related to implementing the techniques on a larger scale. However, biochar has a significant potential to sequester carbon and has few disadvantages compared to other CDR technologies (Smith et al., 2016).

Globally, biochar is estimated to contribute significantly as a carbon sink and mitigation source (Lehmann et al., 2021). Combined with biochar use in agriculture, biochar-producing cookstoves can provide multiple additional benefits, such as increased crop yields (Sundberg et al., 2020). Due to the many benefits of biochar in agriculture, particularly the environmental ones, biochar can play a role in the carbon markets. The revenues from carbon credits can also be a way to increase the usage of biochar (Thengane et al., 2021). Additionally, several biochar projects are geographically located in the Global North, and

there is an existing research gap on the engagement of biochar practitioners in low- and lower-middle-income countries (Fridahl, Haikola, Rogers & Hansson, 2021).

Lately, the interest in voluntary carbon markets (VCMs) has significantly increased. Carbon markets can become a crucial driver of mitigation action, specifically in low- and lower-middle-income countries (Streck, 2021). With the increased interest in permanent removal projects and the demand for more long-term carbon credit solutions in carbon markets, such as biochar, analysing the potential for small-scale biochar projects in low- and lower-middle-income countries are highly interesting.

1.1 Aim and objectives

The study aims to provide knowledge about the enablement of small-scale biochar as a technology in carbon markets, focusing on low- and lower-middle-income countries.

This study's objectives are

- Analyse key actors around the small-scale biochar carbon credit value chain in carbon markets from a multi-actor governance approach.
- Identify drivers and barriers for small-scale biochar projects in low- and lower-middle-income countries to scale in carbon markets.
- Investigate conditions for small-scale biochar in low- and lower-middle-income countries in existing and future carbon markets using multi-actor governance.

1.2 Delimitations

There are several different ways to make classification of countries. For example, measuring the level of development through per capita gross national income (GNI), which makes four different groups. Countries are grouped into high-income, upper-middle-income, lower-middle-income and low-income. The World Bank establishes the threshold levels for GNI per capita. Low-income countries have less than $1,046 GNI per capita, between $1,046 and $4095 are lower-middle-income countries, between $4096 and $12,695 are upper-middle-income countries, and incomes higher than $12,695 are high-income countries. (UN, 2023). The scope of the study covers both low-income and lower-middle-income countries; for readability, they will be grouped as LM countries.

Biochar production can be at various scales and constructed differently. The study focuses on smallholder farmers with micro and smaller-scale projects using biochar cookstoves. A

significant number of farmers in low- and lower-middle-income (LM) countries are smallholders meaning they are cultivating two hectares of land or less (Lee, Ingalls, Erickson & Wollenberg, 2016). Therefore, large-scale production is not taken into consideration.

Compliance and voluntary markets are taken into consideration in this study. Compliance markets refer to markets created and regulated through regulatory national, regional or international carbon reduction schemes such as EU Emissions Trading System (ETS) or Article 6 under the Paris Agreement. Compliance markets consist of several different programs and can have broad geographic coverage (Climate Promise, 2022). Governmental bodies often certify the carbon credits on compliance markets. Voluntary markets usually function outside compliance markets and target companies and individuals that are not intended to be used for compliance purposes. There are several different programs under voluntary markets, which can be national or international (Broekhoff et al., 2019). The study does not focus on a specific program.

2. Background

Carbon dioxide removals and the carbon markets can be complex topics. Therefore, it is necessary to explain what CDR technologies include, how biochar will function as a CDR, the different carbon credit projects, and the difference between the main carbon markets and the policy mechanisms surrounding it.

2.1 Carbon dioxide removal (CDR)

Carbon dioxide removal (CDR) is the technology of capturing and removing carbon dioxide (CO_2) from the atmosphere and storing it, for example, in the ocean, in geological formations or in different products. The time carbon can be stored can range from decades to millennia (Smith et al., 2023). IPCC refers to CDR as the process where CO_2 is removed from the atmosphere. CDR is the opposite of emissions, leading to technologies or practices that remove CO_2 frequently being characterised as reaching 'negative emissions' (IPCC, 2018).

Another possible division is the one between conventional and novel methods. Conventional methods include land management, predominantly afforestation and reforestation. The novel techniques, on the other hand, include carbon sequestration in the ocean or products such as biochar and in the lithosphere, including bioenergy with carbon capture and storage (BECCS) and direct air capture with carbon capture and storage (DACCS). Currently, almost all CDR are from land-based sources such as afforestation, reforestation, and forest management (Smith et al., 2023).

The process can also be labelled more broadly as greenhouse gas removal when more gases than CO_2 are removed. CDR can be divided into two main types: strengthening existing natural processes and removing carbon from the atmosphere by increasing the uptake from trees, soil or other carbon sinks. The second type is chemical processes, such as capturing CO_2 directly from the air and storing it elsewhere, for example, underground (IPCC, 2018). Methods protecting, restoring, and managing ecosystems while at the same time contributing to other economic, social and environmental benefits are often called "nature-based solutions" (Smith et al., 2023).

There is a gap between the need for CDR to meet the Paris Agreement temperature and how much CDR countries are planning. The exact size of the gap between the Paris Agreement temperature goal and the needed CDR varies between scenarios depending on the

assumptions around the societal transformations towards net-zero emissions, meaning more emissions are captured than being emitted. Regardless, there are few plans to increase the current levels of CDR, leading to a severe shortfall (Smith et al., 2023). The CDR methods are at various stages of development; some are more conceptual as they are not tested at scale (IPCC, 2018). Table 1 shows some of the most discussed CDR techniques in the literature.

Table 1: Overview of some of the most common CDRs.

CDR	**Key characteristics**
Afforestation and reforestation (AR)	Afforestation is the planting of trees on land that is not forested recently, whereas reforestation is characterised by the restocking of trees on land that has been recently depleted.
Soil carbon sequestration (SCS)	SCS is defined by the increased uptake of CO_2 in soil due to the improvement of management practices
Biochar	Biochar is a condensed carbon-rich substance possible to produce on a large scale from biomass through pyrolysis.
BECCS	BECCS permanently captures biogenic CO_2 during the energy conversion process from biomass
Ocean fertilisation (OF)	OF enhances the biological process in oceans, which stimulates the uptake of CO_2 from the atmosphere.
Enhanced weathering (EW)	EW stimulates the process of rock decomposition while producing alkalinity and geogenic nutrients, which strengthens CO_2 capture.
DACCS	DACCS captures CO_2 from the ambient air and stores it geologically permanently

Comment: Based on Fridahl, Hansson and Haikola (2020), IPCC (2022) and Terlouw et al. (2021).

2.2 Carbon markets

Carbon markets are trading systems where carbon credits are sold and bought. One carbon credit equals one tonne of carbon dioxide or another greenhouse gas being reduced, sequestered or avoided (Climate Promise, 2022).

Carbon markets can broadly be divided between compliance and voluntary markets. Compliance markets are signified by their creation and control by national, regional or international programs or organisations. Examples of mechanisms in compliance markets are EU ETS or the Clean Development Mechanism (CDM) under the Kyoto Protocol. Carbon markets have gotten increased interest, and currently, 83% of the countries' NDC say they intend to use international market mechanisms to reduce their greenhouse gas emissions (Climate Promise, 2022).

VCMs can be national and international. The target group is often individuals or companies interested in buying carbon credits with no need to buy them on a compliant basis (Michaelowa, Shishlov & Brescia, 2019). The demand can come from a desire to compensate for the carbon footprint, but carbon credits can also be a demand for wanting to trade credits and generate profits. It is usually private entities developing carbon projects, and they then get certified by a standard that creates the credit (Climate Promise, 2022).

2.2.1 Carbon credits

Five crucial criteria determine the carbon credit quality. First, a quality carbon credit needs to have removals or GHG (greenhouse gas) reductions that are not claimed by another, and entity are permanent, not overestimated, additional and not associated with significant environmental or social harm. Permanence refers to how long carbon will be stored or reduced; since emissions are long-lived in the atmosphere, it is essential to ensure that the credit has similar permanence as the emissions released and that no reversals occur. Reversals mean that emissions are rereleased; for example, if a forest burns down, the carbon stored will be released back into the atmosphere, and a reversal occurs. Additionality is determined if it would not have happened without a market for carbon credits. A project or carbon credit is not additional if it would have occurred regardless of selling carbon credits. Meeting the five quality criteria means having high-quality carbon credits since the sustainability aspects of the credit can be ensured to a greater extent (Broekhoff et al., 2019).

A carbon credit project needs to determine the emissions that would have occurred if the project is not implemented, called baseline emissions (Miltenberger, Jospe, & Pittman, 2021). Baseline emissions function as the reference point the emissions removed or reduced are calculated against and are tightly linked to the project's additionality. The carbon credits in a project are calculated by taking the project emissions from the baseline emissions. Baseline emissions can be more challenging to determine depending on the project, and with more considerable uncertainties, there is a risk of overestimating the carbon removal potential or emissions avoided (Broekhoff et al., 2019).

Carbon credits can broadly be issued in two ways, ex-ante or ex-post. Ex-ante means an upfront payment from the carbon credit buyer beforehand without issuing any carbon credits. Ex-post is characterised by the fact that there is only payment after the credit has been issued (Foster, Wang, Auld & Cuesta, 2017). Ex-ante carbon credits are projected to happen in the

future and can rely on payment from buyers. Ex-post means a project already occurs, but payment is usually delivered after the carbon credits have been verified (Lee, Ingalls, Erickson & Wollenberg, 2016).

Carbon credit projects often can produce social and environmental benefits not included in the carbon credit itself, which goes beyond the CDR; these are called co-benefits. Co-benefits can be different depending on the type of carbon credit project. Some examples of co-benefits are biodiversity and habitat conservation, improved community employment and improved educational and health services (Broekhoff et al., 2019).

Carbon credit projects in carbon markets include CDR projects and emissions reductions/avoided emissions projects (von Avenarius, Devaraja & Kiesel, 2018).

Table 2. Overview of different carbon credit projects in carbon markets.

Carbon credit project	**Project type**
Forestry & Conservation	Removal/Avoided emissions
Renewable energy	Avoided emissions
Community projects (i.e. cookstoves & borehole maintenance)	Avoided emissions
Waste to energy	Avoided emissions
Biochar	Removal
Carbon storage (BECCS & DACCS)	Removal
Agriculture management	Removal/Avoided emissions

Comment: Based on the United Nations Carbon Offset platform (N.D) & Williams, Reay & Smith (2023)

Afforestation and Reforestation (AR) and Improved Forest Management (IFM) have long been one of the more common and established methods to sequester carbon. Forestry and conservation have been seen as beneficial due to their natural ability to store CO_2 from the atmosphere and reduce CO_2 emissions from deforestation and forest degradation. However, forest carbon credit projects have also gotten critiques based on the baseline setting, permanence, leakage and additionality. Baselines mean the accuracy of how it is counted, permanence focusing on how long the sink lasts, leakage covering the risk of double counting or claiming and lastly, how additional a project is (Espejo, Becerra-Leal & Aguilar-Amuchastegui, 2020).

Traditional cooking methods are widespread in low-income countries. These traditional methods use fuels such as wood and charcoal, which create severe health and environmental risks. Therefore, a solution is to provide large-scale adoption of more efficient cookstoves that are more fuel efficient and produce less smoke. Carbon credits have provided an attractive option to help scale up the improved cookstove projects since credits can be issued for the emissions that are avoided by using the new cookstoves. However, cookstove carbon credit projects can face challenges regarding the accurate accounting of the avoided emissions and the lack of financial, technical, and human resources required for successful implementation (Lambe, Jürisoo, & Johnson, 2015).

The supply and demand of carbon credits have been more centralised to specific regions. Even though all regions have the possibility for CDR projects, it is not necessarily the same kind (Strefler et al., 2021). Significant mitigation opportunities exist in the agriculture and forestry sectors, especially in LM countries. For example, in the African region, there is a strong possibility to increase the economic potential from the total mitigation potential in the agriculture sector (Lee, Ingalls, Erickson & Wollenberg, 2016).

2.3 Policy mechanisms and instruments

Several instruments are trying to govern the use of carbon credits. The principles for attempting to steer carbon markets can be national, international and within the private and the public sector (Michaelowa, Shishlov & Brescia, 2019). In order to promote efficient climate change mitigation, market-based mechanisms put a price on the emission of greenhouse gases. Generally, two approaches, emissions trading schemes (ETS) or crediting mechanisms, have led to creating and governing carbon markets. ETS usually functions under a cap-and-trade system, meaning there is a fixed upper limit on emissions. Then, the emission permits can be auctioned out or distributed based on different criteria. Crediting mechanisms generally are baseline-and-credit systems and have no fixed limit on emissions; instead, you have a baseline of emissions that you work towards, and it is possible to use credits for things such as climate targets or fulfilling regulatory measures (Carbon-Mechanisms, N.D).

Previously there was an existing market mechanism under the Kyoto Protocol, the Clean Development Mechanism (CDM). CDM allowed a country with emission-reduction commitments to implement emissions-reduction projects in low-income countries. The projects could earn certified emission reduction (CER) credits which equalled one tonne of

CO_2, which then was possible to count towards Kyoto targets. The Paris Agreement replaced the Kyoto Protocol as the legally binding climate treaty (UNFCCC, N.D).

Article 6 of the Paris Agreement, which has several sub-paragraphs, is a crucial governing mechanism for carbon markets. Article 6 establishes international cooperation, including carbon market mechanisms, among others, to achieve nationally determined contributions (NDCs). Within Article 6, Articles 6.2 and 6.4 govern mechanisms in the carbon markets. Article 6.2 is a cooperative approach that recognises that Parties under the agreement can choose to 'internationally transferred mitigation outcomes' (ITMOs) made abroad to achieve their NDCs. Countries wanting to transfer the emission reductions internationally using ITMOs need to report and adjust for these, making a corresponding adjustment. Furthermore, parties must secure environmental integrity and provide robust accounting measures to avoid double counting. There are several robust accounting principles and parts to ensure environmental integrity under Article 6. Double counting means the emission reduction is claimed and counted more than once. For example, the buying country claims the carbon credit unit and the host country where the mitigation efforts are happening. To avoid double counting, the involved parties must make a corresponding adjustment (Schneider et al., 2020).

Article 6.4 establishes a mechanism with international oversight that credits emission reductions possible to transfer and use by other countries to fulfil their NDCs (Schneider et al., 2020). Article 6.4 in the Paris Agreement regulates the parties to cooperate voluntarily to achieve their emission reduction targets and goals in the NDCs. The agreement also regulates the buying of carbon credits both on the compliance and voluntary side. Through Article 6.4 in the Paris Agreement, companies will also be able to get their emission reductions credited as with countries so they can be sold to another entity. The buying party can use the carbon credit to comply with their emission reduction obligations or use it to reach a net-zero target (UN, 2015).

In November 2022, the European Commission published its proposal for the first EU-wide voluntary framework to create a reliable system for high-quality carbon removals within EU borders. The commission's proposal intends to boost innovative CDR technologies and sustainable carbon farming solutions while simultaneously contributing to the environmental and zero-pollution goals set by the EU. With the new proposal, the EU hopes to increase its capacity to monitor, quantify and verify carbon removals to improve transparency. Higher

transparency provides an opportunity to create trust between stakeholders and the industry and prevent greenwashing. Furthermore, the proposed regulation has established four criteria called QU.A.L.ITY to ensure the comparability of CDRs. The criteria are based on quantification, additionally, long-term storage and sustainability (European Commission, 2022).

The proposal from the commission will be discussed and negotiated by the European Parliament and Council. Using the QU.A.L.ITY criteria, the Commission and an expert group will produce tailored certification methodologies for the various CDR methodologies. The first meetings for the expert group are set to be in the first quarter of 2023 (European Commission, 2022). Furthermore, the Commission introduced a proposal in March 2023, the Green Claim Directive proposal, with the goal of tackling misleading claims from companies regarding voluntary environmental claims on products and processes. The proposal will also target claims relying on carbon credits. The proposal includes requirements on the carbon credits' integrity and the accounting's correctness. European Parliament and the Council must approve the Green Claims Directive proposal before implementation (European Commission, 2023).

Voluntary carbon markets have also seen new governance mechanisms. For example, the Integrity Council for the Voluntary Carbon Market, also called ICVCM, is a newly founded independent governance body with the goal of providing global standards for high-quality carbon credits (ICVCM, 2022). Another example of a new initiative for CDR in the voluntary market is the Voluntary Carbon Markets Integrity Initiative (VCMI), a platform with multiple stakeholders. VCMI has, for example, developed a claims code of practice to function as a guide for credible claims and the use of carbon credits (VCMI, N.D).

2.4 Biochar as a CDR

Biochar production, shown in Figure 1, is biomass heated under oxygen-limited conditions, which can also be explained as pyrolysis of organic materials, forming firm carbon structures. Biochar is used to store carbon. Using biochar in agriculture can have benefits since it can increase soil fertility and be used as a carbon dioxide removal technique (Sundberg et al., 2020). Instead of returning CO_2 to the atmosphere when organic materials die, the carbon is captured in the ground (Stover, 2019). Biochar's environmental and climate effects can differ depending on the type of biomass feedstock used, the local soil properties and climate conditions and the management and application practices (Tisserant & Cherubini, 2019).

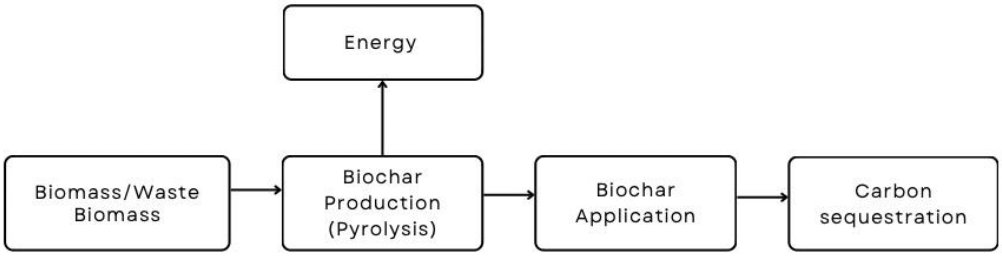

Figure 1. The different aspects of the biochar product as a CDR (Based on Sundberg et al., 2020).

Biochar can be produced in several ways ranging between industrial biochar production systems and biomass-fuelled cook stoves. The cook-stove-based system produces biochar by using biomass as the fuel source. Using a biochar cooking system reduces emissions and produces less smoke than traditional open fires. The emission reductions come from increasing the stove efficiency, which leads to lower biomass used for fuel and cleaner cooking heat production. Furthermore, it provides fuel wood savings when the wood is replaced with waste biomass, and the finished biochar product can increase crop yields when placed in agricultural soil (Sundberg et al., 2020).

Biochar is one of the most affordable CDR technologies for relatively long-term storage and has relatively low risks for adverse environmental impacts. Furthermore, biochar can be seen as a novel technique meaning a relatively new technique, and there is a need for the rapid growth of novel CDR (Smith et al., 2023). The carbon sink from biochar can be estimated in several different ways. Globally, it can be estimated that biochar can contribute to a carbon sink of up to 2,000 million tonnes per year. Biochar could account for between 5-15% of the global cumulative CDR needed (Tisserant & Cherubini, 2019). Furthermore, the potential of retaining biochar in the ground can be over 1000 years (Stover, 2019). During tests in the field, the residence time can be estimated very differently. However, biochar is nonetheless a more permanent and long-term storage (Tisserant & Cherubini, 2019).

Historically biochar has not been included as a CDR technology in compliance markets since most CDR methods within the land use, land-use change, and forestry (LULUCF) sector was not included in the CDM because of significant scientific uncertainties. CDM allowed a country with emission-reduction commitments to implement emission-reduction projects in developing countries. The LULUCF sector covers activities removing GHG from the

atmosphere through terrestrial systems such as land and forests (Olsson, 2023). However, biochar has recently attracted interest in voluntary markets. The demand for biochar in voluntary markets is growing, which has led to several new standards being developed for measuring and verification (Luckhurst, 2022). Several product quality certifications for biochar now exist on voluntary markets, such as the EBC (European Biochar Certificate) and International Biochar Initiative (IBI) (Lehmann & Joseph, 2015).

3. Multi-actor governance (MAG)

Multi-actor governance (MAG) is characterised by the acknowledgement of the state and its many composite organisations and the participation of non-state actors, such as businesses and consumers, in the policy domain (Vukasovic et al., 2018). The participation of several actors spanning across levels is something that characterises carbon markets (Mathur et al., 2014). It is essential to identify the actors that are often more influential in decision-making, which are actors with formal positions in the governing structures. Regardless, it is crucial to broaden the scope and include actors that might not have a formal role in the governing system but have a strong influence (Vukasovic et al., 2018). The multi-actor model is characterised by the inclusion of actors from the public and private sectors (Poponi et al., 2021). This makes it a relevant framework and approach for analysing the biochar carbon credit value chain and small-scale biochar production in voluntary and compliance carbon markets.

Carbon market initiatives and projects are signified by the involvement of an increasing number of stakeholders (Mathur et al., 2014). Multi-actor governance arrangements arise since climate change is a global issue with local impacts and causes which creates a need for solutions spanning local and global levels. Even though carbon markets are signified by market collaboration, they are also covered by several governance structures and policies, such as formal ones, such as the Paris Agreement and the Kyoto Protocol previously or voluntary governance initiatives, for example, several carbon credits standards. The governance structures of carbon markets have been more driven by market forces historically before more formal governance structures have been decided on at the UNFCCC Conference of the Parties (COP). It is a time-consuming process negotiating the specific terms and arrangements for carbon markets at COP, and it is a process that can span several years, which leads to before an overall institutional framework might be in place, voluntary governance initiatives can shape carbon markets (Mathur et al., 2014).

It is vital to identify governance. In the context of collective action, governance is a dimension with cooperatively decided norms and rules to regulate group and individual behaviour. Furthermore, governance is a group of monitoring and coordinating activities that enable the existence of collaborative partnerships and institutions. Governance is defined by the numerous actors involved at multiple levels, international, national, and local, and spanning large groups such as NGOs (non-profit organisations), businesses, citizens, various policy departments and governmental bodies (Koopmans et al., 2018). Furthermore, it is

essential to understand what identifies an actor. The definition of an actor is collected from Avelino & Wittmayer (2016), who state that an actor is a social entity, either a person or organisation or a group of persons or organisations, who can act.

Multi-actor governance allows non-governmental actors to take different steering initiatives by using informal and formal connections to find new and innovative answers to complex societal issues, and new policies can be made collaboratively (Newell, Pattberg & Schroeder, 2012). The MAG approach sparks self-regulating processes and reduces government control. Multi-actor governance creates connections among the involved public, private and civil actors. The actors within MAG can often have different perspectives on issues, solutions, and the appropriate courses of action (Craps et al., 2019). Regardless, cooperation between all actors might be needed to achieve sustainable transitions and reach efficient governance systems for sustainable challenges (Stupak, Mansoor & Smith, 2021).

Environmental issues are caused by a broad spectrum of actions and behavioural patterns spanning the public and private sectors. Furthermore, it covers topics fundamental to human development, for example, water, food, and energy; therefore, the governance must be multi-actor (Newell, Pattberg & Schroeder, 2012). The struggle to make sure that several actors work together is at the centre of many 'wicked' sustainability issues. The need for cooperation among actors crossing scales, contexts and spanning over time is critical to be able to fulfil the Sustainable Development Goals (SDGs) the UNs set goals for 2030 (Bowen et al., 2017). Multi-level governance arrangements often emerge since climate change is a global issue and spans local and global levels (Mathur et al., 2014).

Broadly, actors can be divided into state and non-state actors (NSAs). States can have an issue handling large-scale environmental issues alone, which can lead to NSAs taking a more significant responsibility and providing experimental approaches and innovative solutions (Newell, Pattberg & Schroeder, 2012). NSAs consist of private and hybrid actors that can form new partnerships and networks. According to Newell, Pattberg & Schroeder (2012), public actors can be governmental organisations, cities and international organisations and regional environmental governance arrangements. Hybrid actors are, for example, public-private partnerships (PPP) and transgovernmental and transnational networks and partnerships. Private actors can be multinational companies, private philanthropic foundations, and individuals (Newell, Pattberg & Schroeder, 2012).

Effective multi-actor sustainability governance requires different competencies since no actor usually has all of them, and Schut et al. (2014) proposed four critical competencies regarding biofuels. Still, these can be relevant for biochar and carbon markets as well. The four critical competencies are independence, representation, different types of expertise and operational capacity. Independence is the capacity to develop and promote political, administrative, and judicial procedures. Representation relates to the capacity to ensure the representation of key actors and stakeholders, enhancing credibility, legitimacy, and relevance. Operational capacity creates authority and can mobilise the financial and human resources necessary for development, enforcement, and implementation. Expertise can be divided into four sub-categories normative, audit, political and business. For example, international actors can have the opportunity to develop meta-standards but lack or have limited possibilities to enforce them. On the other hand, nation-states often do have the legitimacy needed to implement sustainability governance, but especially in developing countries, they need more capacity for enforcement. Looking at NGOs, they can require more operational capacity even if they have a strong normative commitment. On the other hand, the private sector has a solid operational capacity but is not independent. Finally, researchers as an actor are generally independent and have advanced expertise but lack robust operational capacity and political influence (Schut et al., 2014).

4. Method

The method for this thesis combined a literature review and qualitative interviews. The literature review provides an overview of the research topic and shows the knowledge gaps where qualitative interviews are needed.

4.1 Literature review

The goal of a literature review is to gather and summarise existing research. Furthermore, it is a suitable method to provide an overview of interdisciplinary research fields and to discover knowledge gaps and areas where more research is needed. However, without following a specific methodology, there is a risk that the literature review is conducted ad hoc and lacks thoroughness, leading to questionable quality (Snyder, 2019).

Several literature review approaches exist, such as systematic, semi-systematic and integrative. Depending on the aim and execution, a particular type of approach can be suitable. For example, systematic reviews have strict requirements regarding the search strategy and inclusion criteria. A systematic approach can be practical when a specific question needs to be answered. However, having a broader approach, researching an interdisciplinary field, and wanting to identify knowledge gaps, a semi-systematic approach can be a better fit (Snyder, 2019). Therefore, this study chose a semi-systematic approach since it aligns with the aim and research question of finding and filling the knowledge gap by mapping information. It was also suitable to combine with qualitative interviews.

The foundation of the literature review sources was scientific articles collected through databases, mainly Web of Science, Scopus, and Google Scholar. Furthermore, some reports and public documents from research institutes, NGOs and international organisation sites were used. Search words were chosen to ensure relevance to the research questions, and through trial searches, it can be found which search words provide the most articles in relation to the aim. Furthermore, using synonyms is valuable since not all articles use the same wording (Xiao, Y., & Watson, 2019). The search words used were Biochar, CDR, voluntary/compliance carbon markets, carbon credits, carbon offsets, low- and lower-middle-income countries, smallholder farmers, small-scale, negative emission technologies, sustainability, multi-actor governance, and actors. The search words were used in different combinations to ensure that the most relevant articles could be found.

To ensure transparency and a systematic approach possible to replicate, the date of search, the search string and the procedure were documented. This also made it possible to quickly identify if new articles were published during the time period the thesis was written. Furthermore, when choosing articles to include, it is crucial to relate to the research questions; if not, they should be excluded (Xiao, Y., & Watson, 2019). The inclusion criteria were set loosely to be flexible and able to find a broader range of perspectives in the literature. However, some criteria were developed, such as a date range and relation to the research question. Since this is a fast-developing research field and new regulatory aspects have come into place, articles older than 2012 were excluded. Connection to the research question was checked by reading abstracts.

4.2 Qualitative interviews

When doing interviews, there is a possibility to choose a qualitative or a quantitative approach. A qualitative approach was chosen since it is more relaxed than quantitative interviews and opens the possibility of receiving more detailed and profound answers. Using a qualitative approach provides more freedom which can lead the respondent to discuss more from their perspectives and elaborate on their views (Bryman, 2016). Non-structured interviews would complicate comparing the respondent's answers since there are several actors to interview. If the interviews were fully structured, there would be no room for adjustments and flexibility depending on the actors' answers. A thematic analysis could be suitable for coding and analysing the interviews. The method suits this project since it categorises the answers into different themes (Magnusson & Marecek, 2015).

4.2.1 Selection of respondents

When selecting the number of respondents, there is no definite answer to the perfect number. For example, some studies require several respondents to conduct a profound analysis. In other studies, a few respondents might be enough if the interview material is sufficient (Magnusson & Marecek, 2015). The risk of having an extensive selection is that it is difficult to conduct a thorough analysis, and with a too-small sampling, no theoretical saturation is met (Bryman, 2016). Due to the timeframe, twelve respondents were the amount suitable for conducting in-depth and rich interviews and analysing them thoroughly. Twelve respondents were also seen as fulfilling the need for theoretical saturation.

The selection of respondents started with purposive sampling. Since the study's goal was to gain knowledge on different actor perspectives, it was necessary to ensure that the different

actor perspectives in the value chain were included. Purposive sampling aims to find relevant respondents to the research questions (Bryman, 2016). The criteria for choosing the first set of respondents were: knowledge about voluntary or compliance carbon markets, biochar, carbon projects or carbon credits or the topics combined. The criteria were seen as equally important, but it was crucial that not just actors knowledgeable about the same criteria was interviewed. Therefore, actors were systematically selected by at least having knowledge about one criterion. The first selected actors were found by searching online on different websites, including these types of actors or writing about biochar projects, reading articles and through some recommendations from the supervisor. Furthermore, they needed to be an actor in carbon market's value chains—however, the sampling size needed to be increased to reach theoretical saturation. Therefore, the actors were used as door openers and snowball sampling was used to increase the number of actors to interview. It was important that different actors were included and that most value chain actors and perspectives were included to get a multi-actor perspective. When the project was closer to theoretical saturation, value chain roles that were not yet represented were prioritised.

Snowball sampling means choosing a group of actors who is relevant to the research questions, and the selected group of actors recommends further respondents who would be suitable. The respondents were asked if they had any recommendations of organisations or people who would be relevant to the interview. The method can have certain drawbacks, such as the selection can be targeted in a specific direction due to the knowledge and choices of the door opener (Dalen, 2015). Moving the selection in a particular direction was tried to be avoided by increasing the representatives from different value chain groups. Furthermore, snowball sampling was seen as an appropriate starting point due to needing more personal contacts within the field and the difficulty of finding appropriate actors through other sampling methods. Furthermore, according to Bryman (2016), an advantage of the technique is that it is possible to find connections between actors in a network which was a part of the research questions for the study.

Theoretical saturation is reached within a category when data analysis reveals no new properties, dimensions, or relationships (Bryman, 2016). After twelve interviews covering most of the actors in the value chain seen in Figure 2, it was found that it was much reoccurring information, and no new properties, dimensions, or relationships emerged. Therefore, theoretical saturation was reached, and it was no longer necessary to continue selecting respondents. The actors were also seen as more representative since, in most cases,

there was more than one actor from the same value chain group. Furthermore, if there were many suggestions on similar value chain roles, they were not prioritised until more value chain roles were covered, and then more actors in similar groups were added.

4.2.2 Interview guide

Before conducting the interviews and writing the interview guide, the interviewer must have adequate knowledge about the subject (Kvale & Brinkmann, 2014). Therefore, the literature review was done before the interviews to ensure that relevant questions were asked and that the interview guide was relevant to the respondent and the study's aim and objectives, as Dalen (2015) points out. The interview guide see Appendix 1, was therefore designed with the existing knowledge, aim and objectives as the baseline. All interviews had the same outlines with the same headings. However, the interview guides were also tailored to fit the specific actor's position since a broad mix of actors was interviewed. They have different roles in the value chain, requiring questions from different perspectives. Furthermore, half of the interview guides were in Swedish and half in English.

The interview guides, as seen in Appendix 1, started with introduction questions to ensure a relaxed environment where the respondents felt comfortable. After the introduction questions, the rest of the guide was divided into themes. Each interview guide had four themes: sustainability, carbon markets, biochar projects and carbon credit value chain actors. The themes were created based on the findings from the literature review and were created from identified knowledge gaps and the possibilities to contribute to fulfilling the objectives. All the themes consisted of several questions, and they were made to be open-ended, meaning no yes or no questions were asked so the respondents could answer openly to the questions. All interview guides also had an ending section where the respondents could add information if they felt anything was missing during the interview. The ending sections also had a question asking if the respondents had any recommendations on more possible suitable people to interview. Adding open questions where there is a possibility to add comments at the end of the interview freely allows the respondents to feel heard and increase the chances of having a good experience during the interview (Kvale & Brinkmann, 2014).

A general set of questions was sent to the respondent a few days before the interview. Bryman (2016) points out that sending the questions in advance can affect the answers since the respondents could decide what to say beforehand. However, it can also be an advantage since the answers might be more well-founded, and the respondents can ensure they can answer the

questions with the best information available. Furthermore, follow-up questions were asked, which were not sent beforehand since they were made up during the interview. Finally, a set of control questions was also asked during the interview, which was not sent with the interview guide since it could possibly lead the respondent in a specific direction.

4.2.3 Conducting the interviews

To refine the interview guide, test interviews were held. The test interviews were done with colleagues from KTH since they have some fundamental knowledge about the topic. Magnusson and Marecek (2015) stress that holding test interviews is helpful to be more confident as an interviewer and refine the questions to be better suitable.

All interviews were conducted online due to the distance, different time zones and facilitation of finding an appropriate meeting time. Video calls were chosen as the preferred setting compared to emails since essential features such as body language and the possibility for in-depth discussions would be lost since that is not possible in text format. An advantage of doing the interviews online is that it increases the chances of the respondent agreeing to the interview due to the flexibility and possibility to make last-minute changes. The negative aspects of an online interview can be the risk of a bad internet connection or technical issues that deteriorates the sound quality or leads to hiccups in the conversation flow (Bryman, 2016). The time span for all interviews was between 30-45 minutes long except for one conversation held with an end-buyer which was done briefly over email.

The interview was conducted online to reach several locations, and many of the respondents are located or have projects in Africa or Asia. The respondents were labelled with a number to keep them anonymous. They were labelled according to their value chain role and a more general description of the company or organisation to see the connection between those. Several respondents also have more than one value chain role.

Table 3. Information regarding the interviews.

#	**Respondents**	**Value chain role**	**Location**	**Time**	**Date**
1	Impact venture	Project developer & Biochar Producers	Africa &Asia	45 minutes	2023-02-22
2	Environmental Consultant	Carbon Credit Retailer	Sweden (Projects in Africa & Asia)	38 minutes	2023-02-23
3	Swedish Environmental Protection Agency	National Climate Targets & Climate Reporting	Sweden	35 minutes	2023-02-24
4	Biochar Consultant	Project Developer & Carbon Credit Retailer	Sweden (Projects in Africa & Asia	40 minutes	2023-03-02
5	Project Manager	Project Developer	Africa	46 minutes	2023-03-02
6	Biochar Consultant	Carbon Credit Retailer	Europe	33 minutes	2023-03-02
7	Standard Organisation	Standard/Registry	Global	30 minutes	2023-03-02
8	Project Developer & MRV Company (Measurement, reporting, verification)	Technical Provider & Project Developer	Asia	45 minutes	2023-03-07
9	The Swedish Energy Agency	Buying Country	Sweden	44 minutes	2023-03-14
10	Environmental Consultant	Carbon Credit Retailer & Project Developer	Africa	35 minutes	2023-03-22
11	Food sector company	End-Buyer	Europe	30 minutes	2023-03-27
12	Food sector company	End-Buyer	Sweden	Email correspondence	2023-03-30

All interviews followed the same setup where first, more in-depth information about the thesis was presented, and it was checked so that they had received the GDPR information. All the respondents were then asked to consent to record the interview leading to most of the interviews being recorded. Most of the interviews were recorded with a telephone for the possibility of later transcribing the material. Two devices were used to record to have a backup if a human error or any technical issues occurred that would make the recording stop. Digital recordings can also be crucial since they allow backups of the material (Bryman, 2016).

4.2.4 Analysing the material

The interviews were transcribed word for word to start to analyse the interview material. A risk with transcribing spoken material is that nuances from the conversation get lost, such as emphasis on words and gestures (Bryman, 2016). In order to prevent significant losses from happening, notes were taken during the interview. Furthermore, a challenging aspect of transcribing the interviews is that the sound quality can be very different depending on the recording leading to potential difficulties in hearing certain words and phrases. To allow the respondents to point out errors and make corrections from the interviews, they were sent the transcribed material or direct quotes to be used in the thesis after the interview.

The interviews were held in Swedish and English, with a split of 50/50, meaning half in Swedish and English. Due to some interviews being in Swedish, the Swedish transcription had to be translated into English to maintain one language. A risk with doing the translations is that it might affect quotations, and some significance may get lost in the translation.

The transcribed interviews were analysed through a thematic analysis which is often a very suitable method for qualitative data. A thematic analysis identifies, interprets, and analyses themes in a qualitative data set. A thematic analysis is helpful since it is a systematic and accessible way of providing codes, and themes and motifs in a text can be identified. In addition, a thematic analysis identifies patterns in the material and can frame critical aspects relating to the research question (Braun & Clarke, 2022). A distinction with thematic analysis is its flexibility, meaning the application is comprehensive (Bryman, 2016), and therefore, it was seen as a suitable analysing method of the material.

Conducting the thematic analysis followed the steps from Braun and Clarke (2022). The steps included making initial codes, looking for themes, and reviewing, defining and naming themes. Codes are the smallest analysing unit and are the basis for creating themes and functions to find interesting aspects from the data collection that can relate to the research question. The codes were created to be able to organise the transcribed material better. Themes are larger patterns used to create meaning, and themes provide a framework to organise, analyse and interpret the data (Braun & Clarke, 2022).

The themes from the interview guide functioned as a starting point in the analysing process, and the research questions guided the thematic analysis. Certain common criteria were used to

identify new themes, such as repetitions, similarities and differences, and relevance to the research focus (Bryman, 2016). By coding the material, new themes were developed, and sub-themes which are smaller themes within the main themes. The reviving phase included refining the material by re-reading it and looking for any missed aspects to ensure that the main findings were reflected in the themes. Sub-themes were also revised in order to improve the structure of the themes. During the last step of defining and naming the themes, it was defined what the essence of a theme was and what a theme included and not. Ensuring a thorough thematic analysis is critical not to miss any crucial steps. Therefore, all the steps were followed.

The thematic analysis resulted in four main themes being developed and used as a basis for the result and discussion. The themes established during the thematic analysis were biochar carbon credit actors, carbon markets, drivers and barriers for biochar in carbon markets and sustainability. In addition, each theme had one or more sub-themes which guided the analysis and provided a structure for the setup of the result and discussion.

4.2.5 Ethical considerations

Ethical considerations are essential to take into consideration when doing interviews. The ethical aspects include informing the respondents about what their participation includes and that they understand it (Kvale & Brinkmann, 2014). The respondents got information about the study's aim and personal data handling before the interviews. The study was discussed during the interviews to ensure the respondents had all the information needed to understand their participation. Furthermore, an essential aspect in considering the respondent's ethical rights is that they have the right to confidentiality and anonymity, and their participation in the study is voluntary (Magnusson & Marecek, 2015). Therefore, all respondents were anonymised, and the recordings were only accessible to the author. The respondents also could drawback the consent at any time.

4.3 Reliability and validity

The following section will show how the thesis connects to reliability and validity and how that has been established. Reliability concerns the trustworthiness of a study. Validity refers to the appropriateness of the used data, tools, and processes (Leung, 2015).

4.3.1 Reliability

In quantitative research, reliability focuses on the replicability of a study and the results. However, qualitative research has various paradigms which make that definition problematic. Instead, in qualitative research, reliability refers to consistency (Leung, 2015). Reliability can be increased if the study can demonstrate a thorough and systematic nature through various processes. An example is to have thorough documentation of the different methodological procedures so that others can follow the same process easily. Recordings, transcripts, and notes can also be reviewed to minimise the risks of mistakes and misunderstandings. It is also vital to ensure that themes and codes are clearly defined to have a consistent process and avoid misunderstandings (Rose & Johnson, 2020).

Reliability was established by maintaining thorough documentation of the research process and providing transparency on the methodological procedures, for example, by providing interview guides and thematisation. Furthermore, the respondents could review the interview transcripts, quotes, or notes to ensure no misunderstandings were made.

4.3.2 Validity

In qualitative research, validity focuses on relevance with the aim and research questions. Firstly, it is vital to check the accuracy of the research question to the aspired outcome and the methodology choice and if there is an appropriate size of data and data analysis. Lastly, it is also crucial that the results are accurate to the sample and context (Leung, 2015). There are several techniques relating to trustworthiness and validity in qualitative research, and there is a wide range of options to choose from, such as member checking and triangulation. Since a wide range of options for trustworthiness techniques exist, one form of validity option is likely more suited for a specific qualitative study (Rose & Johnson, 2020).

Ensuring validity was made by using triangulation. Triangulation aims to view and analyse the topic from multiple directions. When viewing a topic from multiple directions, biases from using material from a single method or researcher can be avoided. By using several techniques, the idea is to present the topic more accurately. There are four types of triangulation. The four aspects focus on data sources, the number of researchers, multiple theories and various methods. Methodological triangulation promotes using several methods for data collection (Rose & Johnson, 2020). This study used methodological triangulation by combining a literature review with qualitative interviews.

5. Results and discussion

The Result and discussion section will present the key findings from the literature review and the interviews using a multi-actor governance approach. Several interviewed respondents have more than one role in the value chain. To keep the anonymity of the respondents and increase the readability of the results and discussion, the respondents are labelled with numbers, and one of their roles, for more information on the interviewed actors see Table 3.

5.1 The biochar carbon credit value chain

Several actors are involved in carbon credit value chains on voluntary and compliance carbon markets (Figures 2 & 3). The number of and which actors that are involved can be slightly different depending on whether it concerns voluntary or compliance markets.

5.1.1 Voluntary markets

The voluntary biochar carbon credit value chain consists of many different actors, as seen in Figure 2. At the beginning of the value chain, the project developers design and develop different projects where biochar is developed (Favasuli & Sebastian, 2021). Then there are the developers of standards and certifiers who verify and work on improving the standards, two roles that occasionally require separation. Then comes the carbon credit retailers who choose, assess, and sell the projects. The target group for buying carbon credits can be public agencies, companies or private consumers wanting to invest in carbon credits. The biochar carbon credit chain is characterised by the cooperation and participation of several public, such as local governments, and private actors, such as project developers, an essential aspect of multi-actor governance (Poponi et al., 2021).

Project developers can take on the role of intermediaries in the value chain and bridge actors together, such as smallholder farmers with end-buyers of the carbon credits (Lee, Ingalls, Erickson & Wollenberg, 2016). In addition, project developers can provide technical support, emphasise co-benefits with the application, help secure payments for smallholder farmers and help them increase efficiency. Project developers also tend to communicate the objectives of the carbon credit project to interested investors and donors to secure funds and assist with the start-up costs. Intermediaries can be crucial in MAG in order to strengthen the commitment of different actors, bring up competencies from less represented actors such as the smallholder farmers and ensure the process is ongoing (Schut et al., 2014).

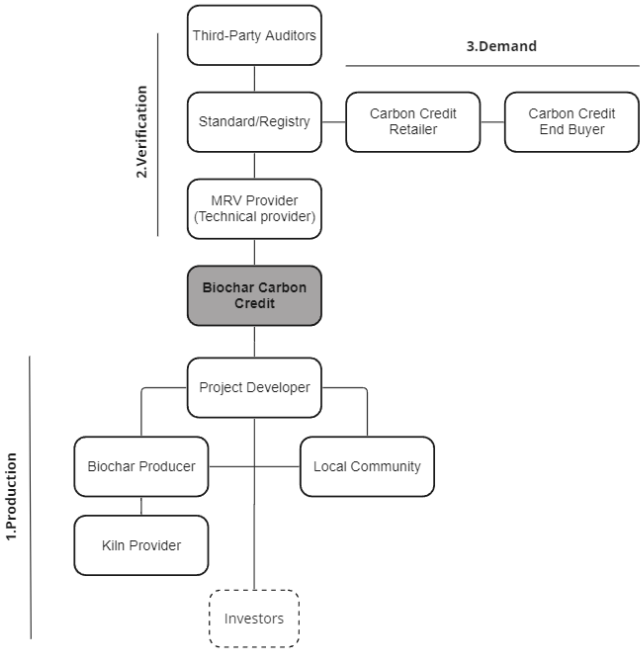

Figure 2. Simplified mapping of key actors in the biochar value chain on voluntary markets. (Based on the interviews).

Depending on the approach, the role of the investor can be different (Foster, Wang, Auld & Cuesta, 2017), and it has therefore got its own shape in Figure 2. For example, with an ex-ante approach, where there is an upfront payment from the carbon credit buyer before carbon credits are issued, the end-buyer can finance the project more significantly, and the same initial investment might not be needed. Conversely, with the ex-post approach, a more significant initial investment might be required since payment only comes from carbon credits after they have been issued. As a result, investors, buyers, and project developers often have the power in carbon markets to influence vital decisions (Mathur et al., 2014).

From a project developer perspective, small-scale community carbon projects can be introduced through a general meeting with local stakeholders (5, Project Developer), and usually, there are no major challenges in getting acceptance from the local community (Siedenburg, Brown & Hoch, 2016). Furthermore, project developers generally can start with incremental introductions and local stakeholder consultations where smaller groups are targeted, and when these have gone through a pilot phase, more communities could be engaged (Broekhoff et al., 2019). As a project developer, using small districts and scaling up slowly might reduce the risks of releasing concerns from local governments or community leaders (5, Project Developer). However, if it is a larger project, it can require more

justification and verification. Gaining approval from regulatory agencies, the community, or local governments can be more significant and challenging for larger-scale pyrolysis plants (Rogers et al., 2022). Furthermore, small networks or cooperatives can be more adaptable and flexible, providing new insights into common governance structures (Koopmans et al., 2018).

Success in agricultural carbon markets with smallholder farmers depends on the ability to effectively bridge actors working at different scales, such as larger corporations buying thousands of tons and project developers working with smaller projects in several locations. According to Lee, Ingalls, Erickson & Wollenberg (2016), objectives for carbon sequestration and co-benefits can get lost without cooperation among actors since they have different knowledge and power and contribute to different aspects. Without bridging actors and scales, there is a risk of losing the win-win possibilities for agricultural carbon markets (Lee, Ingalls, Erickson & Wollenberg, 2016). Furthermore, it is essential due to the uncertainty and urgency of the effects of climate change and the need to address the adverse impacts that particularly affect people with low incomes (Eziakonwa & Gomer, 2022). From a carbon credit retailer and project developer's perspective, it is crucial that farmers are empowered and have the technology needed and that there are network lines with cooperatives, farmers and governments working properly for biochar to be applied effectively (10, Carbon Credit Retailer). Furthermore, cooperatives can have a facilitating function since it can be easier for them to reach and work with farmers. Cooperatives or peer networks can significantly bridge the gap between actors on the local and national levels and increase cooperation which is needed for multi-actor perspectives (Mathur et al., 2014).

The biochar value chain can be an example of where states are lagging behind, and private actors such as consultants, project developers, end-buyers and investors are driving development, which is brought up during the interviews. "What is fun about biochar is that the market itself really drives it, it is not researcher-driven, [...] it is driven by the market, farmers and energy companies, and the state is lagging behind." (4, Project Developer). In MAG, NSAs such as businesses and NGOs can often take on more significant responsibilities, experimental approaches and innovative solutions since states can have problems with handling environmental issues alone. New partnerships and networks are created to drive change and find solutions when states might need assistance to speed up solutions (Newell, Pattberg & Schroeder, 2012). On the other hand, from a governance perspective, it can be argued that sustainability transitions cannot happen solely relying on market forces and that it

requires innovative policies and support by more legitimate powers such as governments (Stupak, Mansoor & Smith, 2021).

5.1.2 Compliance markets

The project developer in the compliance market can often be a private actor that establishes and develops the project who can function as the intermediary working with investors to secure funds and bridge the gap with the buyer (Lee, Ingalls, Erickson & Wollenberg, 2016). Article 6.2 under the Paris Agreement requires bilateral agreements. However, this will not be required under the central market mechanism under Article 6.4 that will come into place in the future. Currently, the buying country negotiates with the project developers, but the host country also must authorise and approve the project. Ultimately the buying country decides on the project but with feedback from the host country (9, Buying Country). This also showcases the potential role as an intermediary that the project developer can have working with both the host and buying country. Cooperation between NSAs and state actors is a critical aspect of MAG (Newell, Pattberg & Schroeder, 2012). Compliance markets are a key example of NSAs such as investors, MRV providers, project developers, and state actors such as host and buying countries and UNFCCC collaborating.

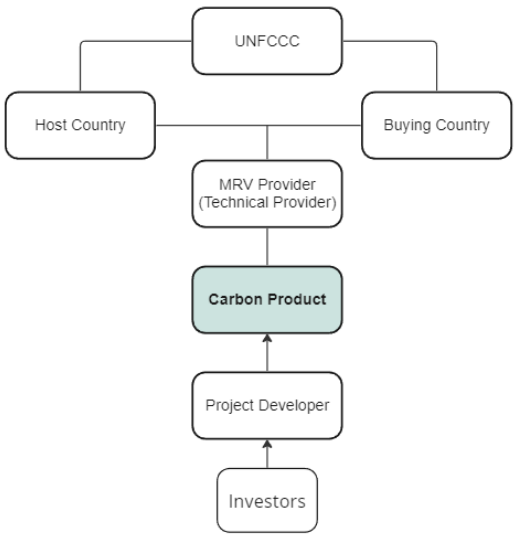

Figure 3. Simplified mapping of key actors focusing on the compliance side under Article 6 of the Paris Agreement. (Based on the interviews).

The figure of key actors for trading carbon credits between countries (Figure 3) does not contain details specific to biochar as it is not yet a CDR process included in compliance markets (Olsson, 2023). The role of the investor can be more significant when countries are trading credits since they generally follow an ex-post approach meaning there will be no payment made before credits have been issued (9, Buying Country). Multi-actor perspective can question the responsibilities and dependencies among actors, for example, states and private actors, such as businesses and investors. For example, which actors should be responsible for investing in long-term sustainability solutions and who can afford to contribute in risk-taking activities (Avelino & Wittmayer, 2016).

5.2 Drivers and barriers for small-scale biochar projects in LM countries in carbon markets

The following section describes the drivers and barriers for small-scale biochar projects in LM countries. Furthermore, it showcases the relationship between the carbon markets, the drivers and barriers for biochar, and whether carbon credits can facilitate or strengthen specific aspects.

5.2.1 Environmental and social aspects

In a study on biochar deployment drivers and barriers in least-developed countries, made by Fridahl et al. (2021), the carbon sequestration potential was found to be a driver for investors of projects and researchers to engage in biochar application to soils. However, biochar's carbon sequestration abilities can be abstract, and it can be challenging for smallholder farmers to link biochar application to climate benefits (Fridahl et al., 2021). For example, one of the carbon credit retailers discusses the perhaps low interest from smallholder farmers in carbon markets: “My experience is that farmers are not very interested in voluntary carbon markets. That is my job, and their perspective is that they want to be fairly paid for the work they put in [...]” (2, Carbon Credit Retailer). However, knowledge gaps about the carbon markets are often a significant barrier for farmers wanting to participate in them (Lee, Ingalls, Erickson & Wollenberg, 2016). Additionally, it can be challenging for project developers to access rural communities even though these have carbon sequestration potential within their communities and would benefit from carbon projects (5, Project Developer).

A possible benefit of biochar production is that it can increase crop yields for smallholder farmers. Increased crop yields are an essential aspect of food security; with increased crop yields, it is also another possibility to increase income since there will be more crops to sell (Tisserant & Cherubini, 2019). Nonetheless, it is essential that biochar is not threatening food

security, which is a risk if crops are grown solely to produce biochar. However, this risk can be reduced if waste biomass is used (Hansson et al., 2021).

Another vital aspect to consider is that agricultural soil erosion is a dangerous threat to food security and sustainability in agriculture among smallholder farmers in LM countries (Tisserant & Cherubini, 2019). Therefore, more agricultural benefits can be linked to biochar in LM countries with degraded soils or low agricultural inputs. Food security and increased crop yields for the smallholder farmers were mentioned as a driver during the interviews.

[...] Food security for the planet. Africa is going to be significant for food production, [...]. They deal with many droughts, and biochar could improve soil health and crop yields. You do not need to pay for expensive fertilisers, especially with the Ukraine war it is harder for smallholder farmers. So, I think food security, not just in Africa but globally, could be a significant driver for biochar. Farmers appreciate the additional income generated directly from carbon credit sales, and the crop yields are improved. That helps them feed their family and allows them to sell more crops at the market. Hopefully, those markets will get bigger and bigger because they can produce more crops than they consume personally, which helps the planet [...]. (1, Project Developer).

Another climate benefit to start adding biochar can be the environmental impacts not necessarily accounted for in the carbon credit (4, Project Developer). Adding biochar to soil can provide further indirect benefits on climate, such as storing more carbon in the ground due to increased production of roots and above-ground residues (Sundberg et al., 2020). Climate benefits beyond the carbon sequestrating accounted in the carbon credit abilities can be seen as a co-benefit. End-buyers are often interested in a range of co-benefits when selecting which credits to buy and can see it as a driver for choosing a specific project (Broekhoff et al., 2019). Furthermore, investors are also interested in the co-benefits and obtaining the maximal benefits from the carbon credits outside the carbon sequestered (Lee, Ingalls, Erickson & Wollenberg, 2016).

What you have to be aware of when you buy biochar as a carbon credit is that it has significant added value. On the biochar that we do not even include in the sink, that is, biochar is a carbon sink, yes, but above all, it is a physical product that can be a soil improver. There is research on the climate effect that is not included, such as the biochar contributing to humus content building up in soils, which causes more carbon to end up in the soil. There are side effects that are not counted, so you get a lot of added value, and it is possible to produce food on certain soils that cannot be used otherwise (4, Project Developer).

Adding value to waste can reduce pollution and increase resource recovery from waste which is essential for sustainable development. Finding technologies to manage residual biomass can

increase sustainability and enhance socio-environmental resilience (Kurniawan et al., 2023). However, there are technical barriers to overcome to increase the sustainable production of biochar from residual biomass (Song et al., 2022). Many smallholder farmers in LM countries have access to crop waste from their harvest, which can be used to make biochar (Kurniawan et al., 2023). Due to the number of farmers, there can be a large untapped potential to reduce waste and make it into a more sustainable product (1, Project Developer). Furthermore, the biochar-based C-sink certificates for smallholder farmers require that the farmers produce their biochar from residual biomass (1, Project Developer & 7, Standard/Registry).

Biochar production can potentially increase gender equality since there are many female farmers (1, Project Developer). Furthermore, women and children often collect firewood for cooking, which is time-consuming (Fridahl et al., 2021). Reducing the need to collect firewood might increase the time they can spend on other things, such as education (5, Project Developer). Using biochar cookstoves can also improve women's health since they are usually cooking, and it produces less smoke than cooking over an open fire (Sundberg et al., 2020). The gender dimension is important to consider for understanding biochar engagement among farmers. For example, more male farmers can decide on the usage and production of biochar compared to female farmers (Fridahl et al., 2021). Standards and certifications for biochar carbon credit can help ensure that gender equality is ensured through having demands on co-benefits and social aspects (2, Carbon Credit Retailer & 5, Project Developer). However, if the process of verifying the co-benefits lands on the smallholder farmers, it can increase the administrative burdens and costs for the farmers. It can instead be a barrier to entering carbon markets (Siedenburg, Brown & Hoch, 2016).

5.2.2 Training and education

The need for training and education to boost skill levels and increase awareness was found to be a key barrier for farmers in a follow-up survey made by Eltigani et al. (2022), of households who received biochar-producing cookstoves in Tanzania. Therefore, there is a need for training and awareness programs as well as field demonstration activities to increase the recognition of biochar's environmental and agronomic benefits (Eltigani et al., 2022). This might be an aspect that the carbon credit income can fund and reduce the barrier around training for smallholder farmers due to the income from carbon credits. Furthermore, the carbon credit income can help employ the local community when local staff run the training (1, Project Developer).

Farmers in low-income households tend to be very loyal to their established farm methods since they fear risks. Agriculture is often their primary income and crucial for a sustainable livelihood (Fridahl et al., 2021). This is emphasised by one of the consultants working with biochar and carbon project developers "[...] This is the livelihood for the farmer, and they get their money from farming. They are used to using chemical fertilisers because they know it works. Speaking with one of the biochar producers, this is one of the challenges." (10, Carbon Credit Retailer).

Understanding the value of applying biochar can be difficult for farmers. It is crucial for smallholders to understand the benefits of biochar application to soils for farmers to start using biochar (Fridahl et al., 2021). Furthermore, understanding the value of biochar is discussed during the interviews as a barrier for smallholder farmers and project developers in order to increase the use of biochar among farmers in LM countries. It can be both concerning the reason for applying it in the soils to increase crop yields or understanding the potential economic benefits of using biochar and selling carbon credits. One of the respondents explains it like this:

> Without biochar having value as an asset, it is very hard. Because the buyer of carbon credits wants to commit to buying many credits for a lower price. Without the price of the asset of biochar, it is hard to sell an affordable carbon credit in the tropics. Biochar has more additional benefits, but if there is no association to a price or a value of biochar, it makes it harder [...]. In one project we are working on in Sri Lanka, they value biochar because they use it in their fields. [...] They use their waste to produce biochar and then apply it to their soils. So, they have given value to the biochar in the number of chemical fertilisers they do not need to buy (8, Technical Provider).

When the benefits of biochar and selling carbon credits are understood among smallholder farmers, it can increase economic feasibility and environmental sustainability (Kurniawan et al., 2023).

5.2.3 Expenses and incomes

The revenue from selling carbon credits through biochar application can be seen as a motivation for starting to apply biochar and change behaviour around agricultural practices among smallholder farmers (Thengane et al., 2021). Furthermore, the increased crop yields and revenues from the harvests can also incentivise adopting of new agricultural practices (Lehmann et al., 2021). Additionally, there could also be cost savings related to biochar application for smallholder farmers since it can reduce the need for more expensive fertilisers.

"It depends on the farmer, but the credit sales are certainly a driver to switch to biochar or to making biochar. But once they have used it for a few seasons, they start to see the crop yield benefits, but then also, if it is a farmer that is perhaps bigger but still a small farmer, there are cost savings too, so there are several income impacts that are available to the farmers if they switch to biochar." (1, Project Developer)

The revenue and extra income might be short-term drivers to start applying biochar for smallholder farmers. However, in a long-term perspective, the increased crop yields might be more important for smallholder farmers (1, Project Developer). Biochar has been shown to possibly improve crop yields significantly in the African context, which is essential in a continent where the low productivity in agriculture is a significant challenge (Sundberg et al., 2020).

The price of carbon credits can have large variations due to various factors such as production costs, the permanence of carbon removal, location, co-benefits, risk, and vintage (the time when the climate impact occurs). Novel techniques, therefore, often cost more since they might have higher production costs and risks (Hayward, 2023). Thus, the production cost for biochar can be high, and it can be hard to produce biochar at an affordable cost (Song et al., 2022). Furthermore, producing biochar for carbon credits tends to have more requirements than only the production of biochar specific to the development of carbon credits (6, Carbon Credit Retailer). For example, verifying the emissions generated, ensuring the biochar quality and the cost of tracking and third-party audits. Smallholder farmers can, for example, produce maybe five credits a year since that might be all that is needed to increase the additional benefits for farmers. In addition, with a small number of credits, audits and tracking can become costly, making it hard for small-scale production to increase (8, Technical Provider).

Furthermore, biochar can be more than one product. It consists of different processes, as shown in Figure 1, which means there can be possibilities for more revenue streams coming from biochar and not only from the carbon credits, which can be an essential driver for smallholder farmers to start working with biochar. Respondent 4 (Project Developer) describes it like this:

"The beauty of biochar is that there are several products. In the best of worlds, you can get paid for taking care of biomass that no one else wants, get paid for the heat or the electricity, charge for the biochar, and charge for the carbon sink. So, there are four widely different revenue streams that are not the same market or the same people who want to buy them, which creates a very resilient system. Then it is not every time you get the four revenues together but maybe two then, but that is the business of it so." (4, Project Developer)

However, the financial aspect is also a barrier for smallholder farmers, project developers and investors to implementing biochar. For example, to be able to start producing biochar, there can be a need for an initial investment to get the equipment (6, Carbon Credit Retailer). High-technology kilns might be more expensive but possibly produces higher-quality carbon credits (8, Technical Provider). For example, through storing more carbon and possibly having longer permanence due to higher pyrolysis temperature (Petersen et al., 2023). With low-technology kilns, there can be a risk that the carbon credits are of less high quality, and low-technology kilns likely also need an initial investment that can be expensive (8, Technical Provider).

"Until you are up and running having biochar production and getting carbon credit revenues coming in, biochar is basically just cost, you have a lot of equipment and operational costs, and it takes some time to get the production up and running [...] so money is tight so helping to reduce and minimise the cost at the start is important." (6, Carbon Credit Retailer).

Middle-income countries have a higher cost of labour and other expenses, and increasing crop yields might be achieved through technical agricultural innovations (Owsianiak et al., 2021). In LM countries, labour can be cheaper but might be more labour-intensive due to the number of people needed. However, the increased crop yields might be more critical since there is a lack of more advanced technical agricultural innovations. In addition, biochar can have positive effects on soils generally. However, the positive effects might be more significant for smallholder farmers in LM countries where degraded soils are a big issue (4, Project Developer).

From a project developer's perspective, the carbon credit income should not be the primary income for smallholder farmers since it can create dependence (5, Project Developer). NGOs, investors, and project developers can spend large amounts of money on a project. However, as projects might end, there are no means for the smallholder farmers and the local community to maintain the project (Siedenburg, Brown & Hoch, 2016). Nonetheless, the income from carbon credits can be essential for the local community and possibly fund needed local investments such as schools or electrification (5, Project Developer). In local communities that get carbon credit income, representatives from different community groups can decide on what the income from credits can fund (2, Carbon Credit Retailer). Commonly, community projects can reinvest the revenue from the carbon credits in the local community (Lee, Ingalls, Erickson & Wollenberg, 2016). However, a critique towards carbon credits has been that they also can hurt local communities or not consider indigenous rights. For example, if local

stakeholders are not included in the development of projects, there is a risk of disenfranchising local livelihoods by not considering the traditional land and incomes and replacing it with carbon projects and restricting the local's access to their land (Miltenberger, Jospe & Pittman, 2021). Certain projects, such as those ensuring local stakeholder consultations with affected local communities and actors, have fewer risks of negatively affecting the communities. The standards and end-buyers must care about co-benefits and local stakeholder engagement so the communities can be benefitted (Broekhoff et al., 2019).

Carbon credits are relatively new in locations such as the tropics, which can generate some scepticism about the payment and trust in the projects from smallholder farmers (8, Technical Provider). Ex-ante payments might help increase the farmers' trust in carbon credits income and possibly help scale the projects (2, Carbon Credit Retailer). However, an ex-ante approach can potentially be more cash risky for project developers if the carbon credits are not produced since end-buyers are expecting credits, and the upfront payment can have been used to launch the project even if not successfully (8, Technical Provider). Ex-ante projects can be perceived as having higher risks since it is based on credit estimates, which can require a higher need to increase the auditor hours to ensure the carbon is sequestered (Foster, Wang, Auld & Cuesta, 2017). Starting with low costs and smaller amounts of credits can help build the trust among the project developers that they will get paid, and that credits will be produced. Through smaller projects and pilot phases, it is possible to use the carbon credit income to scale the projects or invest in better technology (8, Technical Provider). It can be harder to engage smallholder farmers if carbon credits revenues are not provided on time and they feel risks regarding their usual livelihood and practices (Lee, Ingalls, Erickson & Wollenberg, 2016). Successfully facing sustainability challenges requires adequate amounts of mutual trust between the involved actors (Stupak, Mansoor & Smith, 2021).

A barrier for the smallholder farmers in LM countries can be that to get projects approved for carbon markets participation; there can be a need to hire expensive consultants (Siedenburg, Brown & Hoch, 2016). Sometimes, smallholder farmers may require the assistance of consultants to fulfil the requirements of a carbon credit project, despite the potential financial burden. This can lead to a need for increased capacity building before smallholder farmers can develop the projects on their own. Even from the point of view of a biochar consultant and project developer (4, Project Developer), getting biochar certified for carbon removal can require a much work which can be great for consultants. However, it may not be affordable for all smallholder farmers, and it potentially has to be more affordable and not require too

much bureaucracy and administration to open up for small-scale production (Siedenburg, Brown & Hoch, 2016). Nonetheless, to ensure transparency and trustworthiness in smallholder farmers' projects and biochar, things like certifications can be crucial (4, Project Developer).

Under new mechanisms such as Article 6, there are several initial challenges when hardly any projects have been developed (Kreibich & Hermwille, 2021). From a buying country perspective, as project developers can increase their capital, they might be able to expand and take more significant risks (9, Buying Country). Still, investors might need to see that the projects work so they can have faith in the product and the credit mechanism. It can be harder to convince investors in the early stages. Building investor confidence can hinder scaling up the needed amount of CDR to reach the Paris Agreement (Williams, Reay & Smith, 2023). However, as projects develop and they see it can potentially generate good business, it can increase commitment from investors which can speed up project development (9, Buying Country). Non-state actors often take on the role of investors and can help increase carbon markets' success when investment volumes grow (Mathur et al., 2014).

5.2.4 Small-scale production

The small quantities of carbon credits that smallholder farmers make can potentially be a barrier for project developers and smallholder farmers to access carbon markets (Lee, Ingalls, Erickson & Wollenberg, 2016) since the demand from end-buyers might be for larger quantities from the same project. It can be challenging to spark end-buyers interest in small-scale projects (Siedenburg, Brown & Hoch, 2016). Large companies likely want to buy large amounts of credits, which can be challenging for smaller projects and players with fewer credits to sell (2, Carbon Credit Retailer). Smallholder projects can be quite demanding in terms of labour, which, coupled with limited access to produce large amounts of credits, can pose challenges for investors and project developers. The financial and time commitment required for labour can make it more difficult to invest in such projects (5, Project Developer). The time commitment and sometimes the slow process to launch carbon projects can also discourage smallholder farmers if it takes a long time before they can see the benefits of carbon credits, such as the extra income (Siedenburg, Brown & Hoch, 2016).

The carbon revenues can potentially be too low to switch agricultural practices for the individual smallholder farmer (Owsianiak et al., 2021). For an individual smallholder farmer, providing carbon credits can provide more expenses than income with the burden of

bureaucracy and the cost of verification (Siedenburg, Brown & Hoch, 2016). However, a programmatic approach with farmers aggregated together in a joint project, such as cooperatives, could be more likely to lead to changing practices and higher additionality for the carbon credit projects (Broekhoff et al., 2019). Aggregating smallholder farmers together can also be sufficient for knowledge sharing among them, increasing best practices, and facilitating administrative work when auditors are not only travelling to visit one farmer (8, Technical Provider). In addition, cooperatives can facilitate cooperation and bridge private and public actors, which is essential for multi-actor governance (Mathur et al., 2014).

Biochar is a novel technology (Smith et al., 2023). One possible issue with biochar being a novel technique is that biochar might not be well known among end buyers of carbon credits and that novel technologies can be more expensive when comparing carbon credit projects (2, Carbon Credit Retailer). Furthermore, potentially a trust needs to be created with end buyers around biochar as a reliable technology, but the barrier around trust might be challenging to overcome (8, Technical Provider). In sustainability governance, a certain level of trust is needed for the successful implementation of well-functioning value chains (Stupak, Mansoor & Smith, 2021). Facilitating actors around building trust among buyers can be standard organisations and MRV providers since they can validate and showcase the possible reliability of the carbon credit (4, Project Developer & 8, Technical Provider). However, even if trust is created among end buyers, there is likely a need for a willingness to pay more for novel techniques in order to be able for them to expand. End-buyers might be more willing to pay if aspects such as permanence and additionality can be ensured (11, End-buyer).

Small-scale carbon credit projects might be a driver in themselves since they can be tangible and provide high transparency and traceability, and carbon credit retailers can have direct contact with project developers (2, Carbon Credit Retailer). In addition, this is an example of how the project developers can function as intermediaries between end-buyers and smallholder farmers (Lee, Ingalls, Erickson & Wollenberg, 2016). Furthermore, the corporate social responsibility (CSR) aspect can be an essential angle for companies to include when choosing carbon credits projects since they might look for more co-benefits which might be higher in smaller community-focused projects. Since larger projects are often more industrial-focused and often focus on capturing larger amounts of CO_2 rather than including aspects such as improving the livelihoods of communities (Broekhoff et al., 2019). A project manager for small-scale projects explains it like this:

[...] From the point of view of carbon markets, smaller projects can demonstrate a genuine impact on the community level, a genuine uptake, and a strong positive impact on livelihoods. This is something corporations, which ultimately fund the project, it is a very interesting linkage for them. [...] Demonstrating that they are not only investing in credits but also investing in so many other livelihood benefits for communities, and at the level of smaller projects, there is that more direct connection. (5, Project Developer).

Both end-buyers talked about the importance of co-benefits from the project. One of them described it like this: "We especially have a very nice climate compensation project in Nicaragua with which we have a deeper collaboration also around other areas and therefore is close to our hearts". The other end-buyer also emphasises that co-benefits are crucial for the company when deciding on what projects to invest in and that they might not see the same effects from the larger industrial projects regarding poverty alleviation and community benefits (11, End-buyer).

5.2.5 Technological maturity

Another possible barrier for project developers and smallholder farmers might be the obstacle of transferring technology to the context in LM countries due to the challenges around ill-functioning institutions and widespread poverty (Hansson et al., 2021). In addition, technology deployment in LM countries can be a complex challenge since the technology is often going to be transferred from high-income countries that might have different conditions, and the technology is made for those. Furthermore, there can be a lack of more accessible technologies for farm-scale biochar production (Song et al., 2022). The technology barrier is brought up as a barrier for project developers and farmers during the interviews. "In terms of how to scale biochar, we need higher technology to lower the cost of kilns [...]. [...] Being able to produce kilns that require less input or less operational cost and then increase the output would make the profit more substantial." (8, Technical Provider). Furthermore, more technical providers with a well-proven concept technique for producing high-quality biochar might be needed (4, Project Developer).

Technological advancement has been a reason that the production cost and price of biochar have decreased slightly. However, the cost reductions so far might not be enough to make it profitable for farmers to start producing biochar (Song et al., 2022). Low-tech kilns often mean high operation costs; in order to lower operation costs, a more high-tech kiln which is costly, can be needed, and it might be a lack of knowledge of how to use the technology affordably. Nevertheless, a project can start with a low-tech kiln to start producing biochar

and carbon credits. When income from credits arrives, it can provide an opportunity to scale up and finance more extensive and more high-tech kilns (8, Technical Provider).

Access to reliable data on the quality of the carbon sequestrating abilities can be a barrier for smallholder farmers due to the technical demands of establishing a carbon credit project, such as having functional MRV technology in place (Lee, Ingalls, Erickson & Wollenberg, 2016). However, MRV technology tends to be needed to ensure the trustworthiness of carbon credits to other actors such as standards, carbon credit retailers and end-buyers. In addition, tracking systems can be costly for farmers to invest in, but potentially with better remote-enabled tracking systems and technology, it might be possible to reduce costs (8, Technical Provider). The availability and quality of remotely sensed data using, for example, drones or satellite imagery can produce innovations that can decrease the production cost and increase proof of verifiable impacts such as carbon sequestrating abilities. Additionally, long-term remotely sensed data advancement can enable smaller and more diverse projects, such as smallholder farmers producing biochar, to participate in carbon markets and benefit from them (Miltenberger, Jospe & Pittman, 2021).

5.3 Conditions for small-scale biochar in carbon markets

Carbon markets are developing, and the conditions for small-scale biochar production can change in the future. The conditions for small-scale biochar will be discussed from the current and possible future situations related to carbon markets.

5.3.1 Existing conditions

As mentioned, biochar is not yet included as a CDR in compliance markets (Olsson, 2023). Furthermore, several countries do not include biochar towards the target fulfilment of their NDCs (3, Actor working with National Climate Targets) which means there is potentially no current conflict between the compliance market and the voluntary increasing the number of carbon credits generated from biochar. It might open a possibility for further increasing biochar since there is no need for fear of market conflicts.

From a buyer country perspective, it is more resource efficient to implement several emission-reducing activities in each host country since the process of signing bilateral agreements often takes a long time. Furthermore, it can be a time-consuming and complex process to sign bilateral agreements between countries. Therefore, it might not be worth producing an agreement only to get small amounts of tonnes, so more significant volumes of credits can be

needed for efficiency (9, Buying Country). Possibly, the process might speed up when the knowledge around Article 6 increases and more agreements have been made. Nonetheless, in the start, it might be more uncertainties and challenges around alignment (Michaelowa, Shishlov & Brescia, 2019). However, co-benefits are seen as necessary from a Swedish perspective as a buying country when choosing projects which could also influence the decision on project type. Co-benefits, however, might only be important for some buyer countries (9, Buying Country).

Small-scale production of biochar would potentially not be efficient in compliance carbon markets due to the low quantities of credits, even if it has co-benefits. It may be more suitable for voluntary carbon markets since companies have a wider range of credit purchasing needs. Voluntary carbon markets can be seen as more innovative and flexible systems which can provide more opportunities for small-scale projects that are not included in compliance markets (Lang, Blum & Leipold, 2019). Furthermore, small-scale biochar production could potentially be more efficient using cooperatives, making the number of credits more significant (Broekhoff et al., 2019). The question is how many smallholder farmers need to be involved in a project to generate sufficient credits for a buyer to be interested.

Sustainable agricultural practices are possible to include under Article 6.2 of the Paris Agreement (UNDP, 2022). In 2022 Ghana and Switzerland entered a voluntary cooperation approach under Article 6.2 through a bilateral agreement, the first of its kind. Switzerland is going to reduce their GHG emissions by using ITMOs. However, they are not going to be counted towards Switzerland's NDC and are instead complementary. According to UNDP (2022), the project in Ghana includes nearly 80% of Ghana's total rice production, and it will provide training to over 1000 rice farmers. It is possible that similar cases could arise involving the use of biochar.

The European Commission's proposal for a carbon removal certification *COM (2022) 672 final* has possibilities for biochar. However, it is not sure to what extent biochar will be included (European Commission, 2022). The European Commission has previously excluded biochar as a CDR to reach the EU's GHG reduction scenario due to uncertainties about biochar as a carbon sink and the fact that the effects on soil are still in a more laboratory phase rather than being determined on a field scale. The proposal does not apply to projects outside the EU. However, regulatory systems have opportunities to create trust around biochar as a product and increase demand (Heinrich et al., 2023). Regulatory bodies' potential lack of

interest in biochar development can increase the need for voluntary principles to lead biochar development and develop new solutions. Within MAG, it is common for private actors such as businesses and investors to drive change and develop innovative solutions (Newell, Pattberg & Schroeder, 2012).

Several environmental benefits related to biochar are so far unpriced externalities (Song et al., 2022). Governments incentivising farmers to use biochar in agriculture practices through a carbon trading system could help increase the profitability of biochar applications and the trust around biochar as a product. Including biochar to a larger extent in compliance, carbon markets can facilitate the possibility for the carbon sequestration potential from biochar to be recognised and trusted. States usually have the legitimacy and trust required to implement sustainability governance principles. However, more operational capacity might be needed for enforcement. Therefore, private and public actors must cooperate (Schut et al., 2014).

Several governance initiatives exist in voluntary markets (Ahonen et al., 2022). From a state perspective, one respondent discusses it like this: "The initiatives possibly try to prevent state regulation, and perhaps they try to self-regulate through organisations such as ICVCM and VCMI. The initiatives try to regulate both the demand and supply sides of carbon credits by coming up with common principles on how to act" (9, Buying Country). Multi-actor governance often sparks voluntary self-regulating processes and reduces governmental control (Craps et al., 2019). For example, ICVCM recently launched core carbon principles to define a good quality carbon credit; the criteria could also apply to biochar (ICVCM, 2022).

The price of biochar in the current market can be higher than other carbon credit projects, such as afforestation, possibly reducing the willingness to pay for biochar-specific projects from certain end-buyers who would have been interested at a lower price (Lehmann et al., 2021). In addition, private actors such as businesses and investors have much power based on their financial capacity (Newell, Pattberg & Schroeder, 2012), which means they can contribute to increasing or decreasing the willingness to pay for small-scale biochar projects compared to other carbon credit projects.

We have a few interested customers, so we have started looking there, but unlike tree planting projects which can cost around SEK 200, biochar can cost around SEK 2,000. So, when you talk to the customers, and they say we want biochar, how cool, we say there are projects in Sweden, but there are also more in the Global South, and maybe the added value is greater there because those people maybe need it better. However, when we say it is

2000, they back off, so we are having a bit of a hard time getting the deal right now [...] (2, Carbon Credit Retailer).

There can also be a willingness from end-buyers to pay a higher price for a carbon credit if they know that permanence can be assured. Nonetheless, the question will also be how much extra payment is needed to get a technique with higher permanence since the cost of carbon credits will always be important to companies (11, End-buyer). However, end-buyers have the possibility to leverage a significant amount of data and information about carbon credit projects when making decisions. Furthermore, they decide on the purchasing time and the price they are willing to pay; this leads to buyers having significant amounts of power in carbon projects (Lee, Ingalls, Erickson & Wollenberg, 2016).

A challenge for carbon credits such as biochar in carbon markets is that CDR techniques have higher prices than credits based on avoided emissions (Lehmann et al., 2021). Potentially, this could be a possibility to get a larger payment for investors and project developers for choosing carbon credits using CDR techniques compared to avoiding emission projects. However, suppose the necessary verification and validation processes for the carbon sequestrating potential are complex and costly. In that case, the final payment to the smallholder farmer will be lower since parts of the revenue have to finance these processes (Lee, Ingalls, Erickson & Wollenberg, 2016). Nature-based solutions have increased in price since 2019, whereas renewable energy solutions have decreased. However, there is also a trend that the market favours credits showing rewarding co-benefits, for example, on the environment. Therefore, biochar could be favoured if end-buyers prefer CDR solutions as carbon credits rather than avoided emissions projects (Lehmann et al., 2021).

Another risk with biochar being a novel technique is that accounting methods for the carbon sink might be new; since biochar can be produced in different ways, it is critical to know the specific carbon sink based on the biomass used and the production process used (Petersen et al., 2023). Currently, several calculation methods can be used, and to increase the trust further, a more global agreement on the accounting approach might be needed (4, Project Developer). Furthermore, regarding carbon credits, there is a need for a technical assessment to determine the additionality and baselines to ensure that the amount of carbon sequestrated is transparent and accurate and that no overestimation is made (Miltenberger, Jospe & Pittman, 2021). Furthermore, quantifying net GHG reductions from biochar and soil carbon sequestration methods is often more uncertain, making measuring, monitoring, and verification more challenging (Broekhoff et al., 2019). However, that can make the standards

possibly a very essential part of the value chain, providing a method and transparency (7, Standard/Registry & 4, Project Developer). Claims from standard systems relating to purchase should be verifiable. Furthermore, they should address the credibility of the sustainability performance of the purchase to maintain transparency throughout the value chain and provide trust around the impact (Stupak, Mansoor & Smith, 2021).

5.3.2 Future conditions

The lines between voluntary and compliance carbon markets are intertwining (9, Buying Country). Historically, the policy mechanisms under international negotiations and institutional frameworks governing the carbon markets have moved slowly forward (Mathur et al., 2014). Therefore, there is a need to understand when the policy mechanisms and laws are catching up to speed and what the role of smallholder farmers in LM countries can be.

Governments can be hard-headed and powerful actors, but private actors such as investors or buyers can also have increased power (Newell, Pattberg & Schroeder, 2012). Governments might therefore need to cooperate with project developers and investors and facilitate the work in launching carbon projects within their countries. Otherwise, governments might risk losing project developers and investors developing in the country (10, Carbon Credit Retailer). For LM countries, carbon projects can be more significant since carbon markets can provide funding for the much-needed sustainable transition in continents such as Africa with limited funding and technical capacity (Eziakonwa & Gomer, 2022).

Currently, as mentioned previously, there might not be a conflict regarding biochar carbon credits on compliance and voluntary markets. However, this can change in the future since what is included in a country's carbon sink is country-specific and might change (3, Actor working with National Climate Targets). Furthermore, this has happened to other forms of CDR projects, such as forest preservation on voluntary markets, which is an example of the conflicting interests that can occur. Respondent 2 (Carbon Credit Retailer) gives an example:

"For example, Indonesia has put an end to exporting climate credits for voluntary climate compensation, and we had two projects there that we had worked on quite a lot—[...] Two projects where you work with communities that preserve forests. Then suddenly, in 2021, it was said that in 2022 there would be no credits because we had stopped. [...] Because then Indonesia wants to include them in their targets. After all, the projects are affected; they have no income suddenly."

As seen in the previous quote, different actors can view an issue differently, and conflicting interests can occur. Actors within multi-actor governance can tend to have different views on issues, solutions, and appropriate courses of action (Craps et al., 2019). This can lead to conflicting interests when actors need to cooperate on different levels and sectors (Bowen et al., 2017).

Significant numbers of companies and countries have pledged to reach net-zero emissions, which require carbon credits for that to be achieved. Carbon credits are needed since not all emissions can be reduced; therefore, to reach net-zero emissions, some amount must be removed through CDR techniques. However, there can be a need for clarification regarding how voluntary carbon markets should align their business model with the legal structure of the Paris Agreement in order to avoid double counting (Kreibich & Hermwille, 2021). One potential downside of carbon credits is the risk of double counting, which occurs when the same credit is accounted for more than once. This can happen through double issuance or double claiming. Double claiming occurs if several entities claim the same credit multiple times. Double issuance is when more than one credit is issued for the same reduction measure. Carbon credits need to be clearly retired in a registry to avoid that it is double counted (Broekhoff et al., 2019). Article 6 under the Paris Agreement expresses that double counting among countries should be prohibited through robust accounting methods. However, this is still a risk since voluntary and compliance markets are merging, and double counting affects carbon markets' credibility as well as the projects (Lang, Blum & Leipold, 2019). For small-scale biochar projects that can be seen as riskier by buyers and investors, it is necessary to ensure the risks for double counting are minimal since that could affect the credibility further. Furthermore, the risk of double counting puts pressure on project developers, registries, standards, and carbon credit retailers to keep up with the implementation of Article 6 and how that can affect voluntary projects and how biochar projects can be used and claimed in the future so that no double counting occurs.

As the markets evolve and new regulations are being proposed, there might be new ways for companies to claim the carbon credits they are buying. However, due to the number of possibilities to make claims, the trustworthiness among the variations can be debatable (Kreibich & Hermwille, 2021). Some hope for a paradigm shift in the carbon market where claims and the current approaches will change (9, Buying Country). Compliance markets can look at voluntary markets to identify best practices since they are often ahead of compliance markets in terms of development (2, Carbon Credit Retailer). Generally, the multi-level

governance structures for carbon markets have emerged ahead of international negotiations and the frameworks they would operate under (Mathur et al., 2014).

Under the Paris Agreement, in the future, there can be different possibilities for actors on the voluntary markets to make different claims and contributions to NDCs or national climate targets that could then avoid double claiming and double counting (9, Buying Country).

A possibility for the future is to further intertwine the voluntary and compliance markets. In the Paris Agreement, Article 6 says that countries must authorise emission reduction units for different types of uses. Host countries can authorise carbon credits for three different kinds of use. 1. NDC Fulfilment, 2. Other international mitigation purposes, 3. Other purposes (VCM). Host countries can authorise emission reduction units for NDC fulfilment or for voluntary markets, which is then called other purposes. If you then make a corresponding adjustment, the host country does not include these emissions reductions in their emissions balance. Then it enables buyers in other countries to claim this differently because they are not included in the host country's emissions balance (9, Buying Country).

Article 6.4 under the Paris Agreement is regulating the central market mechanism that is not in place yet. However, in the decision-making process around the 6.4 principles, a new carbon credit mechanism is mentioned as mitigation contribution 6.4 ER. The carbon credit is not authorised for transfer, meaning there will be no corresponding adjustment, so the actor who buys the credit can only make a contribution claim, towards the host country's national climate targets. Thereby the emission reductions stay in the host country and the buyer cannot count it towards their own targets (9, Buying Country). The approach can favour environmental integrity, but operationalising this approach can be a challenging task that needs increased political support and innovative solutions (Kreibich & Hermwille, 2021).

The framework under the Paris Agreement Article 6 is not yet finished, which allows companies to make broader claims. For example, stating that a certain monetary investment is made in CDR but without stating neutrality or similar (Hayward, 2023). This was discussed with one of the end-buyers, and they reasoned like this:

The carbon credits would remain, but it depends a lot on which claim would be used. I think that "we have been involved and donated money" is very weak, but on the other hand, say that "we have helped Uganda reach its climate goals", which is fantastic. Then especially if there is a real connection to the Paris Agreement, it would be fantastic. So, I would like all climate credits to be counted against the Paris Agreement. I think it is the future for companies to count like that. So, you try to buy these credits, but they do not exist yet (11, End-buyer).

Contribution claims can favour novel techniques, such as biochar, that require more funding since there might no longer be a need for a company to prove an exact tonnage bought or a specific neutrality claim being made (Hayward, 2023).

Another new concept is insetting, which means implementing nature-based solutions in the own value chain to reduce the GHG emissions in the supply chain rather than buying credits from another project outside of the company (Bhatia, 2022). Biochar could be an alternative for companies to use as insetting, especially for companies in the food sector that import food from LM countries. Insetting could potentially benefit smallholder farmers if they are suppliers to the companies. However, this might only work for a narrow type of food companies, such as coffee sellers working with smallholder farmers who have waste biomass (12, End-buyer). Nonetheless, biochar is perfect for agriculture since there is no need to transport biomass; instead, it can be used on-site (4, Project Developer).

"The use of biochar is being discussed as one of several possible efforts to reduce the climate footprint in coffee cultivation. In order to be a part of financing emission reduction actions, we also want to be able to count these investments towards our reduced climate footprint. Then it is required that the farmer/cooperative can make a baseline and then a subsequent measurement. Alternatively, biochar constitutes an insetting project that can be used in our climate footprint calculation. In general, we are looking more at measures directly in our value chain as an alternative to replace current climate compensation" (12, End-buyer).

Several companies have chosen to act on climate and voluntarily invest in nature-based solutions to reduce emissions. However, the lack of government policies is an issue in fulfilling the Paris Agreement on time (Collins et al., 2020). Companies taking voluntary action should engage with regulators to potentially speed up the process and help scale more corporate and government action on climate. According to Collins et al. (2020), best practices for nature-based solutions include a multi-actor approach where the projects are locally owned but with inclusive and transparent decision-making, spanning different levels and including several actors. Furthermore, there is a need for governmental involvement to improve governance (Collins et al., 2020). Within MAG, the private sector, such as NGOs, investors, and businesses, have a larger operational capacity (Schut et al., 2014), as seen through companies' voluntary actions and the demand created for carbon credits. Governments are needed to create legitimacy, and they can implement sustainability governance mechanisms. However, governments in LM countries especially need help with enforcement and operational capacity (Schut et al., 2014).

5.4 Limitations

Biochar is a novel technique, and carbon markets are fast developing, which means that assumptions have been made on future conditions. Future uncertainties can be limitation of the study since there is no certainty about what will happen with the development of small-scale biochar as the carbon markets move forward and new laws and regulations emerge. Nonetheless, there are trends suggesting the direction the carbon markets are moving and it is possible to make assumptions based on that.

Conditions and decision-making can be country-specific, which increases the uncertainties around the views and possibilities for biochar in carbon markets. Conditions can vary depending on the sources of biomass and the access to residual biomass can wary between countries and which type they might have access to. Nonetheless, this study was a mapping of factors for enablement of small-scale biochar in carbon markets and not focusing on the country-specific conditions, so it is not seen to be a major limitation, but it is a suitable next step for further investigation.

The study aspired to provide perspectives from most of the different actor groups in carbon markets. However, not all actor groups are equally presented, and some were unable to get a hold of them due to the time frame and resources. From the governmental perspective, only Swedish actors are present. There may be uncertainties regarding whether the host country's perspective differs from that of the buying country or if representatives from other buying countries have differing opinions. The target fulfilment towards NDCs and what to include in a country’s carbon sink is country-specific, so perspectives from countries wanting to include biochar in the carbon sink could have provided further insights. However, currently since there is a lack of countries including biochar and bilateral agreements using ITMOs, an increased number of these type of actors would have been harder to find.

The study has not included field visits or direct contact with smallholder farmers. Therefore, only secondary information was possible to get from the farmer's perspective. Not using primary information can contribute to uncertainties, and those aspects get lost during the information value chain. However, several respondents and literature directly working with farmers were included to ensure that the farmers' perspectives were present in the study.

5.5 Future research

The study has investigated general conditions for small-scale biochar in LM countries to participate in carbon markets. Future research should focus on case studies to test the general principles and see if they change under more local conditions. There seems to be a large untapped potential to include smallholder farmers producing and using biochar in carbon markets. Therefore, more research is needed to see what is required in order to realise the potential and how more farmers can be reached and educated about the value of using residual biomass to produce and use biochar in smallholder farming. Furthermore, there can be a need to understand the number of smallholder farmers needed in a common project to be viable and if there can be an upper limit as well if it is no longer seen as small-scale production and if certain co-benefits or additionality can get lost when production scales.

A challenge discussed in the study is the trust around the properties of biochar, both from the farmers to use it in agriculture and from end-buyers to purchase biochar carbon credits. Since biochar carbon credits are relatively new, there is a need to investigate further the aspects that can create a trust for farmers and end-buyers around the value of biochar carbon credits. Furthermore, except for the monetary value of biochar and carbon credits, it is also essential to understand the importance of biochar's effects on crops and soil. Therefore, more tests on different waste biomass are needed to create trust in the permanence of the carbon-sequestration potential from biochar produced by smallholder farmers. It is critical to investigate the willingness to buy from end-buyers and if that can increase when permanence can be ensured more significantly compared to other carbon credits projects.

Carbon markets are developing, and more governance mechanisms will come into place shortly. Furthermore, the lines between compliance and voluntary markets are blurring and might have closer cooperation when the final principles under Article 6 have been decided. Therefore, it will be essential to analyse further the effects of new laws, regulations, and voluntary governance initiatives on the demand and development of small-scale biochar production in LM countries.

6. Conclusions

Many distinctive aspects within MAG are seen in the biochar carbon credit value chain in carbon markets. Some examples are the public and private cooperation needed to ensure efficiency and trust for small-scale biochar in carbon markets. Furthermore, private actors have mainly been driving the biochar carbon credit development. In multi-actor governance, non-state actors such as businesses often take on more responsibility and work with innovative solutions. In addition, private actors such as project developers working with small-scale biochar production can sometimes work easier with governmental actors since the small-scale production is close to the local governments and communities and can require fewer regulatory procedures. However, sustainability transitions may not occur solely through market forces and may require innovative policies and support from more legitimate entities, such as governments.

Several drivers and barriers have been identified for small-scale biochar projects in LM countries to scale in carbon markets. The main barriers for smallholder farmers concern needing training and education, affordable and easily accessed technology in LM countries, trust in the value and properties of adding biochar to soils, a small number of credits to sell and expenses around equipment and costs for providing carbon credits such as demands on measuring, reporting and verifying the carbon sequestering made. Drivers for starting using biochar for carbon credits for smallholder farmers can be additional sources of income both for the individual and the local community, increased crop yields and cost savings from reducing the need to buy expensive fertilisers. However, it can be challenging for project developers to access rural communities and establish trust with smallholder farmers around the product, technology and payment. It can also be challenging for project developers to provide trust around a novel technique to investors, end-buyers and carbon credit retailers. On the other hand, working with smallholder farmers can be a driver for project developers since it can be more transparent and they have direct contact with the farmers, and small projects might have less regulatory pressure and end-buyers might prefer smaller projects since they can have more co-benefits. Furthermore, investors might see the co-benefits around small-scale projects as extra important when choosing projects to invest in.

The use of biochar has various factors that impact its application. When adding carbon credits, there are additional drivers and barriers to consider, and they can shift depending on the actor. Nonetheless, carbon credit income can motivate farmers to shift towards sustainable agricultural practices, incorporating biochar and providing an extra source of income that can

benefit their local communities. Carbon credit income can also support education and training programs, removing knowledge barriers surrounding the impact of biochar in agriculture. Overall, the income from carbon credits has the potential to improve the livelihoods of farmers and local communities while promoting sustainable practices.

Biochar is a novel technique not yet widely provided in carbon markets. In compliance carbon markets, small-scale biochar production might not be the best fit since more significant quantities of credits are more efficient to buy for buying countries, and biochar is generally not included for target fulfilment towards countries' NDCs. In voluntary carbon markets, there is a vast demand for buying various amounts of carbon credits. Depending on the end-buyer and company, they can value aspects such as co-benefits and insetting, and small-scale biochar could be better suited. However, compliance markets and state actors have the possibility to create trust, which could help scale biochar and increase its usage if there is a broader trust for the positive properties of biochar.

Several governance mechanisms that need to be fully established will affect compliance and voluntary markets, such as Article 6 under the Paris Agreement. There are also suggestions for governing carbon credits on the voluntary side, such as the core carbon principles from ICVCM. When the finished mechanisms come into place, that can affect the demand for small-scale biochar production. In addition, compliance and voluntary carbon markets are increasingly converging. This underscores the importance of public and private collaboration among multiple actors to effectively expand the availability of high-quality carbon credits and boost global carbon removal capacity.

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Appendix 1
Interview Guide

Introduction
Please tell me a little bit about yourself and your role at *[Organisation]*?

Can you briefly describe *[Organisation]* main task concerning biochar/carbon credit projects?

The biochar value chain
Who would you identify as key actors in the biochar carbon credit value chain?
Can you tell me a bit about the cooperation between the actors?

What is [Organisations] role in the carbon credit value chain?

Carbon markets
How do you see the role/potential for smallholder biochar projects in carbon markets?

Do you see potential for small-scale biochar projects both in compliance and voluntary carbon markets?

Biochar projects
What are the main drivers for scaling up smallholder farmers' biochar projects?

What is the main barrier to scaling up smallholder farmers' biochar projects?

What resources are needed in order to scale up smallholder farmers' biochar projects?

Sustainability
Which sustainability aspects are strengthened through small-scale biochar projects?

Are there any contradictions between reaching social, economic and environmental benefits from implementing biochar?

Ending
Finally, is there any important aspect we should have discussed during the interview?

Would you have any recommendations for someone I should talk to about this topic?