

Biochar systems: Developing a socio-technical system framework for biochar production in Norway

Abstract

Biochar is charcoal produced from feedstock under pyrolysis. It has gained interests among researchers in recent years because of its agronomic and environmental benefits. It is considered to increase soil fertility and crop productivity, and biochar might play an important role as a climate mitigation tool that is able to capture carbon in the soil.

However, although research has focused on the chemical, biological, and technical aspects of biochar, we seem to be far away from the implementation of a functioning biochar system. One key aspect needed for the actual use of biochar technologies is increased awareness and emphasis on the social and organizational aspects of its implementation. As there are no functional markets for the services and products needed to 'produce' a biochar system, political and market devices are needed. This paper contributes to this debate by introducing a socio-technical framework that investigates the implementation of different biochar technologies in Norway. Based on this socio-technical system framework, we discuss necessary components of a sustainable biochar socio-technical system, and we outline variations of this system based on different levels of biochar production scaling.

Keywords: Biochar systems, socio-technical system theory, climate mitigation

1. Introduction

By storing biochar in the soil, one can reduce greenhouse gas (GHG) emissions and increase soil quality. Consequently, it has gained widespread interest among researchers. Yet, it is not

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widely implemented. Our argument in this article is that the lack of implemented, or functioning, biochar systems is partly due to the fact that research and policy analyses are narrowly focused on technical considerations and omit social and organizational elements of a biochar system. We contribute to the field of research by introducing and moderating a socio-technical system framework that is able to investigate the potential and practical implementation of different types of biochar systems.

Biochar is a form of char produced under pyrolysis, which is a thermochemical conversion of biomass that is carried out at temperatures above 300 C without oxygen. Pyrolysis produces three different products: bio-oil, biochar, and syngas. It is beyond the scope of this paper to discuss the chemical processes of pyrolysis in detail, but in general we can state that slow and intermediate pyrolysis results in higher biochar yields, while fast pyrolysis provides higher liquid yields (e.g., bio-oil) (Duku et al. 2011). Biochar can be produced from a variety of feedstocks such as agricultural crop residues, forestry residues, wood waste, organic portion of municipal solid waste (MSW), and animal manures (ibid), while the type of feedstock and the pyrolysis conditions mainly define the quality of the biochar and thus its stability for sequestering carbon (Hyland and Sarmah, 2014).

The use of biochar as a soil amendment is not a new idea. Its beginning can be traced back to the Amazon where indigenous people amended their soils with biochar approximately 2000 years ago due to its positive impacts on soil quality and crop yields (Lehmann et al. 2004 in Galinato et al. 2011:6344). In recent years, biochar has experienced a new wave of interest. A search on Web of Science shows that the amount of articles that included the word 'biochar' in their titles has increased from 455 published articles in 2013 to 1260 in 2016. Biochar has gained great interest among researchers in recent years because of its perceived agronomic and

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environmental benefits. Maraseni et al. (2010:852) list 8 benefits of biochar on soils. (1) It reduces leaching of soil nutrients, (2) it enhances nutrient availability for plants, (3) it increases water quality of runoff, (4) it reduces dependency on artificial fertilizers, (5) it reduces toxicity of aluminum to plant roots and microbiota, (6) it increases soil structure and pH and therefore reduces the need for lime, (7) it reduces bioavailability of heavy metals, and (8) it reduces GHG emissions by decreasing N₂O and CH₄ emissions from soils. Thus, biochar becomes very interesting for development agencies that are particularly interested in biochar applications for unfertile lands in developing countries to increase crop production. In this context, the production of biochar can lead to increased food production and higher incomes and hence presents a suitable tool for poverty alleviation.

Biochar might also play an important role as a climate mitigation tool by capturing carbon in the soil. A reduction of emissions alone is not seen as sufficient for reducing the CO₂ values from the atmosphere, and methods of extracting CO₂ from the atmosphere in form of carbon capture are suggested (Gaunt and Cowie, 2009). Biochar becomes relevant in this context since it can be stored in the soil and has a high residence of sequestering carbon from 100s to 1000s of years (Duku et al. 2011). However, the duration depends on several parameters such as (1) the temperature during pyrolysis (biochar production with lower temperatures leads to higher residence time), (2) the feedstock material, (3) the degree to which the material is charred, (4) the surface volume ratio of the particles, and (5) the conditions of the soil where biochar is added (Maraseni et al. 2010:853).

Due to its multiple benefits and potential as a climate mitigation tool, researchers work with biochar all around the world. This interest in biochar is also reflected in the formation of the International Biochar Initiative (IBI) in 2006, a platform that aims to “promote good industry

practices, stakeholder collaboration, and environmental and ethical standards to foster economically viable biochar systems that are safe and effective for use in soil fertility and as a climate mitigation tool” (IBI, 2014a). Biochar production has been carried out at different levels varying from pyrolysis units designed at a household level to large-scale commercial production (Joseph and Taylor, 2014). There have been several successful field trials of biochar production as well (Barrow, 2012).

2. Limited implementation of biochar

Despite its remarkable potential, biochar is not yet widely implemented. According to the IBI (2014b), lack of awareness about the benefits of biochar among diverse stakeholders presents a major constraint to its adoption and use. Bjerregaard (2011) found out that only 5 percent of Danish farmers had heard of biochar. Current research has a strong technical focus that mainly investigates the chemical processes of biochar, for example, studying the long-term stability of biochar in soils and identifying optimal pyrolysis mechanisms, while there are only a handful studies that address the social economic and cultural aspects of biochar technologies (Joseph and Taylor, 2014).

Several researchers advocate a need for more social science research on biochar. Matovic (2011) presents a review of biochar applications worldwide and argues that the consideration of economic and policy aspects of mass production, distribution, and application of biochar are important questions for the implementation process of biochar. Barrow (2012) argues that more interdisciplinary research is needed that investigates successful biochar usages. Joseph (2009) suggests that there is currently a lack of these types of analyses of biochar projects.

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The few studies that address the socio-economic aspects of biochar focus primarily on the implementation of biochar in developing countries and address smallholder farmers mainly (e.g., Joseph (2009), Scholz et al. (2014), and Leach et al. (2012)). In addition, those few studies that address developed countries mainly focus on the economic feasibility (Galinato et al. 2011; Roberts et al. 2010) of biochar without taking socio-cultural and political factors sufficiently into account. Clare et al. (2014) states that there is a lack of research that investigates the socio-economic suitability of biochar for small-scale farmers in industrialized countries. Furthermore, an analysis of the socio-economic aspects of biochar at a small-scale level must not only capture the financial output, but a consideration of the social, cultural, political, and environmental impacts is also required (Hamner et al. (1997) in Joseph (2009:360)). It requires a thorough interdisciplinary approach combining particularly agricultural and social science (Latawiec et al. 2017).

We seek to fill some of the omissions in the current biochar research by introducing and moderating a socio-technical system framework to analyze emerging biochar systems. Empirically, we do this in the context of different biochar systems in the case of Norway. In recent years, there has been a growing interest in biochar technologies in Norway.

Particularly, the implementation of biochar systems at the farm level seems to be of interest. Biochar systems implemented at Norwegian farms could be very relevant as a climate mitigation tool.

Norwegian farms are generally small. Currently, an active farm runs around 21 hectares (ha), and only 3 % of the total land area is used for agriculture (Rognstad and Steinset 2012). However, the agricultural sector contributes 9 % to Norway's greenhouse gas emissions (GHG) where methane produced by cattle and sheep constitute the largest part of emissions (60 %)

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(Blandford et al. 2014:59). At a national policy level, biochar could become an important tool to enable the transition towards a low-emission society by 2050 (Meld. St. 13, 2014-2015), and for reducing emissions in non – ETS¹ sectors including agriculture (Norwegian Government, 2016).² The successful implementation of biochar technologies as a climate mitigation tool could be of significance for achieving this goal.

The paper is structured as follows. Section 1 provides background on biochar, and Section 2 addresses the need for more social science research on biochar. Section 3 provides an introduction to our socio-technical system and its application for biochar research. Section 4 presents the methodological framework and limitations of this study. Section 5 discusses three scales of biochar systems in the context of the socio-technical system framework, and Section 6 provides the concluding remarks.

3. Biochar adoption in the lens of socio-technical system theory

Our point of departure is that the successful implementation of biochar systems neither depends solely on economic factors nor the technical features of the chosen processes; in addition, socio-cultural and political factors need to be addressed. One way to address the wide range of relevant factors is through a socio-technical system framework. Based on a socio-technical system framework, we will discuss the necessary components of a sustainable biochar implementation, and we will outline variations on this that are based on different levels of scaling of biochar systems. We use the term biochar systems because “focusing on systems recognizes that technologies are embedded within societal systems” (Markusson et al. 2012:905). Furthermore, Lehmann and Joseph (2009:147) argue that “the benefits of biochar

¹ Emission Trading System

² The target includes a reduction of 40% by 2030.

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need to be viewed from a system perspective in order to full capture the economic benefits and costs, environmental complexity and energy of the technology and to avoid or to minimize unacceptable trade-offs.”

Socio-technical system theory addresses the interplay of complex physical technical elements and networks of independent actors. Thus, socio-technical system theory combines two perspectives that De Bruijn and Herder (2009) call the “system” and the “actor” perspective. The first perspective generally addresses more questions to the physical infrastructure, while the second one includes the interplay of relevant actors who are responsible for the design, implementation, and operationalization of a system (ibid, 2009). They argue that an integration of both system perspectives is important to solve problems and to design appropriate solutions to these problems.

The socio-technical system framework originates from research undertaken at UK Tavistock Institute on the introduction of new coal mining machinery in the 1950s (Davis et al. 2014). In that context, it was realized that the introduction of coal mining machinery (physical infrastructure) led to changes in working practices (networks of actors), which had to find closer consideration for the successful use of this technology. Since then the socio-technical system approach has been applied in several domains, particularly in research that concerns the design of new technologies and the redesign of work roles (Davis et al. 2014:172).

This study applies a socio-technical system approach for investigating the relevant social and technical components for biochar implementation in Norway. According to Smith and Stirling (2008), environmental goals such as the reduction of carbon emissions as it is intended with the use of biochar technologies cannot be achieved through the technology itself alone but requires structural changes (e.g., politics, farm life, value-chain organization) that are captured by a

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socio-technical system approach. Socio-technical system theory has been in the past a very fruitful framework for analyzing existing work organizations and designing new ones (Eason, 2008). The framework has been extended by Davis et al. (2014). Their framework allows analyzing the linkages of technical, social, and organizational factors for technology implementation through six relevant interrelated system components: goals, people, infrastructure, technology, culture, and processes and procedures. All six elements are embedded in a wider context that includes a regulatory framework, financial/economic circumstances, and stakeholders.

The socio-technical system framework has been applied in different contexts, for example, to analyze crowd-related disasters (Challenger and Clegg, 2011) and to map existing organizational efforts to improve environmental sustainability (Davis et al. 2014:176). However, Davis et al. (2014) argue that socio-technical systems research has been mainly applied with focus on IT systems and should find new areas of application. This paper contributes with a new application of this approach in the context of biochar systems to investigate the changes in working practices that influence the success of biochar systems. The approach builds upon the claim that “systems often meet their technical ‘requirements’ but are considered to be a ‘failure’ because they do not deliver the expected support for the real work in the organization” Baxter (2011:4). This applied to the biochar context means that even though biochar systems encompass multiple positive benefits such as increased soil fertility, carbon sequestration, and reduction of GHG emissions, it does not mean that they will be consequently adopted. There are a range of non-technical factors that need to be addressed.

Furthermore, besides the obvious environmental factors that influence the success of biochar on crop productivity such as the type of biochar used, the crop studied, the soil type, and local

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conditions (Galinato et al. 2011), there are a variety of other socio-technical factors that need to be taken into consideration and that are presented as components in our socio-technical system approach.

Only the consideration of both the technical and the social factors can lead to the successful implementation of biochar technologies. The introduction of biochar systems at Norwegian farms will require new forms of work organizations and new goals among a series of actors—for example, some of them not presently engaged in the farm based value chains, new infrastructures, a series of cultural considerations, etc. By addressing the six components in our framework, we can identify multiple relevant factors for this new work organization for different scales of biochar systems. The six components are considered to be interrelated, which means that the change in one of the components in the system will lead to changes in other components (Challenger and Clegg, 2011). Thus, depending on the scale of biochar systems, the different components vary in their meaning. In this paper, we apply this framework to three different scales of biochar systems.

4. Methods, data, and limitations

This study is based on a mixed method approach. It departs with a literature review on research on the implementation of socio-technical systems in general and biochar systems in particular. We have also had a particular view on Norwegian literature of relevance to the implementation of biochar technologies. The general literature review was undertaken in English with 'Scopus' as major search engine. We decided to use Scopus because it is one of the most effective academic search engines for obtaining an overview of available literature on a topic (Tober 2011:143).

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A search on 'Scopus' showed that of 3869 articles published in peer reviewed journals between 2013 - 2017 containing the word 'biochar' in the title, only 57 articles had been published in social science labelled journals.³ This led to that the literature review was oriented towards the growing body of literature that addresses the different technical aspects of biochar systems at different levels.

Due to the lack of social science research on biochar implementation, other fields of literature were incorporated that are able to inform us about the requirements, constraints, and considerations for biochar implementation that need to be taken into account. Since this study investigates the potential and socio-technical requirements of different biochar systems related to the agricultural sector in Norway, we make use of research that address organizational, social, and cultural aspects of the Norwegian agricultural context. This literature includes also articles in Norwegian, which were chosen based on the background knowledge of *[insert name of the research centre]* in the field. We also reviewed literature on bioenergy development in Norway. Bioenergy has been of great interest in Norway (see: Norwegian Government, 2014) and since it makes use of the same resources as biochar production and faces similar challenges in the implementation, this literature can provide crucial information for biochar development and implementation in Norway.

³ Search in Scopus "TITLE-ABS-KEY (biochar) AND (LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "SOC"))".

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The literature review is supplemented with empirical results from a web-based survey that investigates knowledge and interest in biochar among Norwegian farmers.⁴ An email with a link to the survey was sent out to a random sample of 1500 registered farmers in Norway. The survey was sent out in April 2016, and two reminders were sent to those that did not reply to the first request. Totally we received 198 replies. This means that the response rate was 13.2 percent, which is quite low. However, a check shows that the data have a reasonably high representativeness. No counties are more than 2 percent over-/under-represented; the mean age equals the mean of 52 years in the total agricultural population; the gender distribution is a bit more skewed than in the population at large – with 10 percent women vs 16 percent in the population. Thus, it is reason to believe that our findings resembles those on the agricultural population. Yet, with a sample of only 198 respondents one should make interpretations based on these data alone with care.

In addition, to the literature review and the survey, additional data are gathered from two qualitative interviews with a Norwegian farmer who installed a continuous biochar unit in October 2016. This farm presents the first case of a farm scale installation of a pyrolysis unit in Norway.

Biochar as a theme and as a technology relevant for agriculture is new and relatively unknown. Thus, the analyses and discussion of this article is an important early step in the development of knowledge on agricultural uses of biochar, Yet, it is also important to mention some of the limitations of this study. Clearly, the empirical foundation is not very broad. The presented framework for biochar implementation addresses the Norwegian case, and the values of the six components might vary depending on the national and external context. A key notion in Science

⁴ The survey was conducted in Norwegian and results were translated to English for this paper.

& Technology Studies (STS) is that technology development and implementation is context dependent as well as constituting new or changed contexts. Generalizations are difficult though. However, the model presents a tool that allows for an analytical generalization, i.e., a way of exploring new technologies. Furthermore, this paper does not address a technical evaluation of different biochar technologies for the different levels of implementation. This is a task for more engineering research in the field. Hence, we treat the technologies largely as “black boxes” and focus mainly on choice of technology concepts and considerations on technologies’ different scales.

5. Scales of biochar systems and their system components

A series of biochar technologies are available. One central feature is that such technologies are scalable at different levels of centralization. We depart from a continuum where we have small-scale, decentralized biochar systems at the one end and large-scale, centralized, industrial biochar systems at the other end. Still, there is room for cooperation between farmers on different parts of the value chain, where we imagine a medium-scale production of biochar (see Figure 1). We assume that for all three scales, the six components of the socio-technical system framework will be relevant, although it will be fruitful to analyze different configurations and components⁵. Choice of scale is more than choice of production volumes though. Most basically, it involves choices of a technology concept.

Decentralized biochar systems produce biochar locally at the farm for local use. Small-scale decentralized systems for biochar production are currently mainly applied in developing

⁵ The external environment is considered to be constant for all three levels, and thus the focus is directed towards the six components.

Notwithstanding, we can state that the three scales of biochar systems put different demands on the costs and spatial temporal availability of feedstock (Lehmann and Joseph 2009). It also evokes different types of social and cultural considerations. According to Joseph (2009), different scales of biochar projects require different methods of analysis and evaluation.

Based on descriptions of necessary features of the different parts of the biochar value chains at different scales, we aim at pointing towards factors of importance to the choice and implementation of biochar systems. We will present a system analysis for each of the three biochar systems. Analyzing all three system scenarios will assist project managers in the technology concept choice for biochar implementation. In the following, we will address the six relevant system components across the three different scales.

5.1 Goals

The first component we address in the socio-technical system framework presents *goals*. A local decentralized biochar production and subsequent moulding down of the biochar under the ground can increase the soil fertility and thus crop productivity at the local farm area. Biochar could be particularly interesting for areas prone to flooding due to its ability to improve soil drainage. Furthermore, it can lead to a reduction of GHG emissions and can help to sequester carbon for the atmosphere. The three benefits count for all three levels. For the farmers as actors, the potential achievement of these advantages are the goals.

In the survey, Norwegian farmers were asked, which advantages of biochar they value as most important. The answers presented in Table 1 show that agronomic – and economic – advantages are most important. Improved effect of artificial fertilizers and increased crop and biomass production are the two most important. In line with earlier research (Flemsøter 2013; Aasprang

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2012; 2013), we see that general climate related concerns as carbon capture in the soil is of less interest for the farmers.

Table 1

Potential benefits of biochar application

<i>The addition of biochar to soils has several potential benefits. These are listed below. On a scale between 7 and 1 how important are these effects for you and your farm?</i>							
Type of benefit	1: Not at all important	2	3	4	5	6	7: Very important
Increased water storage capacity in soils	21,72	10,61	16,16	24,24	13,64	9,09	4,55
Increased crop production/biomass production	6,57	3,03	4,55	18,18	28,79	18,18	20,71
Increased carbon levels in soil	8,59	4,04	11,62	34,34	22,73	10,61	8,08
Increased pH in soil	3,03	3,03	4,55	28,79	26,26	16,67	17,68
To improve the effect of artificial fertilizers	7,07	2,53	4,04	15,66	28,79	17,68	24,24

The interviews with a Norwegian farmer who has installed a biochar unit at his farm confirm these general findings. In an interview he states that his primary interest in biochar is in improving the quality of the compost and increase plant growth. He considers the potential it has for climate mitigation as a positive side effect but not a primary motivation (Interview biochar farmer, 04.05.2017).

These findings indicate that unless relatively tangible results can be shown for biochar effects on soil deprivation, it is reasonable to believe that neither goals related to soil improvement will be sufficient as a motivation for biochar system implementation. Only if and when climate goals can be converted to agronomic and/or economically viable goals and incentives can we expect

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to see environmental and economic goals together to motivate farmers and other actors to engage in biochar systems. Note that this accounts for all three scales.

5.2 People

Decentralized biochar systems put high demands on people's participation for the success of the projects. Several actors can be identified as relevant for the implementation process. Farmers are the key players for biochar production and implementation at this level. Farmers become both consumers and producers (i.e., prosumers) of biochar since they produce biochar on their farms and consume the same biochar by burying it into the soil.

In addition to farmers, the extended network in the advisory system surrounding farmers may become important players both to build knowledge of new practices and confidence that the new practices are sound and represent good farming (see 5.5 *culture* below). We here follow the definition of advisory services given by Faure et al. (2012:462): “ (...) advisory services include: (i) the actors involved in the advisory activity and the relationships they maintain with each other and with other external actors; and (ii) the methods that are used by advisory service actors to create knowledge and know-how in individual and/or collective learning processes.”

In addition, the local government (municipalities) should be taken into consideration in the project design. They are considered to be the key implementer of central government policies (Cavicchi et al. 2014 :357), and the potential of biochar as climate change mitigation tool might be of particular interest for municipalities to actively contribute to the reduction of emissions in Norway.

For a medium-scale system, the involved actors include local farmers, forest owners, and the local government (municipalities). The local government presents a relevant actor in developing

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conditions for the establishment and operation of medium-centralized biochar cooperatives. Forbord et al. (2012) showed that local authorities played a key role both as providers of public support and as customers of bio-based energy. In the biochar setting where the technology concept is connected to the production of heat, municipalities may play the same double role as supporter and as buyer of heat as a by-product of biochar. Government support through e.g. Innovation Norway⁶ can also become relevant for financing medium-centralized biochar systems. The composition of relevant actors is very similar to the decentralized system. However, this system may require fewer farmers involved than the decentralized system, but requires higher levels of social organization from the side of the farmers, which will be discussed within the component *culture*. We can see in Table 2 and Table 3 that very few farmers are aware of the use and production of biochar. This is presumably a major hindrance for the development of decentralised systems that require high engagement from the farmers to ensure the sustainable functioning of biochar systems.

Table 2

Application of biochar among Norwegian farmers

<i>Have you or anyone you know used biochar for climate mitigation or soil improvement? (multiple answers are possible)</i>	
	% All
Yes, myself	1,01
Yes, others	3,54
No	95,96

Table 3

Production of biochar among Norwegian farmers

<i>Have you or anyone you know produced biochar for climate mitigation or soil improvement? (multiple answers are possible)</i>	
	% All

⁶ Innovation Norway is owned by the Norwegian government and aims to enhance the innovation and development of Norwegian companies.

Yes, myself	0,51
Yes, others	3,54
No	95,96

At a centralized level, following a technology concept based on wood residues as raw materials, a very interesting actor would be the forest industry. Forest owners become relevant key actors for centralized biochar systems since most of the biomass is retrieved from forestry. There has not been any studies that measure the attitudes of forest owners towards biochar, but a study by Brough et al. (2013) that explores intentions of Norwegian non-industrial private forest (NIPF) owners to provide harvest residues for bioenergy showed that NIPF owners were interested in extracting harvest residues for bioenergy production. It also showed that the interest in harvesting residues for bioenergy production decreases with age. The respondents had a very positive image of bioenergy as good for the environment but doubted their economic benefit and considered governmental support schemes as necessary. This might also relate to the fact that only 8 percent of the respondents had forestry as their main occupation, and for 82 percent, forestry income only represented 20 percent of their total income (ibid).

5.3 Infrastructure

In terms of infrastructure, a local production of biochar that is economically viable requires the local availability of feedstock. Decentralized biochar systems seem very suitable due to the high availability of biomass in Norway. Several sources of biomass may be imagined, but two seem to be of particular relevance. First, in central east Norway and parts of mid-Norway, one can probably base the production of biochar on residuals from grain production (straw). In this type of production, the gains from incorporating biochar into the soil may be of particular relevance. Thus, in these regions the infrastructure may be kept very local. Harvesting of biomass, performing pyrolysis, and applying biochar in the soil may all take place on the farm. Second,

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one can make use of biomass from forests. Approximately one third of the country is covered with forest (Statistics Norway, 2013). Furthermore, in comparison to most of the countries in Europe, Norwegian farms are located close to the forest areas, which provide many farms with the opportunity to engage in the decentralized production of biochar based on forest biomass. In this case, infrastructure is needed to take biomass from the forest to the pyrolysis station, and infrastructure is needed to store and transport biochar back to relevant farm land for application. For the first task, it is easy to imagine infrastructure built around additional technology adapted to forest harvesting technology. Also, the second task can utilize or adapt to existing infrastructure. The survey results confirm that picture and indicate that high amounts of biomass resources are available on farms, particularly forestry and plant residues (see Table 4).

Table 4

Access or surplus of biomass on farms

<i>Does your farm have access or surplus of biomass which could be used for the production of biochar? (multiple answers are possible)</i>	% All
Yes, from plant production	22,22
Yes, from forestry	51,52
Yes, from local sources (free access)	10,10
Yes, from local sources (purchased)	4,04
No	34,85
Others (specify):	2,02

The interview with the biochar farmer shows that in the daily management of the farm, the issue of transport and handling was vital, and that a system that puts few demands on transportation is positive.

A medium-centralized biochar system puts higher demands on the local infrastructure since the cooperatives must be organized. The feedstock for biochar could come from the (visited) farms directly, but this approach would exclude farmers who are interested in the use of biochar for

their land but who lack feedstock. If these farmers must be included as well, higher demands of logistics and infrastructure are given because local feedstocks would have to be picked up and preferably a local storage place would have to be identified where the feedstock could be stored. Furthermore, the access to farms plays an important role for mobile biochar systems. Farms that are located in very remote areas and hence are difficult to reach will be difficult to include in this network.

Centralized, large-scale systems frees the farmers from transportation operations, but put even higher overall requirements on infrastructure since the feedstock for producing biochar would have to be transported from different areas in Norway and brought to a central warehouse. The transportation distances for feedstock certainly have an impact on the economic profitability of biochar (Montanarella and Lugato, 2013). According to Garcia-Perez et al. (2011:1), it is economically inefficient to transport low energy density biochar further than 96 km⁷. Furthermore, long distances of transport in addition to unsustainable biomass feedstock sourcing can limit the positive climate effects of biochar production. “It is essential that the complete process chain of the biomass, including the production, harvest, transport, preprocessing required, and alternate uses, be considered to assess the true net benefit of the biochar pathway” (Downie et al. 2011:51). In Norway, forestry presents the largest potential supplier source for biochar.

⁷ The number refers to Washington State and serves as a reference frame for the Norwegian context where an exact number is missing.

5.4 Technology

The fourth component *technology* captures technological hardware and software aspects. Decentralized systems require high user involvement since it is the farmer who produces biochar. Studies on other technological systems that require high end-user involvement have shown that these technologies work very well in a laboratory setting but that problems arise with their real use in the field (Tillmans and Schweizer-Ries, 2011). In these cases, the (technical) knowledge of the end-users of using and maintaining solar PV systems is essential for their long-term use. This can be related to the literature on biochar where different ways of pyrolysis can be tested successfully in controlled settings, but this does not necessarily conclude that the same situation would take place in the real setting. Hence, in order to make decentralized biochar systems successful, the farmer needs to know how to install, handle, and maintain biochar systems. This, in turn, puts high demands on the simplicity, accessibility and user friendliness of the technological concepts that are chosen. The survey results show that farmers value easy accessibility of biochar units as important for considering the use of biochar (40 percent) (see Table 6).

Regarding user friendliness, the interview with the biochar producing farmer implied that small-scale biochar units can be very labor demanding since it is a manual process that needs someone who can constantly operate the unit. This can limit the success of decentralized systems.

...A batch unit requires that at least *one* person stands there and watches it all the time. And if you are a small scale farmer somewhere then you do not want to stand next to that - You have something else to think about than standing next to such a coal oven in a way [translated from Norwegian] (Interview biochar farmer, 30.10.2015).

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In addition to simplicity, the compatibility of technological solutions for pyrolysis and soil application with existing technologies on the farm presents a key factor⁸. It is reason to believe that a high degree of associative similarity to existing machinery and the possibility to combine existing technologies on the farm (e.g., tractors) will make the barriers to make use of new technology easier to overcome in addition to the effects of economies of scope.

Regarding the “hardware” aspects of technology, several technologies can be identified, such as the CarbonZero Experimental Biochar Kiln, the Simple Two Barrel Biochar Retort, or the Simple Two Barrel Biochar Retort with Afterburner (Biochar info, 2014). Ronsse (2003) state that small-scale steel ring kilns that are commercially available are considered to be the best option for small-scale biochar production. Furthermore, a batch process of biochar production is preferred over continuous production. These, on the other side, are more labor intensive and hard to combine with other tasks at the farm as the previous interview quote with the farmer showed. Moreover, *technologies* also capture uncertainties and risks related to the use of biochar. Markusson (et al. 2012) have analyzed seven different types of uncertainties of CCS (carbon capture storage) technologies. One of these uncertainties concerns the safety of the storage. According to McHenry (2014:450), some forms of biochar can contain toxic materials. Furthermore, there might be an uncertainty whether biochar is good for the soil in the long term. Farmers are considered to be risk averse. The smallest uncertainty of the long-term effects of biochar in soils can make farmers hesitant to invest in decentralized biochar systems.

⁸ See Rogers (2003) who mentions simplicity and compatibility as two major relevant factors for the adoption of new innovations.

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...initial adoption of biochar by farmers is likely to be limited due to perceived risks and farmers' reluctance to change their current practices and embrace new technologies (Gwenzi et al. 2015:258).

The survey results show that Norwegian farmers lack knowledge on biochar. The majority (82 percent) of the farmers indicated that they have either “no knowledge on biochar” or “to a small degree” (see Table 5). This means also that they most likely see a higher risk in the use of biochar.

Table 5

Knowledge of biochar among Norwegian farmers

<i>The production of biochar is considered by both international organizations and Norwegian authorities as climate mitigation tool because it stores carbon in soils instead of emitting it to the atmosphere. In principle biochar can be produced from a variety of biomass types. It can be mixed with soil and contribute to soil improvement. To what extent do you have knowledge of this type of biochar?</i>		All%
No knowledge at all		41,92
To a small extent		40,40
In some extent		15,66
To a large extent		1,52
To a very large extent		0,00
I don't know		0,51

According to Barham et al. (2014), risk can be divided into two components: risk and ambiguity. Risk is when the user (in our case, the Norwegian farmer) knows about the outcomes and its known probability of distribution. Ambiguity, in contrast, presents an additional risk. Here the users are not sure about the probabilities of outcomes. The success of biochar technologies will most likely be higher if they do not present an ambiguity. A parallel may be found in the literature on the use of sludge in agriculture. Studies of farmers' attitudes to – and aversions against – the use of organic waste/sludge on agricultural land shows a rather widespread skepticism due to perceived risks of consequences from toxic rests, contamination,

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and restrictions of land use related to the same (see, e.g., Refsgaard et al. (2004) for a study of Norwegian use of organic waste).

This risk can be narrowed down at the small scale level by producing biochar from the farm's own resources. Biochar that has been produced with a small scale pyrolysis unit at the first farm in Norway is planned to be produced from three different resources. These include wood chips, horse manure and crop residues. First trials have shown that the wood chips can vary strongly in their size and moisture content that influences the quality of the biochar. Thus, the wood chips have to go through a thorough screening process prior to the pyrolysis. In addition, the delivered horse manure sometimes contains other items such as for example riding boots or brooms that need to be removed before feeding it to the machine (Interview biochar farmer, 04.05.2017).

Concerning medium-scale systems, mobile pyrolysis units that can be placed on a truck have already been developed outside Norway (see, for example, IBI (2014c)) and could be adapted for the Norwegian context. Furthermore, researchers can investigate the role of bio-oil (as a by-product of pyrolysis) for mobile biochar systems, depending on the type of biomass and the pyrolysis mechanism levels of biochar and bio-oil production differ. One consideration for mobile systems could be to use the biodiesel produced through pyrolysis to transport the feedstock from one place to another. However, this is not easy. The quality of bio-oils depends on the feedstock and pyrolysis conditions. In general, bio-oils can be used directly as fuel for diesel generators to produce energy, but they need to be refined to be used for transportation purposes (Brick and Wisconsin, 2010).

Furthermore, it requires cost-benefit calculations since the higher production of biodiesel leads to a lower production of biochar. In addition, as with the decentralized systems, batch processes

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of biochar production are preferred over continuous biochar production that produce biochar on demand. However, these are often more costly and thus are not economic for a medium scale level. In addition, small and medium scale technologies seem not to be well known.

It is just strange we looked all over the world for a farm scale operation but the technologists...you know people have been talking about it for 20 years but there is not anywhere you can call and get a good farm scale solution. The industrial one you can get (Interview biochar farmer 04.05.2017).

For large-scale biochar systems, rotary kilns/retorts seem to be suitable since they can produce biochar continuously with varying forms of biochar that is necessary for an industrial production (Ronsse, 2003). At this scale, we are preferably interested in the continuous production of biochar.

5.5 Culture

In general, we can state that cultural factors become more relevant for medium and decentralized systems since the farmer is not only a consumer of biochar but also a producer. Thus, levels of agency increase with the decentralization of biochar systems. At a large scale level, the farmer is only a consumer who purchases biochar and then plows it into the soil. Hence, the following section addresses mainly cultural concerns for medium and decentralized levels of biochar production, where the farmer is involved in the production of biochar.

For a decentralized biochar system, culture is particularly important since the success of biochar technologies relies on a new system and practice that are to be implemented in an existing social and cultural context. For a decentralized farm-based technology concept, the farmer is expected to take the system into use and adapt this to existing practices. A core question is then whether

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the practices as well as goals and values of the new system are compatible with the existing one. Burton (2012) and Burton et al. (2008) explore the cultural schemes in agriculture and document how cultural factors are important for agricultural practices. Although cultural schemes (e.g., in forestry) differ fundamentally, the degree to which these are more or less compatible with biochar systems remains to be researched, but the basic finding remains: Culture and values matter for the ability and will to absorb new practices. Culture is documented to have multiple effects on technology use (see Pacey (1983)). Earlier studies on technology implementation have shown that cultural factors can both enable and limit a successful technology implementation (Author, 2014).

The interviewed farmer is planning to use the biochar unit mainly in the low season (between November and December) when more time is available. In addition, he is planning to connect the unit with one of his greenhouses to make use of the excess heat from the biochar production process that is now lost.

We want to make an air to air exchanger, a simple one. We only have three months. The greenhouse is only heated for three months. But this design can be also very good for water and heating. I think there is a lot of potential. We can stop buying diesel. Now we are going for burning horse manure, mixing the biochar with digestate and using the heat for the greenhouse. (Interview biochar farmer, 04.05.2017).

For the farmer time plays a key role that determines the use of the biochar unit. The farmer plans to automatize the machine since it functions manually at the moment and hence requires the continuous guidance/presence of someone. The farmer states that by having a manual pyrolysis labor costs need to be included, which will increase the price for biochar and make it too expensive for him (Interview biochar farmer 04.05.2017).

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For decentralized biochar systems in the Norwegian context, it is particularly important to take the social organization of farm life and the daily routines at farms into consideration. Furthermore, we need to understand the predominant values of farmers. These aspects are often underestimated in technology implementation. The focus is often on the economic viability as the key factor for successful implementation. However, this perspective does not explain why new agricultural techniques are not used even when they show clear advantages. There is a variety of non-economic aspects that are important for farmers' decisions on production and investment (see Knutsen (2007) and Mzoughi (2011)).

Some studies have shown that the meaning of farming can influence the success of new agricultural technologies. Besides economic gain, several other meanings of farming could be identified among farmers that are important for Norwegian farmers, such as the production of high quality food, sustainable and environmentally sound farming, independent lifestyle, the performance of work tasks, working with animals, and passing on the land in good condition (Kvakkestad 2015:85). Therefore, in order to implement decentralized biochar technologies successfully, there is a need to identify what farmers perceive as relevant.

In addition, Norwegian farm households are traditionally based on diversification (on-farm and off-farm) (Daugstad et al. 2006). This means that they pursue multiple income earning activities within and outside the agricultural sector. According to Daugstad et al. (2006:68), only a fourth of all farm households utilize full-time farming as their only source of income. A recent study conducted by Storstad and Rønning (2014) found that only 5 percent of the farmers questioned stated that they earn 100 percent of their household income from farming activities. Furthermore, a high percentage of the respondents stated that they earn the largest part of their income outside the farming sector (ibid).

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This presents a challenge for biochar production in multiple ways. First of all, off-farm diversification might reduce the interest in biochar production because it leads to an extra workload for farmers. The Food and Agriculture Organization (FAO) of the United Nations (FAO, 2010) developed a list of multiple barriers to the implementation of Integrated Food Energy Systems (IFES) at and beyond the farm level, and increased workload due to the introduction of IFES is considered as a major barrier to the successful adoption of these technologies. Thus, in the Norwegian context of diversification, the question arises of how far biochar systems can be integrated in the daily farm life without leading to extra work load or interrupting other farm activities and income diversified activities.

In addition, farms that are characterized by off-farm diversification might also be less interested in biochar production as soil fertilizer if production does not present the primary strategy of farmers to increase their income. Off-farm diversification often includes work in the service sector and transport outside the farm (Rønningen et al. 2004), and in this context increasing production (with the use of biochar as soil fertilizer) is not the preferred means for increasing the local income. Focus should be also given to the motives for farmers' diversification, which are complex and capture more than just economic benefits (Hansson et al. 2013). Motives for diversification are context-dependent (Author, 2011). Many farms are run as family businesses, and thus for decentralized biochar systems we need to take into account the local family relations that influence farmers' decisions concerning levels of diversification.

Furthermore, the importance of the social identity of farmers as food producers can be relevant in the context of biochar implementation because of its potential to increase soil fertility. A study by Burton (2004) undertaken with farmers in the UK shows that the production-based roles of farmers are very important. The importance of the role as food provider is also

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confirmed in a study by Sharpley and Vass (2006) who investigate the role of tourism as an income generating activity for farmers in northern England. Their study revealed that a majority of farmers would like to continue with farming as their main business and that their identity as food provider was important in that context. We assume here that farmers who emphasize their role as food producer might be more interested in a decentralized biochar system that can lead to higher crop production. For medium-centralized systems, the production of biochar in the form of local cooperatives would provide a new business opportunity for local farmers or forest owners.

The survey results show that most Norwegian farmers lack knowledge of biochar. However, the majority of those who are interested in producing biochar state that they would be primarily interested in producing their own biochar (34 percent) than buying it from others (see Table 6). This shows that decentralized biochar systems might presents an additional activity contributing/strengthening farmers' perceptions as food producer.

Table 6

Relevancy biochar use

<i>What would be most relevant if biochar should be used on your farm?</i>		All%
Producing myself		34,34
Buy locally (for example from a producer in the area)		8,08
Buy from a known source		15,66
Not applicable, I anyway will not consider its use		3,03
Other:		0,51
I don't know		38,38

As mentioned earlier, for many Norwegian farmers diversification is a common practice and the success of biochar production will very much depend on how much importance Norwegian farmers give to farming activities. However, the study also showed that some farmers reported

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that levels of collaboration with other farmers are declining because farmers either have a full time position outside of the farm life or quit farm life altogether. Because of this, there are fewer farmers available, and the distances between the farms increase. Furthermore, due to the fact that more people work outside of the farm, fewer people are left to work on the farm, which leads to a higher workload for these people

However, medium-centralized biochar systems could also present a new form of diversified farm activity. Hansson et al. (2013) define diversified farm businesses as those farms that use their farm resources for activities other than production of conventional crops and livestock to generate income or that add value to raw materials originating from primary production, e.g., by running a small-scale processing plant. Medium-centralized biochar would suit this definition by adding value to biomass residues through a mobile pyrolysis unit. Mobile pyrolysis systems impart requirements to the social organization of Norwegian farmers. The culture for cooperation with using machinery and other production components varies considerably between regions. Some farmers rarely cooperate or share machinery, while other places are willing to share resources. For example, a study by Eriksen and Selboe (2012:163) showed that 34 of 42 interviewed farmers reported that they were engaged in some type of sharing with other neighboring farmers, and that sharing of machinery has been a tradition over several generations.

Nevertheless, these aspects need to be considered for the design of mobile biochar systems for Norwegian farmers in a particular area and should be included in future research assessing the social acceptance.

5.6 Processes and procedures

Examples of processes and procedures are political support schemes. The potential range of solutions is substantial. Probably, several of the support schemes used for, e.g., bioenergy, could be used also for biochar (see, e.g., Forbord et al. (2012); Thornley and Cooper (2008)). The provision of green certificates presents an option to increase the interest in biochar systems from the farmers' side, particularly for a small-scale system. Other countries such as Australia have implemented an Emissions Reductions Fund (ERF)⁹ that provides farmers with economic incentives if they decide to store carbon or reduce GHG emissions on their land (Kragt et al. 2016)). The IBI has launched a voluntary, self-certifying biochar certification program based on predefined product definition and product guidelines (IBI, 2017). However, this program is currently limited to Canada and the USA. A national research project in Norway involving researchers from NIBIO¹⁰, SINTEF¹¹, NMBU¹² and CRR¹³ currently investigates the Norwegian conditions and standards for a national certification of biochar.

However, biochar is not included in current agricultural policies due to its uncertainty related to its long-term effects, as mentioned earlier. This uncertainty is increased by the fact that biochar cannot be removed from the soil again once it has been added. These uncertainties need to be solved in order to make biochar a part of current policy approaches (Jones et al. 2012), which counts for all levels of biochar systems. However, the situation with mobile biochar systems is more complex. Policies need to ensure that farmers who actually add biochar to their fields receive the subsidies. Otherwise, we might risk that the mobile produced biochar will be

⁹ Which builds on the earlier CFI (Carbon Farming Initiative)

¹⁰ Norwegian Institute of Bioeconomy Research

¹¹ The Foundation for Scientific and Industrial Research

¹² Norwegian University of Life Sciences

¹³ Centre for Rural Research

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burned instead, as it is the aim with some large-scale industry producers and then the aim of being carbon negative would not be achieved. The survey results show that 55 percent of the farmers would consider the use of biochar if the technology costs are low enough to ensure a positive added value through increased crop production. This confirms to a recent study on the social acceptance of biochar in Poland where costs were identified as a crucial factor determining the adoption of biochar systems (Latawiec et al. 2017).

Nevertheless, in order to provide farmers with low costs biochar units, new policy strategies are necessary to be implemented in the startup period that will increase knowledge on biochar and enable the market. 70 percent of the farmers in our survey view increased knowledge of the use and effect of biochar as crucial for the adoption. In addition, 28 percent state the introduction of new subsidies as important factor for the adoption of biochar system and 30 percent state that a targeted compensation for storing carbon in soils would increase their interest (see Table 7).

Table 7

Factors for farmers to consider biochar use on their farms

<i>Which factors can contribute that you consider the use of biochar on your farm? (Multiple answers are possible)</i>	
	% All
Increased knowledge on the use and effect	70,20
That new subsidies are introduced	28,28
That I get a compensation for storing carbon in soils	29,80
That I can sell carbon credits	7,58
New public regulations	8,08
That several others in the area where I live apply biochar	11,11
That the technology is easily accessible	40,91
That I have someone to collaborate with	17,17
That I can see the production and the use in practice (testing facilities)	25,25
That some of the producer organizations recommend it	7,58
That the agricultural advisory services recommend it	23,23
Very low costs so that it contributes to a positive added value through increased crop production	55,56
Nothing (I will not use it anyway)	7,58

At a centralized level, processes and procedures addresses Norway's energy policy. For a long time, the Norwegian energy policy focus has been on oil and hydropower. When it comes to policy formation, the political system is characterized by a centralized energy policy that lacks connection with district or agricultural policy or municipalities (Cavicchi et al. 2014:362), even though the hydro power industry has been developed locally and is closely associated with municipalities. In order to implement centralized biochar technologies successfully, policies need to support the production of biochar. However, the current focus of bioenergy might lead to a competition of different uses of biomass. The policy focus would have to include biochar as well to engage local enterprises. However, since only a small number of people are involved in forestry as their main profession (eight percent, as stated earlier), support levels must be high if income from residue delivery for biochar production is expected to be an essential factor. Furthermore, as mentioned earlier for medium-centralized systems, subsidies for the end-users are necessary to ensure that the biochar will actually be added to the soil.

6. Conclusion

At this point, we have presented the three different scales of biochar systems and the values of all six components for each system based on a literature review supplemented with quantitative and qualitative data. We can see that the situation is complex, and the implementation of biochar systems requires a thorough analysis of relevant social and organizational factors that not only address the physical technology and economic benefits.

The aim of this article was to investigate non-technical aspects for the implementation of biochar systems in Norway by applying a socio-technical system approach. Research that investigates the non-technical factors mainly address the economic feasibility of biochar. However, in this study we showed that this is a very narrow perspective since it is not only the

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potential economic gain that determines the adoption of new technologies. This perspective ignores the social aspects of technology adoption. There is a variety of non-technical factors that need to be considered. Within the socio-technical system approach, we identified six relevant components that presented the basis for our analysis. The values of these six components were studied for three different scales of biochar systems (i.e., centralized, medium centralized, and decentralized).

Even though some of the values are similar across the different systems, there are also huge differences between the values of the non-technical factors that need to be addressed in the project design for biochar systems. At a decentralized level, both lack of knowledge, and a range of cultural factors such as level of diversification and farmers' social identity might present a challenge for biochar projects, while centralized systems put higher requirements on infrastructure by requiring a central storage and transport system that picks up the feedstock from different areas and delivers it at a central point. A big scale plant may, on the other hand, be easier to realize as it does not require the same level of local engagement in the development of a functioning biochar system.

The complexity of the non-technical factors shows that there is a need for more social science research on biochar systems that should take place in close collaboration with natural science research to help in the process of choosing the appropriate technology of scale.

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