



The social shaping of technology – a case study of **biochar** in Denmark

A case study of the innovation journey of biochar in Denmark: insights for businesses, researchers, investors and policy-makers.

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Executive Summary

During 2010, I conducted an investigation on the Relevant Social Groups (RSGs) related to biochar-production and their current perception of biochar as well as the general public. The results suggest that the future technological development of biochar will depend on its multifaceted capacity to *'mitigate climate change'* through its ability to be a *'stable carbon storage'* and subsequently a *'possible CDM'*. In continuation of this, biochar-production might also prove helpful in solving waste disposal problems as biochar-production has the potential to be an *'environmentally friendly disposal method'*. Other key components depend on biochar's ability to *'increase crop productivity'* by functioning as a *'soil conditioner'* hence offering an economic benefit to farmers. However, among all RSGs, there is a widespread appreciation that *'research is needed'* before being able to make intelligent choices on the allocation of resources into the biochar-technology and extracting the full range of benefits offered by biochar. Another key finding as a result of this uncertainty has been the discovery of a collectively passive behaviour among most RSGs, which has left room for a very active and influential Entrepreneur to act.

Keywords: Biochar, Environmental Management, Social Construction of Technology, Science and Technology Studies, Socio-technical Analysis, Social Entrepreneurship

KEY MESSAGES FOR DECISION MAKERS

- The academic and international biochar-community is currently focusing their efforts to overcome the challenge of **categorising types of biochar**, which might constitute a tipping point for the technology.
- Biochar is currently not recognised as a Clean Development Mechanism (CDM), which – if adopted would significantly transform the economics of biochar. Earlier this year, biochar was incorporated in the American Power Act, a plan to secure America's energy future, which might be an **early indication on the future recognition of biochar that could lead the way for more widespread adoption**.
- International and regional collaborations are promoted at a significant pace at the moment. If Danish companies and a Danish market are to gain a lead-position, the current **need for organising knowledge-sharing devices** like e.g. a Danish Centre for Biochar, should be attended to.
The expectation of scientists and entrepreneurs is that biochar at some point will reach a tipping point and **be on the market within the next 5-10 years**
- Entrants to the Danish biochar market might gain a competitive advantage if they focus their efforts on **producing biochar based on the clean input-factors** as mentioned in Bilag 1 in Biomassebekendtgørelse (i.e. tree and straw), given this does not include municipal instructions and opportunity costs can be avoided following prescriptions in the Slambekendtgørelse.
- **Using waste as an input-factor could prove valuable** in that biomass waste disposal, according to the EU landfill directive, is being phased out. However, the costs of using organic waste would largely depend on costs imposed by law (see Slambekendtgørelse).
- **Large-scale biochar plants are very unlikely** given the physical infrastructure in Denmark. Future **biochar-production has advantages in small-scale clusters** (e.g. farming consortia), which is especially competitive with regard to the transportation parameter since this can be done within short distances (approx. 10-40 km) and the transportation of biomass from and back to land will not constitute a significant economic barrier. **A driving mechanism is the economics of Combined Heat and Power (CHP) Plants** that also can offer bio-electricity and/or heat to local district heating systems.
- A study suggests that **pyrolysed biochar can outperform direct combustion of biomass at 33% efficiency** in terms of carbon abatement, even if there is no beneficial indirect impact of biochar on soil greenhouse gas fluxes, or accumulation of carbon in soil organic matter.
- Adopters of the biochar-technology should pay **attention to the specific carbon payback period for the input-factors**. Straw and coppiced hedgerow feedstock give clear carbon savings within a 20-year time frame, but tree-based biochar acts as a net carbon source over 20 years.

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A FRAMEWORK OF ANALYSIS

INTRODUCTION

In response to the coming resource crisis, promising technologies such as hydropower, solar photo-electrics, solar steam generation using mirrors or biofuels are held up to be the new technologies and solutions that can ensure our economy and lifestyles in the future.

However, these “new” technologies are not as new as they are made out to be. In 1941, scientists from twenty countries including China, India, US, the Soviet Union and many European countries met at the Royal Institution in London to decide which policies to adopt after the war (Bruges 2009). The scientists at the conference in 1941 already then discussed the abovementioned technologies as well as the possibility of using North African deserts as centres of power generation. This is something a consortium of European companies (The DESERTEC Foundation) just recently decided to engage in - 68 years after it was first suggested.

Today, many perceive these new and green technologies as great opportunities for both job creation and climate change mitigation. However, these technologies, which are still in their infancy, could also be perceived as an immense lost opportunity. If the scientists' ideas – and proposed technologies had gained more acceptance and the world community after the Second World War had invested in these technologies and chosen another path for the post-war reconstruction, these new green technologies would not still be in their infancy today.

Thus, in this perspective, the lack of knowledge, economic incentives and action lead to a temporary halt of approximately 70 years in the development of these technologies.

Today the situation is remarkably similar. As reflected by the rapid growth of scientific publications, articles and public debates, climate change is claiming its rightful place at the front of the public conscience in these years and is already proving to cause immense challenges for communities and the agricultural sector around the world.

It is now widely recognised that climate change poses a serious range of threats such as desertification, warmer temperatures and rising sea levels. However, public debates are still characterised by a lack of awareness and widespread ignorance in regards to related problems such as water scarcity, fertiliser shortages or declining agricultural outputs. The solutions typically being discussed in the public sphere often refer to windmills, solar power, biofuels or electric cars, which leaves out underexposed and potentially more promising areas of research like the one of biochar.

Biochar and the biochar movement are fairly new concepts that have emerged in conjunction with soil management and carbon sequestration (Lehmann & Joseph 2009). Biochar conceptually descends from the now less-known concept *agrifar*, and it was therefore no coincidence that it was the International Agrifar

Initiative, which was founded at the World Congress of Soil Science in Philadelphia in 2006, that formed the International Biochar Initiative.

The historic traces of biochar dates back to pre-Columbian times, where Indians in the Amazon Basin used it to produce, what today is known as Terra Preta (*black earth* in Portuguese), to improve soils for agriculture. Today, the Terra Preta - thousands of years later - still displays high levels of soil organic matter and nutrients like potassium, nitrogen, calcium and phosphorus, and it remains significantly more fertile than the surrounding lands (Glaser et al. 2001).

The basic idea behind biochar is that plants sequester carbon through photosynthesis, and instead of letting plants rot, which releases green house gasses back into the air, the plants can be burned through pyrolysis (thermal degradation in an oxygen free environment), which then creates the coal-like substance called biochar. To add value to the process, the sequestered carbon in the biochar is then buried to improve soil fertility, increase crop yields and sequester carbon. Thus, biochar distinguishes itself from charcoal by the fact that biochar is intended to improve soil productivity and store carbon, and not as a component in energy production.

Biochar is, however, still a technology in its infancy and offers a unique opportunity to investigate the social shaping of a currently developing technology. Allegedly, Biochar has several benefits: retention of nutrition in the soil, absorption of CO₂, reduction of the need for artificial fertilizer, increased crop yields and the utilization of biomass-waste products that otherwise would have decomposed and produced methane. The unique properties of biochar therefore seem to be able to create a win-win-win scenario, which is why this emerging technology is worth some scrutiny.

RESEARCH QUESTION

It is interesting to note that even though biochar according to some sources has a great potential for mitigating climate change and improving the agricultural sector around the world, the actual usage is almost non-existent and the public awareness is close to zero. In a recent analysis published in the journal Atmospheric Chemistry, Tim Lenton, a professor at University of East Anglia, rated biochar as the best available technology to curb global warming, which puts him in line with NASA's top-scientist James Hansen and Chris Turney, professor of geography at the University of Exeter, who represents the opinion that biochar is the closest thing scientists have to a silver-bullet solution to climate change.

Critics on the other hand argue that farmers in developing countries might be forced to produce fast-growing monocultures on agricultural land to supply the biomass used for biochar instead of using the land for agricultural purposes. According to Alan Robock, a climate scientist at Rutgers University, biochar could backfire and even worsen the climate situation and distract attention from the need to reduce emissions.

Overall though, most scientists agree that the science behind the technology is still too new to say anything definitive and the general approach is eloquently summed up in a recent review of Geoengineering by The Royal Society where it is stated that *it remains questionable whether pyrolysing the biomass and burying*

the char has a greater impact on atmospheric greenhouse gas levels than simply burning the biomass in a power plant and displacing carbon-intensive coal plants (The Royal Society 2009: 12).

It is these considerations that lead me to pose the question of whether biochar will make it to the market by examining: **Which social actors are influencing the technological development of biochar in Denmark, and what are the characteristics of these practices?**

Posing the question about how a green technology becomes a commercial success or failure can help us better understand the processes through which the structures and mechanisms emerge – or fails to emerge – rather than assuming a static process of path dependence. However, given that biochar is a technology in its infancy and there exists a high degree of uncertainty regarding its capabilities, the research strategy is deliberately designed to ensure a constructivist and explorative approach that rejects any preconceived ideas of the behavioural patterns of social actors and the development of the technology itself.

To go about this, I have chosen the theory of the Social Construction of Technology (SCOT) within Science and Technology Studies (STS) that allows exactly this. SCOT allows the researcher to incorporate the various realms of both community, companies and other social groups, and based on their perceptions, create an overview of the key issues regarding the technology as well as identifying relevant social groups, communication distribution and behavioural patterns.

SCIENTIFIC APPROACH

The overall scientific approach to the domain is a social constructivist frame of understanding. I have chosen this approach due to the social and qualitative character of the subject at hand, and because this approach becomes valuable, as the research process is highly dependent on personal impressions, assumptions and interpretations – and deductions made on the basis hereof. A social constructivist frame of understanding encompasses all of these factors along with providing the ontological guidelines for reaching an understanding of these. Additionally, it has been imperative to select a theoretical orientation that allowed for an analysis of the interaction between technological development and markets as dynamically evolving processes, as there exists a significant gap in the literature concerned with empirical studies incorporating such an approach (Reijonen 2008).

The social constructivist approach builds on the notion that reality exists in a world outside language, and that human realisation does not have the possibility to understand it, given human realisation happens though the use of words and concepts that are mediated through language (Rasborg 2004). The logical consequence of this viewpoint is that knowledge cannot be seen as something absolute or independent of human interpretation, but rather as *highly ephemeral, in that it will vary by both time and place* (Bryman 2004: 18). The epistemological consequence of this assumption is then that we should reject the idea of

truths and instead focus on viability since a predetermined objective reality does not exist. The scientific approach, and analytic premise, is thus that *the world (...) is constituted in one way or another as people talk it, write it and argue it* (Bryman 2004: 18).

Social constructivism as a theoretical focal point essentially focuses on relations – e.g. between constructions and the surrounding world, social practises, objectified societal conditions etc. – which allows for an examination of green technologies, in a context where the social groups, their arguments and prevailing concepts can be understood as results of complex social negotiations and dynamic processes.

SELECTION OF THEORY

Whether or not a technology will become a success or not, there has been the area of interest within Science and Technology Studies (STS) where technology is considered to be an object of social circumstances and not just a result of the best available technology. STS should therefore be seen as a field opposing technological determinism that sees technological development as something predictable, rational and beyond cultural influence. The field of STS is, in other words, the study of how political, social and cultural values affect scientific research and technological development, and vice versa.

As a result of the dual approach of the field of STS, there has historically been a division in the literature between theorists who seek to deconstruct science and theorists who seek to deconstruct technology. My interest, and the purpose of this thesis, is however not to gain any insights in how the actual technical development happens but rather who pushes the development, through which channels and in which context.

Theories descending from the STS-field (e.g. Actor Network Theory, Social Network Analysis or Semantic Theories) all offer analytic tools to answer these questions, but I have found that Social Construction of Technology (SCOT) provides the most suitable option for reaching the research objectives – especially mapping the relevant social groups. SCOT essentially differentiates itself by offering not only a conceptual framework that makes it possible to cluster similar social actors into groups and investigate *the social*, but SCOT also provides a methodological and heuristic data collection methodology that lies in line with the chosen research strategy.

SCOT will serve as the overall theoretical framework to examine the *seamless web* of society and technology (Bijker, Hughes & Pinch 1987) since it is applicable to the present field and allows for conceptually perceiving broader selections of comparable social actors as groups instead of individual social actors – and thereby making the analytic parts more comprehensive, which, given the complexity of the field, are attractive arguments that can help ease the job to gain insights in how a technology like biochar can develop.

As mentioned, SCOT is not solely just a theory. SCOT also includes a data collection methodology and suggests starting one's data collection by simply beginning to ask a few presumed relevant social groups to identify the relevant social groups and thereby starting to roll a *snowball of data*. The reasoning method used in SCOT therefore takes its starting point in an inductive approach but integrates the collected data in a deductive context, which complies with the overall abductive approach set out later in the methodological approach.

RESEARCH STRATEGY AND DESIGN

A research strategy addresses questions of whether the scientific approach should be empirical or theoretical, the direction of the research process, choice of data collection methods, the procedures for analysing the data material, how to deal with ambiguities and make it as transparent as possible how I progressed from problem to conclusion (Alvesson & Deetz 2002).

Now, given social organisation takes place in fragmented and multiple contexts, the construction of markets for biochar cannot either be assumed to take place in only one location (Czarniawska 1998). Therefore, a research design that reflects these issues is needed in order to approach this suggested multiplicity of the construction of new markets and the roles of the relevant social groups therefore require a research design reflecting these issues.

An explorative research design does in this regard offer valuable qualities, and is highly suitable to the premise of the construction of markets as a dynamic evolving process.

To fully grasp the assumed diversity of local choices and actions made by social actors, an explorative research design can bring about the recursive and reductionist progression that will - to a larger or lesser extent - change the research process from the initial focal point through the recursive movement from processing the data, concept-development and analysis-interpretation. Furthermore, this has the analytical advantage of being open for possible new insights and incorporate unexpected findings.

The exploratory research design is also chosen partly due to the urgent need for empirical research that approaches the emergence and development of new markets for green technologies as something dynamically evolving (Reijonen 2008: 21).

Prior to my fieldwork (interviews with scientists, entrepreneurs, public officials etc.), I rejected the notion of applying pre-made theoretical categories or hypotheses to the data material in trying to investigate the data

OVERALL RESEARCH OBJECTIVES

Map the relevant social groups within the biochar field (through an exploratory research design where initial pilot interviews and content analyses helped create an overview)

Identify key topics (through a recursive movement between analysing the interviews, content analyses and historic sources)

Explore biochar from different perspectives (by including viewpoints from different social groups and allowing for co-existing and conflicting understandings through the construction of scenarios)

more freely and obtain more diversified data sets. The initial exploratory research design should therefore be seen as reflecting this as well as being a part of the broader conceptual framework offered by SCOT, which also has an exploratory approach integrated in its theoretical design, data collection methodology, as well as the spirit behind the use of the theory.

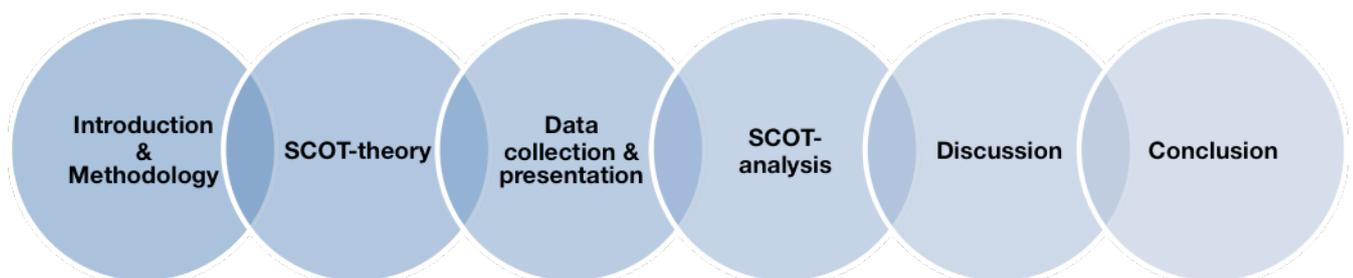
In short, the conceptual framework of SCOT should be employed as *a collection of sensitising concepts that aims to provide the researcher with a set of heuristics with which to study technological development* (Bijker 1995: 49).

Given the research question, the subject at hand, and the context-dependent approach, this study can furthermore be seen as a case study-contribution to the wider literature in Science and Technology Studies. As observed by Yin (2003), the relevance of case study designs should be considered when: (1) the focus is on *why* and *how* questions; (2) the researcher cannot manipulate the behaviour of the participants in the study; (3) the researcher wants to examine contextual conditions because he believes they are relevant to the phenomenon; or if (4) the boundaries between context and phenomenon are not clear.

Yin (2003: 13) essentially suggests applying a case study strategy when trying to investigate a *contemporary phenomenon within a real-life context especially when the boundaries between phenomenon and context are not clearly evident* - conditions that are all met in the present study.

The present study enrolls itself in the line of exploratory case studies that makes it possible to explore phenomena by using a variety of data sources and through different lenses by including the viewpoints from different social actors, which is useful as the phenomenon needs more clarification and there is no clear outcome (Yin 2003).

The impetus of the study is taken in (1) the research question and the chosen methodology, and (2) the theoretical lenses through which the answers have to be found. To find these answers, I have chosen to perform content analyses of the Danish public sphere, a scientific review and an academic conference since this allows me to identify patterns in the data material and pursue the data I obtain underway, and just as important, to ensure the reader access to the data prior to the SCOT-analysis. (3) The data will accordingly be presented and (4) the SCOT-analysis will be carried out and form basis for the subsequent (5) discussion of the findings, and lastly (6) concluding on the basis of these findings.



METHODOLOGICAL APPROACH

It is essential for any rigorous research attempt to clarify and explore which methods (interviews, observations, etc.) should be used, which methodology (action research, ethnography, etc.) governs the choice of methods, and how the theoretical perspective of looking at the world and sense-making (systemic thinking, theory of language, etc.) affect the reasoning method(s) and how it provides a context for applying the methodology (Brown & Sice 2005).

As prescribed by SCOT, the data collection methodology is characterised by investigating the field through the use of an inductive approach where the researcher simply begins to ask a few presumed relevant social groups to identify other relevant social groups, and thereby starting to roll a snowball of data. To encompass such a fairly heterogeneous set of data sources, this approach calls for a methodological approach that reflects this diversity while being able to provide a framework for this to be analysed. And a field that offers this is the analysis of documents in qualitative research.

The field of documents in qualitative research is mainly comprised by semiotics, qualitative content analyses and discourse analysis, and as elaborated more on in the following section – has *texts* as the analytic unit. Common for qualitative research strategies is that they predominantly emphasise inductive approaches, reject positivism (in particular in how individuals interpret the social world), and embody a view of the social reality as a constantly shifting property of individuals' creation (Bryman 2004: 20).

Given that the data collection focuses on *why* and *how* the different social groups speak of and describe biochar and its semantic functions, semiotics as well as discourse analysis could contribute to a qualitative take on the textual analyses. Content analyses have traditionally been referred to as a quantitative method, which would rule it out in this qualitative context. However, because relational content analyses are more than a quantitative approach to textual analysis and as elaborated more thoroughly later on, this conceptualisation of what a content analysis is allows for both a qualitative and a quantitative perspective on the data material.

But before going into a deeper discussion of this, I would like to turn attention to the underlying scientific reasoning that is used to conduct the thesis. The two general approaches, induction and deduction, are fundamentally different in that inductive reasoning involves moving from a data set to general conclusions whereas deduction tests data within a theoretical framework.

Using either one of these methods under the present conditions would prove to be a rather troublesome and rigid business since the data collection phase is characterised by an inductive methodology and the subsequent analysis of the data and the formation of analytic constructions differentiates itself by its deductive nature.

It is, however, possible to take a starting point in observations and then test them against existing theories (Cooper & Schindler 2008). This approach is referred to as abduction, which applied to the present circumstances, constitutes a suitable reasoning method.

Abductive reasoning takes its focal point in observations that will be analysed through analytic constructions, which then makes it possible to deduce insights in the field. For this thesis that means that based on the analysis of the data material, through the theoretical background, it is possible to provide insights into the technological development of biochar.

However, this approach has problems of its own. Since the present research field is not directly observational, it is imperative to include theory, statistical data, and social experiences in the process of answering the research question and ensuring triangulation of the data sets (Krippendorff 2004).

CONTENT ANALYSES AS DATA SET

The content analysis is one of the most important tools within social sciences and makes it possible to deduct data from *texts* (broadly defined as opinions, articles, conferences, informal conversations, arguments, interviews etc.) within a given discourse. The strength of the content analysis lies in its ability to extract the presence of underlying themes and certain concepts or words – and relevant for this thesis: identify the relevant social groups and key issues.

Formal definitions of content analyses vary, but the general assumptions are that it allows the researcher both to quantify and analyse the presence of words and concepts, and also to investigate the relations between these and subsequently make it possible to make inferences about what the concepts mean to people and how this meaning makes them act (Bauer 2000; Krippendorff 2004).

When the term *content analysis* is employed in this thesis, it will be referring to a mixture between what is in the literature referred to as *relational* and *conceptual* content analyses. In this context, the content analysis is, as such, a quantitative method that seeks to identify and quantify special characteristics. This then allows for a deduction of meaning from the chosen texts and the construction of frames¹.

To support and justify the deductions made in a context that is not logical, and to ensure a high degree of validity, Krippendorff (2004) therefore suggests that researchers create analytic constructions from the texts. These analytic constructions *operationalise what the content analyst knows, suspects or assumes about the context of the text and procedurally accounts for the drawing of inferences from that text* (Krippendorff 2004: 171), which is also closely related to Kvale's (1995) concept of *thematizing* that also covers these analytic constructions.

The concept of analytic constructions should therefore be seen as explicating the thematisation of the data sets, which additionally has the advantage of making the research process more comprehensive and transparent to the reader.

¹ The content analysis can thereby provide some indication of relative prominence and absences of key characteristics in media texts, but the inferences that can be drawn from such indications depend entirely on the context and framework of interpretation by which the texts analysed are circumscribed. (Hansen, Cottle, Newbold & Negrine 1998: 95).

However, the formation of these analytic constructions, or frames, is however not a walk in the park. Texts cannot be seen as isolated or objective but only in their context and how the recipients interpret them, and especially how the researcher processes them (Krippendorff 2004: 81).

The actual construction of these analytic constructions/frames have thus been created through a creative process where I have processed the texts in over and over again to ensure a proper categorisation of the content, and often had parallel discussions with my co-advisor, Sander Bruun.

In this categorisation-process, I have created analytic constructions that are not necessary mutually exclusive but due to the analytic purpose of gaining a more thorough understanding of the complexity of the data sets I have done it to create contexts for any relevant findings.

Finally, as noted by Krippendorff (2004: 39), the scientific validation *may be difficult or infeasible, if not impossible, in practice*, which underlines the need for a high degree of transparency and triangulation of the data sets.

INTERVIEWS AS A TEXT

My approach to the conducted interviews has not only been getting my questions answered but also to be open to any new knowledge the respondent might have. This approach should make it possible not only to go into depth with specific questions, but also leave room for new insights that cannot be placed into predetermined categories (Kristensen 2007). I have therefore conducted the interviews with a focal point in my semi-structured interview guide (see Appendix E) while having a strong focus on the exploration of new themes and issues.

My approach to the interviews has been that an interview is not merely a give-and-take of answering and asking questions. The constructivist critique that has been targeted towards the traditional structured interview and its assumptions about the researcher-subject relationship has led to a greater understanding of the actual interview situation, and that it is both socially and historically mediated (Dunbar et al. 2002).

The focus obviously remains on gathering data but the emphasis on procedural matters are broadened to also include the realm of meaning and the social context the interview finds itself in. Following this constructivist tradition and its emphasis on gaining an understanding of the data material, it also makes it relevant to ask questions like whose facts, for what purpose are they saying what they are, and in what setting (Marvasti 2004).

To do this, I have tried to entail a delicate trade-off between making sure the interviewee and I were on the same page while at the same time trying not to influence the interviewee too much. Practically speaking, this means that I have tried to create room for the interviewee to answer my questions but instead of taking

the answers for granted and adding my own interpretations to the concepts and wording, I have tried to pay attention to not only *what* has been said but also *how* this has been said.

On a practical note, whenever I have been in doubt of what the interviewee actually meant I have tried to sum up what I interpreted have been said and asked again – not as a leading question, but to provoke more straightforward answers, which gave the interviewee the chance to correct any incorrect interpretations from my side (Kvale 1996).

Realising that this act could lead to a bias towards my interpretations rather than the original thoughts of the interviewee, I have tried to do this carefully and chosen this practice due to the less attractive alternative - letting fundamental misunderstandings go unnoticed (Kvale 1996).

DELIMITATION

The overall objective of this study is to gain an understanding of the most important aspects of the construction of markets, and in particular the construction of green technologies, and to map the relevant social groups that are influencing the technological development of biochar. In examining this, the theoretical lens to analyse this through is constituted by the SCOT that originally was offered by Pinch & Bijker (1984).

Now, as Sonis notes in Sonis & Hewings (2009: 245), the complexity of innovation diffusion processes require a multidisciplinary unifying viewpoint, which is simply not possible by the sole reason of space limitations. However, SCOT does offer a multidirectional approach to the domain of interest, which has the preconditions to provide valuable insights into the field.

In answering the research question, it has been a balancing act to ensure both depth and scope throughout the thesis, and decide what is nice to know and what is need to know for the reader. An example of this balancing act is the prioritising of which themes and key issues that deserve to be elaborated on more carefully and which does not. Furthermore, this is made difficult since not even the relevant social groups themselves can be expected to have a clear idea about the future and what could be expected to drive the technological development of biochar, which the data material also suggests.

Relevant questions like whether it might be the biochar itself or the overall biochar-system (and its bi-products) that will drive the development, or exogenous factors like subsidies, or completely different factors are obviously relevant, but as a matter of methodology and space limitations, I will gloss over details and solely focus on what the social groups perceive as the key issues.

The next step was to limit the scope to a single market, where the obvious choice was – because of my location in Denmark - the Danish market due the relatively easy access to the Danish social groups. However, the arbitrary boundaries of nation-states do not naturally mean boundaries for ideas, trade or historic sources. Early in the research process, I realised the importance of international research on biochar (for Danish RSGs) and in trying to stay true to my explorative research design, I decided to explore the latest key concepts and concerns by participating in a biochar-conference held in London.

Overall, the theoretical orientation and the methodical approach provide the foundation for creating context-dependent knowledge, which the findings and conclusions should be evaluated as.

VALIDITY OF DATA MATERIAL, ANALYTIC PARTS AND CONCLUSION

Qualitative research within the social sciences tries to identify intangible variables like behaviour and opinions that consequently demand very different validity criteria from that of natural sciences, for example. In continuation of *the linguistic turn* in Western philosophy during the 20th century, the notion of universal truth is in this context rejected, but the possibility of specific forms of truth is generally accepted. As alluded to earlier, there is therefore an aspect of probability to truth that bases itself on the emphasis on the social and communicative aspects of establishing truths. In this context, validity is usually measured to the extent it *investigates the phenomena intended to be investigated* (Kvale 1995).

The criteria by which one can evaluate the validity of qualitative research also reflect a variety of existing approaches one can choose from. However, a common feature is that the validation of science is fundamental for its quality as well as its legitimacy and justification. Validation therefore has to ensure that the scientific results represent real phenomena and is replicable for other scientists (Krippendorff 1980).

To do this, Kvale (1995) introduces a pragmatic and craftsmanship-like approach to the concept of validity. Kvale (1995) rejects the, in essence, positivist epistemological notion of finding the truth and integrates the aspect of the social construction of validity as a communicative and discursive one.

The idea of knowledge as a mirror of reality is thus substituted by the idea of knowledge as a result of the social construction of reality. As noted earlier, the aim for this thesis cannot be to come up with universal truths on biochar or specific characteristics of the relevant social groups, but to advance sensible insights in how the social groups discursively construct their interests and arguments, and how they influence the perception of the potential biochar might have.

This approach is very much in line with the overall scientific theoretical approach but it also reflects the basic presumptions made in SCOT in that SCOT applies *the concept of interpretive flexibility to technological artefacts to show how artefacts are similarly the product of intergroup negotiations* (Klein & Kleinman 2002: 29), which is in agreement with Kvale's (1996: 239) definition of *truth [that is] constituted through a dialogue; valid knowledge claims emerge as conflicting interpretations and action possibilities are discussed and negotiated among the members of a community*.

The validity criteria proposed by Kvale (2007: 123) builds on the abovementioned and focus on *the quality of the researcher's craftsmanship throughout an investigation, continually checking, questioning, and theoretically interpreting the findings*, which should also expose potential biases that may interfere with the interpretations. Thus, the main criterion for validation is to question and check.

How this questioning and checking is conducted is obviously a tricky matter, hence no perfect rules can be set out for qualitative research. However, some of the tactics used in this study to check whether the findings are valid is the use of triangulation and the continuous endeavour to ensure transparency (for example by including as many relevant quotes as possible).

These tactics are used so the craftsmanship of this study is open for external inspection and to integrate a broader data set where opposing views are more likely to be included.

Specific to the issue of interviews is the concern that a respondent obviously can be misleading or ill-informed, but to a researcher, this is close to impossible to uncover, and the only way we can evaluate the validity of a statement and its interpretation depends on the question posed to the statement (Kvale 1995). In continuation of this, Kvale (1996: 247) warns against any heavy reliance – when processing the interviews - on the inter-subjective validation as this might lead to *a lack of work on the part of the researcher, and a lack of confidence in his or her interpretations, with an unwillingness to take responsibility for the interpretations*. The validation of qualitative research findings therefore highly depend on the craftsmanship and the researcher's ability to question the complexity of the investigate field.

Two other key concepts in Kvale's (1995) conceptualisation of validity are Pragmatic and Communicative Validity. The concept of Communicative Validity represents the view that validity of knowledge claims are tested through dialogue. The basic idea is that valid findings are decided through the argumentation of the participants in a given discourse, and in the context of this thesis, this mean that the Communicative Validity has been increased by the continuous consultation of my advisory team, in discussions with key stakeholders, participation at conferences and by comparing previous literature with my findings.

However, there might exist inconsistencies between what people say during an interview and what they do in real life, which leads to the concept of Pragmatic Validity. Pragmatic Validity is obtained by ensuring common grounds between interviewer and interviewee – mainly by asking questions of a practical nature and follow-up questions to ensure a better understanding of the interviewee's statements.

THEORY

THE SOCIAL SHAPING OF TECHNOLOGY

Before introducing the theory of Social Construction of Technology (SCOT), it serves to place the theory and its assumptions into a wider context of the advances already made in the field of STS.

A large array of disciplines and an exponentially higher number of theories offer valuable insights into how successful technologies develop. However, to limit this context, the focus of this study is in opposition to conventional wisdom that views technological development as something that is simply answering a need of society (i.e. if a product is good, there is a market). This thinking has since Thomas Kuhn's book in 1962

'The Structure of Scientific Revolutions', been challenged and has led the way for the currently prevailing notion that *successful technologies are constructed through a process of strategic negotiation between different groups each pursuing its own specific interests* (Webster 1991: 27).

At the most basic level, it can be argued that an innovation reflects a market/consumer need (Wejnert 2002). The fundamentals of understanding the concept of an innovation therefore also comprise of how *technology meets market*, which lead me to field of market studies that also has its origins in STS. A constructivist perspective on markets is that markets at the end of the day are the result of ongoing construction work (Callon & Muniesa 2005) made by Homo Socialis rather than the rational choices made by Homo Economicus.

I will withhold a detailed discussion of the concept of Homo Socialis due to lack of space, but simply turn attention to the methodological and theoretical assumptions in this thesis all build on the behaviour of this Homo Socialis.

SOCIAL CONSTRUCTION OF TECHNOLOGY (SCOT)

The fundamental premise of SCOT is that technological development is an open process that can produce very different outcomes depending on complex social processes. SCOT represents an explorative, constructivist and a less theory-restrictive approach within STS, which is highly suitable in the case of an innovation like biochar where the boundaries are very unclear and there exists a high degree of uncertainty in regards to the technology's qualities, as well as the analytical premise of dynamically evolving processes.

The development of an artefact should therefore be seen as a complex negotiation based on variations and selections, and not for example a normal new product development process with predetermined stages.

This approach also leads to the exploration of all kinds of conflicts: for example, the conflicting technical requirements between different social groups or conflicting solutions to the same problem. Following the developmental process in this way, we will see growing and diminishing degrees of stabilisation of the technological artefact (Pinch & Bijker 1984: 416).

Pinch & Bijker (1984) argue that this approach is, to some extent, the result of a series of case studies and not purely a theoretical analysis. SCOT is primarily based on a heuristic approach to explore all relevant aspects, which hardly can be done using a theory based on predetermined categories.

Bijker (1995: 46) suggests that the researcher interviews a few actors in the beginning, asking them to identify relevant groups and from there *roll a snowball* of data. Obviously, this approach is no guarantee against methodological pitfalls that can lead to distortion or a lack of accuracy in the analysis. Thus, the snowball method might overlook relevant social groups and let social structures go unnoticed, which consequently leads to questions on the value of the research and whether or not it provides a complete picture of how a technology is constructed.

In confronting this concern, Bijker (1995: 15) argues that it is only the actors and issues that are consciously recognised by the relevant social actors that are of analytical importance. The conceptual framework of SCOT should therefore also be taken in *the right spirit - as a collection of sensitising concepts that aims to provide the researcher with a set of heuristics with which to study technological development* (p. 49) rather than as an undisputable approach to the study of technological development.

To go about this heuristic process, the conceptual framework of SCOT consists of four analytic concepts²: interpretive flexibility, relevant social group, stabilisation and closure, and the wider context, which will now be explored.

INTERPRETIVE FLEXIBILITY

Given the constructivist foundation of SCOT, both the technological design of an artefact and the social value attributed to an artefact are seen as a result of contemporary circumstances. To explore the social complexity in designing an artefact and to explore the technological development, it is therefore necessary to examine the interpretive flexibility.

The overall concept of interpretive flexibility refers to the different interpretations an artefact can be attributed, and builds on the premise that the development of an artefact is a result of social negotiation.

Different social groups can represent different interpretations of an artefact. However, interpretive flexibility is not only relevant when examining the different positions of the relevant social group: it is also relevant to examine the role of interpretive flexibility during the process of technological design and the actual use³.

This turns attention to a point that is often overlooked: the duality of technology tends to be suppressed in the organisational discourse that favours only one view of technology – a view, that is even more separated in time and space from that of the actions that actually constituted the design of the technology (Orlikowski 1992).

In other words, the actions that led to the design of an artefact (often occurring at a manufacturer and afterwards vendor organisations) are often separated in time and space from the actions that are enabled from the practical use of the artefact (often at customer sites).

The notion of interpretive flexibility is consequently a result of the social interaction within different discourses. Key elements in this regard have been identified as the material (e.g. the specific hardware comprising the technology), the human actors (e.g. motivation, experience), and the organisational context (e.g. social relations, resource allocation, task assignment) (Orlikowski 1992).

From an organisational perspective, there is a tendency to institutionalise practices and rhetoric - and thus limiting the interpretive flexibility - to pursue the prime legitimate goals of rationality and justice within organizations (Dobbin & Pedersen 2006: 898).

² Pinch & Bijker (1984) originally only define three components as *the wider context* was considered to be a sub-concept. Later works have however merited the wider context equal status, which it also has in this thesis.

³ Orlikowski (1992) calls this *design mode* and *use mode*

So on one hand high interpretive flexibility is counterproductive in regards to reaching stabilisation and closure, which is key for any technology's success, and on the other hand, if the degree of interpretive flexibility is too low it can be counterproductive in achieving higher functionalities.

Summing this up, groups interpret artefacts differently, and artefacts can thus be designed just as differently to meet the different needs and meanings attributed by the different interests (Bijker et al. 1987: 40).

RELEVANT SOCIAL GROUPS (RSGs)

In the original work from 1984, the concepts of *relevant* and *social groups* are rather broadly defined. The terms include institutions, organisations as well as organised or unorganised groups of individuals for which the artefact has a meaning. The key requirement is simply that *all members of a certain social group share the same set of meanings, attached to a specific artifact* (Pinch & Bijker 1984: 414).

As a practical guideline, Pinch & Bijker (1984: 438) state that *there is no cookbook recipe for how to identify a social group. [However] quantitative instruments using citation data may be of some help*, which I have made use of in my initial stage of the research process through the content analysis of the Danish public sphere that made it possible to map the presence of different social groups.

How this communication is formed is to a large extent a question of the approaches the different participants choose to take and how the *persuasion* is formed. The form of communication is therefore decisive, and might for example involve a discourse where the degree of information sharing is very limited and the participants are cautious about giving away competitive advantages or a form of communication that has a cooperative form where participants have incentives to share knowledge and resources (Garud & Karnøe 2003).

Another question that needs to be addressed is whether a social group is homogeneous in respect to the meaning given to the artefact or whether it makes sense to divide rather heterogeneous social groups into different social groups? Methodologically speaking, Pinch & Bijker (1984: 414) are open to this possibility, but they do not go into detail of how such a division should be handled.

Essentially it comes down to the notion that it is the social groups and their understanding of the artefact that plays the decisive role in defining the way in which the artefact can be expected to develop (Bijker et al 1987: 30), and under any circumstances should every RSG be described in detail in order to define the functions of the artefact with respect to each social group.

STABILISATION AND CLOSURE

Pinch & Bijker (1984) note that the stabilisation of an artefact will always be a matter of degree. Pinch & Bijker (1984: 424) exemplify the concept of stabilisation through three statements: *The experiments claim to*

show the existence of X; The experiments show the existence of X; and, X exists. Not only does this example show a progressively higher degree of stabilisation of X but it also illustrates how the context (subject to alternation) becomes less important through the process of stabilization. The number of definitions of biochar and relevant statements about biochar are therefore also a focus area in this analytic part, since this can be used as *a measure of the degree of stabilization, which the artefact has achieved* (Pinch & Bijker 1984: 424).

Pinch & Bijker (1984) observe a variety of closure mechanisms bringing about the stabilization of an artefact. Two distinct concepts are identified: rhetorical closure and closure by redefinition.

Rhetorical closure is defined as *definitive proof or knockout arguments*, which has the consequence of closing the debate. A problem for a RSG can for example be solved in the sense that the problem no longer is perceived as a problem. The problem of a social group therefore does not have to be solved in the common usage of the word but can simply be solved in the sense that the problem is perceived as solved. In this process, marketing can for example play an important role.

Closure by redefinition of a problem can for example occur when a problem seems to solve another problem. Lets us say, for example, that if the smell of manure used in biochar-production was able to keep killer bees far away from the biochar-facility and the surrounding towns, the smell of manure might not pose the same problem as it does in the public eye today.

The technological development of an artefact continues until such conflicts are resolved and the artefact no longer poses a problem to the RSGs. Closure is achieved and no further design modifications occur. However, complete closure does not happen. New groups may form and reintroduce interpretative flexibility, which makes stabilisation and closure a question of degree.

In other words, *groups may have different definitions of a working technology, so development continues until all groups come to a consensus that their common artefact works* (Klein & Kleinman 2002: 30). Thus, technological design does not cease to develop because the technology in some objective sense works, but rather because the RSGs accept that it works for them (Bijker 1995).

THE WIDER CONTEXT

Pinch & Bijker (1984) do not elaborate in detail on what is meant by the wider context or how to define it, which has also received some criticism. The authors refer to the descriptive *snowball* methodology that focuses on how the relevant social groups add meaning to the technological artefact, which has to be seen in its contemporary context. To examine the wider context, Pinch & Bijker (1984: 428), propose a heuristic method and turns attention to *the socio-cultural and political situation of a social group [that] shapes its norms and values, which in turn influence the meaning given to an artefact.*

To come to grips with the meaning of the wider context, many formal and non-mutually exclusive definitions are offered within many parts of the literature. Sonis introduces in Sonis & Hewings (2009: 246-247) the

concept of an *active socio-ecological territorial environment of multiplicity of social collectives* that adjusts the innovation to the socio-economic environment, whereas Wejnert (2002) talks about an *environmental context* that also includes geographical settings, societal culture and political conditions. Others have broadly coined this as *the social system* (Rogers 2003), *larger historical and structural context* (Lie 1997) or *institutional properties* (Orlikowski 1992).

All of these cannot be anything but broadly defined, and to a large extent, can only serve as an implicit context for the study.

To get started and examine all of the above, Pinch & Bijker (1984: 421) suggest the hands-on approach by conducting interviews *with technologists who are engaged in a contemporary technological controversy* and historic sources.

PRESENTATION OF DATA AND ANALYTIC CONSTRUCTIONS

CONTENT ANALYSES

As mentioned earlier, a content analysis is a method that is used for studying the content – this being defined as texts - in a given discursive context. The methodology of content analyses makes it possible to: gain insights in the characteristics of the discourse; identify the RSGs; and examine their specific interests, choice of frames, and techniques of persuasion, which all are fundamental for mapping the key topics of the communicative space among the RSGs.

To examine, the perhaps most important communication channel for innovation diffusion and to gain an initial understanding of the subject at hand, I performed a traditional content analysis of the Danish public sphere as constituted by Danish media (see Data set A, Appendix A)⁴. Through this, I could identify the key actors and issues. Subsequently, I contacted key actors and conducted a few pilot-interviews, which provided me with a better understanding of the field of RSGs. Through this initial process, I became aware of the unique position the Academic Research Community has among the other RSGs and I subsequently decided to participate in the 2nd Annual UK Biochar Conference in London. To gain a more thorough understanding of which issues enjoy the most attention within this group, I performed a content analysis of the abstracts presented at the conference (see Data set B, Appendix B). Given that data set B only provided me with indications on the stabilisation and closure within the Academic Research Community, I triangulated the data by integrating a summarisation of the scientific research made on biochar (Data set C, Sohi et al. 2009). Lastly, and simultaneously with the above data sets, I conducted interviews with a range of key actors (Data set D, Appendix D). The semi-structured interview guide used for these interviews is enclosed in Appendix E.

⁴ The content analysis of the Danish public sphere was been performed after searching *biochar* and *biokoks* using Infomedia and including all media in the period of 24.03.2005-24.03.2010. The importance of having included both words in the data collection is underlined by the appearance of the words biochar and biokoks 92 and 87 times, respectively.

IDENTIFYING THE KEY ISSUES AND RSGs

This section aims to present the categorisation of RSGs as well as the identification of the key issues currently surrounding biochar technology.

The below table (Table 1) reflects the degree to which the identified issues have reached stabilisation (marked in bold). The differences between data set A, B and C partly reflects the origin of the sources. Data set B and C largely represent the concerns and interests of the Academic Research Community whereas data set A more so reflects the concerns and interests of the Entrepreneur. This is exemplified in the issues of *Biochar-production can contribute to self-sustaining/local energy consumption* and *Biochar promotes organic farming*, which both are outspoken interests of the Entrepreneur, but are not currently issues for any other RSGs. Overall, the below table (Table 1) presents eight key issues that has reached a high degree of stabilisation. However, even though these issues currently play a constituting role for the biochar-technology, the reader is advised to note the depth and breadth behind these issues. So even though there exist a high degree

of stabilisation on certain issues, this stabilisation should to a larger extent be seen as a stabilisation of the choice of frames/issues as the details behind the issues are far from stabilised or closed.

| | Data set A | Data set B, C |
|---|------------|---------------|
| Key issues | | |
| Biochar can be used for mitigating climate change | X | X |
| Biochar as a potential environmentally friendly disposal method | X | X |
| Biochar can be used as possible CDM | X | X |
| Research is needed* | X | X |
| Lack of awareness | X | X |
| Biochar is under current conditions only rarely financially viable | | X |
| Collaborative research projects and pilot projects are rare but do exist | | X |
| An accurate and reproducible method for the categorisation of biochar is needed | | X |
| Current research is extremely broad and complex | | X |
| Evaluation of Biochar Systems (LCA) | | X |
| Market development is needed | | X |
| Biochar promotes organic farming | X | |
| Biochar-production can contribute to self-sustaining/local energy consumption | X | |
| Biochar is easy to produce | X | |
| Defining Biochar properties | | |
| Biochar as a stabile carbon storage | X | X |
| Biochar as soil conditioner | X | X |
| Biochar can increase crop productivity | X | X |
| Biochar as a range of complex char-products | | X |
| Biochar as a product of (slow and fast) pyrolysis, gasification, BtVB and Hypy | | X |
| Biochar solely as a product of pyrolysis | X | |

Table 1 – Summary of key issues

*Research is needed in many different areas and are particular related to the water holding capacity and aggregate stability of the soil; the decreased emissions of non-CO₂ greenhouse gases (e.g. N₂O and CH₄); the carbon and nitrogen cycles in soils; and long-term monitoring research stations to assess the long-term stability and dynamics of biochar in soil.

THE DANISH PUBLIC SPHERE (DATA SET A)

From the outset of this study, it was apparent that an initial overview of the biochar-field was needed to start rolling the snowball of data. To do this, I conducted a conceptual content analysis of the RSGs, as represented in the Danish public sphere, which subsequently would provide me with a platform that would make it easier for me to contact the relevant persons. Through this content analysis, the following persons were identified on their presence (based on their numerical appearance):

- Barritskov/BlackCarbon/Thomas Harttung (see A1,4,6,8,9,10,12)
- Risø DTU/Henrik Hauggaard Nielsen (see A1,10,15,16,19)
- Sander Bruun/KU-LIFE (see A9,10,15,16,18)
- Klaus Illum, ECO Consult (see A4,8)
- Niels Bech Christensen, Kemiteknik (see A15,16)
- Claus Felby/KU-LIFE (see A9,10)
- Stirling (see A10)

The above referents reflect the different RSGs presence in the public sphere and it is in this regard noteworthy to emphasise the significant roles played by the Entrepreneur and the Academic Research Community, the very limited number of the total RSGs as well as the very modest sample size (21 articles over 5 years).

Summing up the research already made on this field, Sohi et al. (2009: 44) offer a comprehensive overview of the beneficiaries, which also has influenced my process of categorising RSGs. However, integrating the data from data set D, it has been necessary to expand the RSGs suggested by Sohi et al. (2009) to also include the political domain as well as academics, actors in the energy sector, technology suppliers and entrepreneurs. The overview offered by Sohi et al. (2009) suggest the following beneficiaries/RSGs:

PYROLYSIS ENTERPRISES will economically gain from biochar produced for either agricultural or environmental purposes. They may also gain from the interests shown by NGOs, who could also facilitate a dialogue and a diffusion of knowledge between producers and investors, as well as researchers and users. Currently the amount of biochar available for use as a soil amendment (and hence carbon sequestration) is limited to an extent where even assessment of products for non-energy use is limited.

CHARCOAL PRODUCERS may experience an expansion in the market for charcoal if its use as a soil amendment is supported by land-users for carbon sequestration or enhancing soil fertility. There is a precedent for charcoal being produced on a commercial scale within Europe, with almond charcoal supplied to power companies in Spain.

WATER COMPANIES that are users of activated charcoal could benefit from large-scale pyrolysis-derived biochar that could reduce costs. Large-scale use of biochar on agricultural land in intensively farmed areas may also reduce diffuse pollution and the need, and hence costs, for treatment of water.

LAND USERS or farming consortia would benefit due to greater profitability as a result of savings on energy and fertilisers (Sohi et al. 2009: 44).

Common for the data sets is the relatively small number of social actors, and an even smaller number of forums. The complexity really first begins with the debate on what biochar is and what it can do.

Based on my reading of the data sets and what I have identified as reoccurring social groups, I have identified the following RSGs: (1) The **Political and Regulatory Domain**, (2) The **Academic Research Community**, (3) The **Technology Supplier**, (4) The **Established Players**, (5) The **Biomass Suppliers**, (6) The **Entrepreneur**, and (7) The **Buyers (and Users/Payers)**.

THE POLITICAL AND REGULATORY DOMAIN

(Danish Ministry of the Environment, Environmental Protection Agency, Danish municipalities, Fornyelsesfonden, Danish Energy Agency, EU legislation, Political parties, Lobby organisations)

The Political and Regulatory Domain is implicated in all relevant areas: the commercialisation (by being able to provide financial incentive structures to this and competing technologies), the technical implications (by setting environment standards for the biochar production facility) and the application to soils (by imposing regulations on biochar use in soils).

According to Lise Bagge, Miljøstyrelsen, it is especially the legislation concerning the application to soils, the specific input factors, and whether a biochar-facility is a combustion- or reuse-facility, which is relevant to the Danish context.

If the specific type of biochar-production is categorised as a combustion-process, it will be the Affaldsbekendtgørelsen (if the biochar is intended for CCS. § 19 in Miljøbeskyttelsesloven is furthermore relevant in this context) or the Slambekendtgørelse (if intended for agricultural purposes) that will be put restrictions on the application of biochar on soils. If however, the production of a given type of biochar is categorised as reuse and the input-factors for example are comprised by the input-factors mentioned in Bilag 1 in Biomassebekendtgørelsen (i.e. clean tree and straw. Otherwise § 29 in Slambekendtgørelsen comes to the fore), then the Biomassebekendtgørelse form the legal framework under which (if the input-factors mentioned in Bilag 1) is used, does not even include municipal instructions.

Overall though, there does not exist any specific guidelines for biochar-production in Denmark and the legal schemes vary in accordance to the type of input-factors, production method, the end-product and application, which are all production specific questions.

It is, however, worth noting that it is a political objective to return the bio-ash (which is not necessarily biochar) to the fields from which the biomass originated (Miljøstyrelsen 2008). Depending on how biochar

will be regulated by this social group, incentive structures and regulatory decisions will undoubtedly play an active role in shaping the future of biochar – either directly or indirectly by supporting competing technologies.

Special characteristics:

- This social group plays a decisive role in determining the technology's success or failure by influencing almost all relevant aspects of its properties – or at least how these can be utilised, subsidised (i.e. via Forsynelsesfonden) or taxed.
- Members of this social group (incl. all political parties and NGOs) have strategies to promote biomass usage, or at the minimum, expect biomass to play a much more significant role in the future energy production.

Interests:

- It is an outspoken objective for this group that biomass and renewable energy play an increasingly important role in the future (Klimakommissionen 2010, Klima- og Energiministeriet 2010, EU Directive on Renewable Energy). Long-time member of the Danish Parliament's Committee for Energy Policy, Anne Grete Holmsgaard, supports this and furthermore assesses that the outlook for biochar in particular "*looks promising*".
- The relevant regulatory interests are outlined in Bekendtgørelse om biomasseaffald, Bekendtgørelse om anvendelse af affald til jordbrugsformål, Bekendtgørelse om anvendelse af bioaske til jordbrugsformål and Bekendtgørelse af lov om miljøbeskyttelse.

THE ACADEMIC RESEARCH COMMUNITY

(Risø DTU National Laboratory for sustainable energy, Faculty of Life Sciences at Copenhagen University, International Biochar Initiative, Soil and Agricultural research institutions)

Much depends on the stabilisation the Academic Research Community can provide on key issues through its work and its position with the social groups. Given the complexity regarding the different input factors in combination with the different heating processes creates an enormous variety of different biochar types, which consequently have very different effects depending on the different types of soils. However, scientific closure exists on the matter of stability. As one of the leading Danish scientist, Sander Bruun, states, "*is there one thing there is agreement on within the scientific community, it is the solidity (life time) of biochar*".

Special characteristics:

- Indicative of the major role this group plays is that all other RSGs refer to findings of this group and regard the RSG as the decisive role for the technological success of biochar. This is furthermore reflected in Danish media (data set A), where Technical University of Denmark, DTU, appears 17 times in a data set consisting of 21 articles.

- The diversity of this group descends from different disciplinary focal points (chemical, agronomic, biologic), which is very likely to affect the research foci on biochar. An example of this is the different institutionalised networks between research institutions. DTU is, for example, a part of a project, within framework of the Interreg IVB North Sea Region Programme, that seeks to “*develop, implement and disseminate the Biochar-strategy in the North Sea Region (NSR) for climate change adaptation and climate change mitigation by increasing soil quality and stability*”⁵. Now, this focus on the alleged agronomic capabilities of biochar naturally delimits this specific partnership to a strong focus on the agronomic qualities rather than e.g. the development of new heating processes or how to exploit the alleged CCS-capabilities.
- A pressing issue, one that is also well accepted within this social group, is the lack of structured approaches in categorising the different types of biochar and defining different evaluation techniques.
- Common scientific approaches, under which the research is performed, do not currently exist. However, collaborative research projects and pilot projects do exist, and are intended to aid in bridging the gap between lab-scale and field-scale biochar production and testing (C3), and categorisation (C5).
- Perhaps symptomatic for a highly technical area like this is the lack of network connections between the participants, or at least the lack of present communication lines and structural frameworks in which research-projects could be carried out and ensure collaboration not only between research institutions but also research institutions and businesses. This is for example apparent in Denmark where a national centre for biochar does not exist.

Interests:

- Funding, and especially public funding, is fundamental for this social group. As senior researcher at DTU Risø, Henrik Hougaard states, “*my task is to try to draw attention to this field and obtain funding*”. It is therefore this social group’s interest to expose this research field and gain as much positive attention as possible. However, a concern, Henrik Hougaard, also addresses is that early studies might contain wrongful information with overly-optimistic predictions that could prove counterproductive in that they would disappoint other relevant social groups and make it easier to criticise the technology.
- Sohi et al. (2009: 41) identifies and sums up the current research priorities as: (1) Determine a predictive relationship for properties and qualities of biochar and its manufacture such that it can be optimised for use in soil; (2) Examine how the possibility of adverse impacts on the soil and atmosphere can be eliminated with certainty; and (3) Model the impact of alternate bioenergy systems on the carbon cycle at the global scale, and in the context of national targets, in order to support policy decisions and devise suitable market instruments.

⁵ <http://www.northsearegion.eu/ivb/projects/details/&tid=117>

THE ENTREPRENEUR

(Producers of biochar, Thomas Harttung, BlackCarbon)

This social group is mainly comprised by a few individual social actors who, by coincidence, were introduced to biochar and originally had related interests in either becoming self-sustaining on electricity or wanted to explore the agronomic effects of coal, but saw additional benefits in biochar-production. As Thomas Harttung, founder of BlackCarbon, describes it “*we were planning to introduce gasification as a means to become self-sustaining with electricity. Then I heard about biochar and thought that we might be able to use that instead of gasification and add a third valuestream. Then you have electricity, heat and biochar*”. Harttung subsequently initiated a partnership with the Danish company Stirling DK that is a leading provider of carbon-neutral, small-scale combined heat and power (CHP) generation, in biochar-production based on pyrolysis. This partnership was partly a development project for Sterling (receiving 4.99 mill DKK of public funding through Energistyrelsen) and involved the Academic Research Community, represented by DTU Mekanik.

Special characteristics:

- Similar to the other social groups, this social group is less active than it would be if the proof of concept or interpretive flexibility were more stabilised. This uncertainty has led to a limited interest and decisions of not adding external capital to the as well as only allocating very limited manpower to projects. When this group sees stabilisation and closure on key topics, the network that is in place (i.e. external investors and business strategy) can be activated. To prepare this process and persuade future investors, Thomas Harttung has for example applied for two patents that can prove valuable in the process of attaining external capital.
- The main driver behind biochar-production is not only cost-benefit analyses or business strategies, but the Entrepreneur’s *gut-feelings* and the possibility to *do good* while earning a profit.
- The Entrepreneur has influenced the majority of other social groups – either by persuading other groups to act or by initiating contact and thereby introducing biochar to other social groups.
- Symptomatic for the Entrepreneur’s developmental process is a trial-and-error approach and technical problems with the pyrolysis-facility (e.g. problems with the pyrolysis-plant and spontaneously combustible biochar), which currently have delayed the full utilisation of the production capacity.

Interests:

- The personal interest, aside from profitability, consists of trying to figure out how we can sustain a global food production without degrading the earth (e.g. through the use of organic farming). In so doing, Thomas Harttung perceives the pyrolysis-technology as constituting a blue ocean (see Kim & Mauborgne 2005), while other technologies seeking to replace fossil fuels with biomass comprise a red ocean where there is very little to be contributed.
- Harttung describes the original idea was that “*this energy-technology has a very clear carbon-benefit,*

which I better could understand given my agronomic knowledge. I thought, if this is true, we stand before a radical technology". In other words, personal interest and gut-feelings are main drivers.

THE TECHNOLOGY DESIGNER

(Providers of pyrolysis-plants, Sterling DK)

Given the uncertainty related to the properties of biochar, and thus its commercial value, the technology designers are currently best characterised as mostly passive. This is best illustrated by Stirling, the pyrolysis supplier to BlackCarbon, which does not perceive biochar-technology to be ready for commercialisation. *"This technology is not commercially ready"*, states Gitte Videcrantz very clearly. Thus, Stirling does not currently consider biochar a strategic business area, which constrains the actual efforts of developing the technology and allocating manpower to the technology. As suggested in the following quote, there is also a strong belief that *"when the technology has matured, the market will be there"*, as clarified by Project Department Manager, Gitte Videcrantz. This statement is also supported by Ulrik Henriksen, programleder at Risø Nationallaboratoriet for Bæredygtig Energi (and the technical architect behind the current pyrolysis-plant at BlackCarbon), who is also of the opinion that the technical challenges are not major and that if this technology was mature, it would be fairly easy for producers of pyrolysis-facilities to keep pace with such demand. Given that the task of building a pyrolysis-facility is a fairly simple one, many producers could be expected to arise if the technology appeared to be a potential business area.

Special characteristics:

- This social group is highly characterized by a hesitant approach towards the technology. The group is constituted by a supposedly large number of currently latent social actors that, due to relatively low market-entry barriers (e.g. know-how and capital) can easily enter the market if a demand for biochar is articulated. Thus, this social group will not play an active role until a tipping point or triggering event makes a demand evident for this group.
- Overall, this social group is characterized by caution and reluctance, due to the scientific uncertainty in regard to biochar's properties and effect on soil.
- According to Ulrik Henriksen, programleder at Risø Nationallaboratoriet for Bæredygtig Energi Given, the pyrolysis-process is a proven technical process, and the cost of such a production facility would not constitute a significant barrier to the diffusion of this technology.

Interests:

- As well as The Entrepreneur, this group too has a clear interest in stabilisation of the interpretive flexibility of biochar's properties and effects on soils.
- Before this RSG choose to allocate resources to the development of pyrolysis-facilities, a change in perception is needed towards perceiving the biochar-technology as a mature and relatively safe investment.

THE BUYERS (AND USERS/PAYERS)

(Farmers, Gardeners, CCS-companies, Individuals, District heating-, Water-, Chemical-companies, Decentralised Power Plants)

Given that this technology is still in its infancy and not yet introduced as a commercial good, this group is primarily formulated on the basis of the data presented by the relevant social groups. However, qualified guesses among the RSGs suggest four main target groups: farmers; individuals; district heating companies; and CCS-companies, which can be further divided into how high/low the interest is for the biochar and/or the biochar-facility and its bi-products.

Depending on the outcome of the ongoing research, if biochar proves to have significant effects on soils, farmers and individual consumers is be expected by the Entrepreneur to show interest in biochar – with the individual consumer to a lesser extent (usage in their gardens). The district heating sector might also be interested in biochar-production given rising subsidies for bio-electricity and a lowering in the heat-supply in rural areas. Furthermore, if biochar gets recognized as a CCS-tool, and the price of carbon is perceived as attractive, CCS-companies are very likely to take on the biochar-technology. A CCS-use of biochar furthermore opens up for the possibility of using waste as an input-factor, given that CCS is not necessarily targeted to soil application and therefore works under a lower and different standard.

Sohi et al. (2009: 37) also indicate a possible use of biochar (activated carbon) in the removal of contamination in water treatment processes. However, the Danish Water and Wastewater Association (DANVA) forecasts a very modest increase in the demand for activated coal within the next decade, which makes this aspect insignificant in a Danish context.

Special characteristics:

Establishing the characteristics of this social group is related with a high degree of uncertainty. In one of the interviews with Thomas Harttung, he suggests that only 5 % of Danish farmers have heard of biochar – a group that is expected to be a driving force in the diffusion of the technology through market-pull. The second large social group, that is expected to represent a large part of the demand, is CCS-companies. According to Harttung, Henrik Wejdling and Inge Werther, Coordinators at Dansk Kompetencecenter for Affald as well as contacts I encountered at the 2nd UK Biochar Conference, who wish to remain anonymous, this group oversees and follows the technological development of biochar very closely. However, there are no current signs of this group engaging in any investments before the Political and Regulatory Domain recognizes biochar as a CCS-tool.

Interests:

It is clear that the expected main drivers of a market-pull scenario (farmers and CCS-companies) are reluctant to invest in and adopt this technology given its early stage. However, if biochar gets recognized as a CSS-tool (as the international NGO International Biochar Initiative tries to), and/or if farming (organic farming in particular) adopts biochar as a practice then it seems very likely that this technology will be soon

to take off. This is supported by the other social groups' indications of a fast involvement in the diffusion of biochar if these barriers are overcome.

| Interests in biochar / biochar-facility | High (interest for biochar-facility) | Low (interest for biochar-facility) |
|---|--|-------------------------------------|
| High (interest for biochar) | Farmers, Gardeners, CCS-companies | Individuals |
| Low (interest for biochar) | District heating companies, Chemical companies | Water companies |

THE BIOMASS SUPPLIERS

(Domestic as well as foreign suppliers of energy crops, virgin wood, agricultural residues, food waste, and Industrial waste)

Danish agriculture not only plays a key role in utilising biochar, but also plays a key role in supplying the biomass for the production of biochar – as well as the future need for energy. The use of biomass has more than quadrupled since 1980 and is today the largest source of renewable energy in Denmark - accounting for 69% of the renewable energy production (Landbrug og Fødevarer 2009). The main components of this development have been the use of biodegradable waste, wood (willow tree in particular) and straw. However, there are strong indications that the Danish biomass suppliers cannot keep up with future demands, which would significantly enlarge the current market for imported biomass products. This trend is supported by DONG's expectations of the future ratio between domestic/foreign biomass usages. According to Lise Lyck, Regulatory Affairs at DONG, DONG's expects to import 60 % of its biomass usage whereas in 2008 DONG only imported 8 %.

Depending on what kind of biochar will have the highest demand, the biomass from which this type of biochar descends, will determine what type of biomasses will be in demand. And what determines this is the science that provides stabilisation on what effects different kinds of biochar will have on different soils.

Special characteristics:

- Currently the forestry and agricultural sector do not perceive biochar as a relevant business area, but if this technology shows commercial potential by either a market-pull or market-push, the two groups would not need much time to adapt. The main driver for these social groups is profit.

Interests:

- Given the future demand for biomass, which is also expected to cause an increase in imports of biomass, it is very likely to give rise to the price of biomass, which then again will affect biochar's profitability; however, this factor is uncertain.

THE ESTABLISHED PLAYERS

(Energy companies, Consultancies, Fertiliser companies, District heating companies, Research institutions, Power plants, Chemical producers)

Biochar-production would directly affect the demand for biomass, the supply of heat and electricity and/or increase the syngas and bio-oil production, and soils in very different ways, and thereby influences the groups that fulfil these tasks (e.g. fertiliser-companies and energy-companies). Presently, the large waste and energy companies in Denmark are primarily engaged in combustion and gasification-technology, which is more effective than pyrolysis. This should partly be seen as a result of lack of awareness, but also that biochar is not perceived as a relevant business area due to the advantages of combustion, the commercial uncertainties surrounding biochar-activities and investments in competing energy-focused technologies (i.e. biogas-plants). The importance of biomass combustion is stressed by Per Ebert, the CEO of the Danish division of Vattenfall, who states that Vattenfall *“is in serious considerations about changing power plants to biomass. We are currently in dialogue with politicians about which power plants and under which framework. We feel that the discussions are pointing in the right direction because the politicians are very interested in biomass”*⁶.

Special characteristics:

- The established players of this group play the role of being in the background and keeping up with the scientific developments on the field. This social group has no interest in investing in the biochar-technology before it sees the perspective of a profitable business area.

Interests:

- Larger organisations as Vattenfall, Dong and Amagerforbrændingen, all have an outspoken interest in gasification and the use of biomass for heat as well as electricity-production. This social group represents large research and development investments and could be expected to pull the development of biochar, if the CCS-aspect of biochar was perceived attractive or if there was a change in the overall business strategy.
- As it is the opinion of Ulrik Birk Henriksen, Associate Professor at Risø National Laboratory for Sustainable Energy and all other RSGs - gasification is superior to pyrolysis in maximising the energy output from biomass, thus it would not be the aspect of combustion that would constitute a driving mechanism.

⁶ <http://www.energy-supply.dk/article/view.html?id=50600&ref=newsletter>

SCOT-ANALYSIS

To enhance the reader-friendliness of the four data sets, I have chosen to present the data material through the following three categories: **Commercialisation**, **Application to soil** and **Technical implications**.

This categorisation is based on my reading of the data material and the reoccurrence of these themes as well as very close guidance from my co-advisor Sander Bruun.

Relevant for the categorisation is that the categories are not necessarily mutually exclusive. Since some of the research regarding the application to soils is also fundamental for the commercialisation, and some of the legal and institutional frameworks regarding the technical implications related to operating biochar-facilities also overlap the aspect of commercialisation, there will exist sporadic overlapping issues within this categorisation. However, this categorisation offers a valuable focal point from which one can gain insights in the field as well as identify and analyse the different areas of interests.

COMMERCIALISATION

All data four sets indicate that the all interests (personal, political or commercial) in the biochar-technology currently originate in its alleged capabilities to manage climate change and/or agricultural development (see Sohi et al. 2009). And it is within the context of these two main areas of interest, and the bi-products originating from the actual biochar-production (heat, electricity, oil etc.), that constitute the boundaries of the socially negotiable characteristics of biochar.

A recent study performed by the UK Biochar Research Centre suggests that the largest contribution offered by the biochar-technology comes from the prospect of carbon stabilised in biochar, and secondly the more uncertain indirect effects of biochar in the soil (B16). These two points are key issues continuously being brought forward and highlighted by the Entrepreneur and the Academic Research Community, but for these two issues (the CCS and agricultural potential) to be commercial workable, Sohi et al. (2009: 21) identify the following issues to be overcome:

- Assessing the monetary value of direct and indirect emission savings arising from the use of biochar against the opportunity cost of biochar combustion or alternative use;
- Providing certainty, verification and possibly evidence for carbon-equivalent savings; and
- Considering the indirect costs and benefits to land users and upstream food processors from the use of biochar in soil. The latter might include the cost of biochar application, weighed against the marketing benefits gained through carbon-neutral food products.

Sohi et al. (2009: 21) furthermore identify the following areas as key areas to achieve greater certainty (interpretive flexibility) to assess biochar-application:

- The stability of biochar carbon in soil;
- The indirect impacts of biochar on carbon-equivalent emissions; and
- The security, reliability and constancy of price for pyrolysis feedstock.

As already illustrated (in Table 1), all data sets reflect that there is a great need for further research, which currently inhibits the adoption and realisation of this technology. Any predictive measures to resolve this and to diminish the current uncertainty regarding the categorisation of biochar-types and/or how to optimise the useful characteristics of biochar could therefore constitute a tipping point for the technology (Sohi et al. 2009).

Reflecting the two main areas of interest (managing climate change and/or agricultural development), the commercialisation of biochar can furthermore be divided into what I will coin a CCS-system (a scenario in which the climate change aspect is the main driver), an AGRI-system (a scenario in which the agricultural effects constitute the main driver) and a combination of the two in a COMBI-system.

CCS-SYSTEM

The monetary value of biochar intended for CCS largely depends on the future stabilisation and closure on biochar's ability to sequester carbon and – assuming this closure leads to certification as a Clean Development Mechanism (CDM) - the subsequent complex carbon markets that are influenced by energy supplies and demand, the supply and demand for low emissions technologies, the availability of alternative carbon sequestration technologies, and global policy responses to climate change (Sohi et al. 2009: iv).

Adding to the complexity of this is the lack of markets for pyrolysis feedstock, which are not currently accessible or at the best ill-developed. As well as the general lack of awareness of bioenergy systems and the potential for carbon credits for avoided emissions in which farmers could engage (Sohi et al. 2009: 39).

In regards to biochar's ability to sequester carbon, scientists currently disagree on how to measure this but regard the stability to be ranging in millennial-scale (Sohi et al. 2009: iv). However, the actual carbon-negative characteristic of biochar has been questioned (see Bruun 2008), given over longer timescales an increasing portion of the sequestered carbon would return to the atmosphere as a result of degradation. A concern also raised by other scientists (see Lehmann & Joseph 2009).

Overall, the CCS-system is primarily targeted biochar-production intended for carbon-offsetting schemes, which changes the legal and agronomic quality requirements from that of biochar intended for agricultural use. Thus, this system largely disregards the possible agronomic value of biochar (depending on future legal schemes), and the evaluation of this system almost solely depends on the value of stored carbon, which, in the case of biochar, currently is non-existing.

To add additional value to the CCS-system, waste (sewage sludge, municipal waste, organic waste etc.) or non-virgin feedstock might be considered as relevant feedstock, due to the avoided cost of waste-fees and/or because of low prices, which furthermore can help local authorities as well as companies divert waste from landfills (B18), or provide a basis for the production of biofuel or high energy crops on landfills and brownfield sites that would otherwise be unsuitable for agricultural cultivation (B10). Essentially this

system offers the opportunity of reducing the carbon footprint by processing waste to biochar (B15), which, however, may conflict with environmental sustainability aspects (B1).

For this CCS-system to emerge, stabilisation and closure needs to be established on the issues of the stability of carbon in biochar, and a concept that might gain future importance in this regard is the concept of Carbon Stability Factor (CSF). This concept is only presented once in the data material, and refers to the proportion of total carbon in freshly produced biochar that remains fixed as recalcitrant carbon over a defined time period (B16). The carbon abatement efficiency of Pyrolysis-Biochar Systems therefore depends on this concept of CSF, which currently only are used within the Academic Research Community.

A relevant aspect is in this regard, the emissions from feedstock. Carbon accounting for biochar has generally ignored emissions from feedstock but given that one of the key justifications associated with biochar use is to mitigate climate change, this should also be expected to occur on a project level. And if not, the use of biochar can and should be questioned by the RSGs. When accounting only for the carbon sequestered and carbon emitted, the choice of feedstock is essential for determining the carbon payback periods (e.g., straw and coppiced hedgerow feedstock give clear carbon savings within a 20 year time frame, but tree-based biochar acts as a net carbon source over 20 years) (B17).

AGRI-SYSTEM

Producing biochar with the intent of increasing crop yields raises a lot of unanswered scientific questions, and significant organisational and institutional (legal) obstacles (Sohi et al. 2009).

Even though some research offers indications on the agricultural and biological questions, the widespread opinion, in particular within the Academic Research Community, is that it is still too early to say anything conclusive on the effects of biochar application. This is also supported by Thomas Harttung, the most prominent biochar-producer in Denmark who states that *“we do need specific knowledge on the precise effects of biochar applied to soils. And that takes time. Documentation needs to be presented before this technology will be adopted”*.

However, both data set B and C (see B1, B8 and Sohi et al. 2009: 38-39) points to two niche areas could constitute initial drivers of the biochar-technology in the AGRI-system:

SALINE AND ARABLE SOILS

Many studies suggest the greatest dividend from biochar descends from application in degraded soils. Degraded soils are relative to normal soils, more prone to take on biochar’s benefits, such as: increased soil pH; declined nitrate flux in the soil leachate (B8); increased germination success; reduced need for nitrogen (B12); increased moisture retention (B14); reduced fertilizer needs; reduced N₂O emissions; and increased soil organic matter (B16); which all have positive effects on crop yields.

HIGH-VALUE ADDED PRODUCTS

Biochar may already, without subsidies, be an attractive option for producers of high value crops where certain characteristics (e.g. water storage) can add high economic value. Biochar may also add to companies' brand values as biochar can be used in CSR-initiatives and present social actors as carbon neutral. Biochar might in this context also be used on recreational land or sports turfs (B1, Sohi et al. 2009).

The adoption and success of the AGRI-system is furthermore very likely to depend on the specific type of organisation among the RSGs. If adopted, this system can be expected to be affected by the degree of collaboration between farmers and the success of *closed loop* AGRI-systems where the biochar is returned to the same land as the feedstock originated, since this offer some opportunity costs in that biochar's stability would make regular applications unnecessary. The aspect of *closed loop* systems is often highly relevant for biomass and bioenergy facilities as this affects the logistic cost of both gathering and distributing the biomass (Sohi et al. 2009) and is already a central narrative within farming.

Additional factors that might also influence the profitability of biochar in the AGRI-system could be the cost of not only acquiring the biochar, but also of applying the biochar to the soil (Sohi et al. 2009: 28). Other factors, such as the availability of by-products from other bioenergy or bio-gas/fuel systems, might also affect the off-farm usage of biochar.

COMBI-SYSTEMS

Given it is very unlikely that any diffusion of this technology will limit itself to solely the AGRI-, or CSS-system, I will briefly comment on a combination of the two systems.

Combining the systems also means combining the qualities, downsides and uncertainties of the two systems. However, even though some research indicates that biochar has an enormous potential for usage within horticulture and agriculture while being capable of sequestering carbon and potentially raise soil fertility (B14), this is less well-established and requires further research (Sohi et al. 2009: v). However, applying biochar to agricultural soils is currently the most widely proposed path, since it is more likely to overcome the opportunity cost in energy production (Sohi et al. 2009: 21). There does however also exist among the RSGs a very positive attitude towards the adoption of the CCS, which would speak for the acceptance of the CCS-system (Shackley et al. 2007).

KEY UNDETERMINED FACTORS

External factors, such as the value of the bi-products resulting from biochar-production, might also affect the economic viability. Increasing prices on waste disposal fees might effect the production and application of biochar for electricity (Sohi et al. 2009: iv) or the technology might be considered as an environmentally

friendly disposal method for farm and urban organic wastes, as well as a product of sustainable bio-energy production (B14).

The biochar-technology might also be influenced by the value of chemicals. Given that the heating processes of torrefaction and gasification differ from biochar in physico-chemical properties, such as particle pore size and heating value (Prins et al., 2006) and have industrial applications, such as production of chemicals (methanol, ammonia, urea) rather than agricultural applications (Sohi et al. 2009: 2). Birgitte Holm Christensen, Head of the Biomass and Waste Department at FORCE Technology, also supports this forecast and expects that “*pyrolysis can play a minor role in the production of ‘sustainable’ chemicals*”. However, given the lack of stabilisation on biochar’s agricultural capabilities, Christensen currently perceives the leading opportunity to be within the decentralised heat and power generation.

APPLICATION TO SOILS

Biochar is widely⁷ regarded as a soil conditioner with the potential of bringing about significant agronomic benefits. In contrast to this though, some studies do report no or few adverse effects, which suggest that the extent of the effect of biochar has on crop productivity is subject to high fluctuations - mainly due to the different bio-physical interactions and processes that occur when biochar is applied to soil, which are not yet fully understood (Sohi et al. 2009: iv). Subsequently there exists a clear interest in producing an accurate and reproducible method for the categorisation of biochar to assess its capabilities and stability in a range of different environments.

Currently a wide variety of thermal, chemical and optical methods are utilised, which inevitably produces a range of different results, as demonstrated by Hammes et al. (2007) (see B4, B5).

The agronomic effects of biochar will vary depending on the type of feedstock (crop waste, wood chip, municipal waste, manure, etc.), production process (mainly temperature and time) being used as well as the soil itself. However, there does not currently exist a rapid screening technique for comparing biochar materials to a particular use (B6), which has led to the following (some partly conflicting) suggestions within the Academic Research Community:

- Establish preparation criteria that will give rise to properties with desired effects. A classification system is needed that will indicate the values of biochar for different applications (B5);
- Considering source and type of biochar seems pivotal for assessing its potential as fertilizer or soil conditioner (B7);
- Biochar application to temperate soils should be given serious consideration (B8);
- Thermal Analysis coupled to Quadrupole Mass Spectrometry (TA-QMS) should be used to characterize biochar before addition to soil (B6).

⁷ Article 1,2,3,4,5,6,7,8,9,10,12,13,14,15,16,18,19 and 20 (Appendix A)

These suggestions are not only interesting because they represent a need for assessing and categorising biochar and its effects for scientific purposes. But because they reflect an underlying understanding of how important a categorisation is for a commercial adoption of the technology. This is for example reflected in the very conscious choices of research priorities within the Academic Research Community where it is the most desired effects that have top-priority.

Today, the majority of research on biochar application to agricultural land is associated with the incorporation into arable soil, with a large amount of this research originating in tropical climates. Naturally, this leaves a gap in the need to assess the potential for biochar application in other than arable soils if the full potential of biochar is to be achieved.

Furthermore, highly relevant for the application to soils is the farming practices (e.g. no-till farming) concerning this issue. In regions where the agricultural soils are grassed and cut for hay, the soils are for example not disturbed. The lack of soil disturbance thus means that any addition of biochar must be undertaken without incorporating the material into the soil – at least through conventional means.

This might not sound that important but given previous research has shown significant increases in soil carbon losses with disturbance (B19), this is an important aspect when estimating the carbon payback periods and performing Life Cycle Assessments (LCA).

TECHNICAL IMPLICATIONS

Generally, it is regarded as relatively easy to construct and manage a biochar-facility⁸. However, there are practical concerns about the optimal production capacity, the ability to take in different feedstock and the optimal heating process.

The data set A⁹ clearly indicates an interest in the field of the optimal heating process since this field is rather unexplored and could improve the desired qualities of biochar. However, in mapping the current methodologies for this, Sohi et al. (2009: 12) stresses the difficulty in categorising organic carbon in soil on account of its chemical complexity, its inherently un-reactive nature and the uncertainty there general exists on the topic. Sohi et al. (2009: 13) refer to the study made by Hammes et al. (2007), which was also referred to in data set B (see B4), and list a wide variety of current methods (e.g. oxidative approaches, spectroscopic methods, chemo-thermal oxidation methods, thermal analyses etc.).

In other words, there are various technical methods from which one can choose when categorising biochar-types and effects.

It is constituted as common knowledge within the field, and reflected in all data sets, to perceive the different heating processes as tools to satisfy different objectives (e.g. a higher ratio of biochar rather than gas), and optimise and adjust the ratio between the end-products (char, oil and gas). In this regard, current research as well as legislation (see Slambekendtgørelsen) suggest that the type of feedstock used in the

⁸ Ulrik Birch og data set A

⁹ Article 1,3,4,7,8,9,10,11,14,15,16,17,18,19 and 20 (75 % of the articles)

heating process is legally and agronomically more important when the biochar is to be applied as a soil conditioner.

However, there is little consensus as to what constitutes the optimal feedstock for energy production, but as Sohi et al. (2009: 5-6) note, the feedstock that are currently favoured for bio-oil and fuel-gas are those that have low mineral and N content. Sohi et al. (2009: 6) furthermore emphasise the low degree of interpretive flexibility that exists on what produces the highest biochar yields – feedstock with high lignin content pyrolysed at moderate temperatures (approx. 500 °C) (see Fushimi et al. 2003; Demirbas 2006).

Currently, the prevailing notion is that biochar is a product of (thermal) pyrolysis. But even though there is overwhelming data to support this, there also exist competing heating processes. Gasification, which is perceived to be the superior technology in regards to combustion, can also be used for producing biochar (but at a much lower percentage of the biomass). Gasified biochar has in continuation of this shown to have potential to increase soil fertility by increasing plant available nutrient concentrations, effective cation exchange capacity (in sand), or water retention (C7). This is interesting since it goes against the widespread and mainstream notion that biochar and pyrolysis are inseparable parts. To provide us with an overview of the currently competing heating processes, Sohi et al. (2009) describe and sum up the following processes:

CARBONISATION describes a number of pyrolysis processes that most closely resemble traditional, basic methods of charcoal manufacture, and which produce biochar of the highest carbon content. For wood, 24% of wood mass was converted to biochar of 76% carbon content at 400 to 500°C, but carbonisation at 600°C gave 28% biochar with a higher carbon content of 89% (Sohi et al. 2009: 9).

INTERMEDIATE PYROLYSIS describes a hybrid technology under evaluation at Aston University designed to produce bio-oil with very low tar content, with perceived potential for use as a motor fuel. The process has been tested with woody and non-woody feedstock, and produces biochar in greater quantity and of contrasting quality than fast pyrolysis (Sohi et al. 2009: 9).

SLOW PYROLYSIS is the thermal conversion of biomass by slow heating at low to medium temperatures in the absence of oxygen, with the simultaneous capture of syngas. Feedstock in the form of dried biomass pellets or chips of various particle sizes are fed into a heated furnace and exposed to uniform heating, generally through the use of internal or external heating in retort furnaces or kilns, respectively (Sohi et al. 2009: 7).

FAST PYROLYSIS leads to a much greater proportion of bio-oil and less biochar. It was with the objective of achieving this high yield of liquid fuel that fast pyrolysis technology was developed. The time taken to reach peak temperature of the endothermic process (the ‘residence time’) is approximately one or two seconds, rather than minutes or hours as is the case with slow pyrolysis. The lower operating temperature also

enhances the overall conversion efficiency of the process relative to slow pyrolysis. It is considered to have an advantage over typical fuel oils in zero SO_x, and produces lower NO_x emission on combustion (Bridgewater 2004). Bio-oil also contains high value bio-chemicals of relevance to food and pharmaceutical industries. (8) However, there are currently no published studies to assess the effects of biochar from fast pyrolysis when it is applied to soil (Sohi et al. 2009: 9).

GASIFICATION is the process by which any carbonaceous material (coal and petroleum as well as biomass) is substantially converted into a stream of carbon monoxide and hydrogen in a high temperature reaction and controlled-oxygen environment, sometimes at high pressures of 15–50 bars (Bridgewater 2006). The gas mixture is the key energy output and the gasification process has an application as a clean waste disposal technique (Bapat & Manahan 1998). In slow pyrolysis facilities, gasification is often used to generate syngas. Syngas may be used for: generating electricity via gas or steam turbines (or both); manufacturing chemicals and fertilisers; or as liquid fuel after further cleansing. Since conversion of feedstock to syngas is often the main objective, the process is maximised for gas production and so the biochar yield from gasification tends to be very low. However, this also carries the risk of higher levels of metals and minerals that may be concentrated in biochar, with potential safety implications as regards application to soil (Fernandes et al., 2003). Biochar from gasification also has high value use for activated carbon production (Sohi et al. 2009: 9-10).

Other, and less significant, competing heating processes are BtVB (Valorisation of (ash rich) Biomass) and Hypy (hydropyrolysis). BtVB presumably is able to process all kinds of biomass and biogenic residues, and combines pyrolysis reactor, gasifier and an algae production to generate new feedstock. This kind of biochar can furthermore be targeted power plants (C2). Hypy is a process by which pyrolysis is assisted by high hydrogen pressures and can allegedly reduce labile organic matter to volatile products in a controlled manner and prevent generation of secondary char (C4). The above heating processes only appear one time each in the data material, which is significantly less than the others.

DISCUSSION

The present chapter seeks to elevate the level of analysis to a more general and theoretical perspective, from which common features and trends in the data material can be analysed and integrated in a theoretical context. The present theoretical context is important to highlight, as it is this that has formed the overall research process and provided the analytic framework for *un-black-boxing* the development of biochar in a Danish context.

Through the lenses of SCOT, I will put forward the argument that there exists closure on key issues related to the biochar-technology (refer to Table 1). I will provide rival explanations by integrating literature on path creation, path dependence and the arguments for simply perceiving innovation processes as random processes. All these approaches have that in common that they all aim to provide theoretical frameworks for understanding technological development and on how (niche) technologies can eventually challenge or become a technological regime.

SCIENCE AND TECHNOLOGY STUDIES: A BRIEF OVERVIEW

As the name suggests, the field of Science and Technology Studies (STS) not only focuses on the interaction between science and technologies, but also on how these interact with society, and vice versa. This consequently turns attention to the questions of how scientific institutions frame issues and the knowledge they articulate as science, and identify commitments that are both institutionalised and taken for granted, and thus not deliberately introduced (Wynne 1996: 19).

STS has drawn from many different disciplines including: organisational sciences; anthropology; philosophy of science; and sociology. This multi-disciplinary background has had a clear impact on STS, reflected by the historical branding and rebranding of the field under such labels as *the sociology of scientific knowledge*, *social studies*, *science studies*, and *social studies of science and technology*. Regardless of what the field has been called, historically the field has focused on science studies. Thus, it is no coincidence that the early STS-studies focused on what *shaped* scientific knowledge by examining hidden assumptions and trying to un-black-box the technological and conceptual development of artefacts by exploring the positions of relevant social groups.

Elaborating on this, Wynne (1996: 21) identifies three key points of wider significance for academic institutions and science, which in the case of biochar, also plays a fundamental role:

- The fundamental interaction between scientific expertise and lay-publics is *cultural*, in that scientific knowledge embodies social and cultural prescriptions in its very structure;
- The problem of public uptake of science therefore lies in the institutional forms of science and of its incorporations into policy and administration;
- 'Local' case studies (...) should be seen as an expression of deeper problems of modernity as embodied in dominant institutional cultures.

The latter point is especially relevant, on an epistemological level, as studies within the field of STS have been preoccupied with the specificity of case studies, and because the traditional distinction between social theory and empirical research is non-existent in a STS-context as *theoretical arguments [are developed] through case studies* (Law 2008: 16).

This is also partly due to a turn to *performativity* within STS, where social actors are attributed an active participatory role in the *doing* – instead of the *making* - of realms.

In continuation of this, and as exemplified by Cussins (1996), all social actors adopt a very active role in the objectification and naturalisation of artefacts, which as Cussins (1996) argues, also can be done by creating specific narratives related to the technology.

However, as an epistemological consequence of building upon a social constructivist paradigm, such narratives should also be seen in their social context, which according to relational approaches, such as SCOT, entails that even basic relational theory concepts such as *trust* and *credibility*, can and should be questioned.

Wynne (1996: 41) challenges the predominant analytic tendency to treat these key concepts as unambiguous, quasi-cognitive categories of belief or attitude that people supposedly just simply choose to adopt or reject. Wynne (1996) instead suggests perceiving these concepts, such as trust and credibility, as analytic artefacts themselves to gain a greater understanding of the underlying tacit processes of social identity negotiation.

Adding to this constructivist approach, Akrich (1992: 208) argues that *designers thus define actors with specific tastes, competences, motives, aspirations, political prejudices, and the rest, and they assume that morality, technology, science, and economy will evolve in particular ways. A large part of the work of innovators is that of 'inscribing' this vision of (or prediction about) the world in the technical content of the new object. I will call the end-product of this work a 'script' or a 'scenario'*. In other words, Akrich (1992: 209) turns her attention to the totality of situations and the hybrid-interaction between non-humans (technology) and humans, and offers a definition of technical objects as scripts – which define a *framework of action together with actors and the space in which they are supposed to act*.

In continuation of this notion of inscribing or predicting prospective hybrid-interactions, some scholars have turned their attention to concept of *the user* and criticised it as it *singularises what is actually a multiplicity and fails to differentiate actors with very different relations to a given artefact* (Suchman 2007: 188). Consequently, companies, scholars and other social actors should replace the misplaced singularity of *the user* with a more generalised formulation that contrasts company-specific insiders and outsiders (Grint & Woolgar 1997). I have tried to integrate this aspect by incorporating the diversity among expected users of biochar in the “The Buyers (and Users/Payers)”-section.

THE GREENING OF TECHNOLOGY

As new green technologies arise to meet the challenges of climate change or resource depletion (concepts that themselves are subject to interpretive flexibility), a wave of studies has been conducted to map the structures and mechanisms behind the failure or success of green technologies.

Most of the current body of literature on the greening of businesses focuses on the actual adoption of an artefact at an organisational level and usually refer to the process of the diffusion of innovations as a black-boxed process (Reijonen 2008: 11). However, on what motivates or shapes companies' environmental orientation and strategy, Reijonen (2008: 4) offers a summary on the literature and suggests the following driving forces:

- Competitive advantage benefits
- Legislative pressures and opportunities
- Responsiveness to other stakeholders
- Individual commitment (especially top management commitment)
- Managers' emotional perception of environmental issues
- The salience and weight of the environmental issues related to the business area
- The cohesions of networks of firms in the same industry
- The characteristics of the general business environment

From a meta-design perspective, the application of biochar and many other green technologies would call for radical changes (transitions) in socio-technical regimes and everyday practices. Even though it can be argued that technological development generally has a high degree of path dependency due to infrastructure of production, regulation, user practices, techno-scientific knowledge, etc., green technologies – and especially those in their infancy – are constituted by new social actors and new discourses, and thus less likely to be subjected to the same degree of stabilisation and path dependency as e.g. incremental technological innovations.

Given that radical new technologies has no pre-existing social groups and pre-existing narratives, the basic premises for path dependency are somewhat diluted. Instead, it serves to shift attention to the notions of deliberate actions and strategic change (within the field of path creation) rather than portraying the infancy of radical new technologies as solely historically embedded processes. However, depending on ones interpretation of both path dependency and path creation, one does not necessarily exclude the other.

Another approach to innovation processes is to refer to them as random, which builds on the notion that the source of innovation is exogenous to the system and every innovative event represents an equally likely draw from an underlying probability distribution of possible actions in a seemingly random process (Chang & Van de Ven 1996).

However, the main setback of choosing this approach is that it only offers ad-hoc explanations and might neglect key dynamics or assign too great an importance to exogenous events specific to the given process.

But as a response to this, later innovation literature suggests that the seemingly random product development process may not be random at all; it may simply be chaotic. And building on this premise of approaching it, which integrates human aspects of technology and perceives technology as the outcome of strategic choices and social behaviour, allows for an investigation of the possible mechanisms of technological failure or success, and ultimately makes the processes more comprehensive and manageable. One could call this approach a *soft* determinism - one that is mediated by human actors, and organisational and societal contexts (Orlikowski 1992).

Overall, subscribing to the assertion that technological regimes are the result of activities of social groups that are producing and reproducing habituated activities, this by definition makes technological regimes socially constructed (Geels 2002: 1259).

FROM NICHE TO REGIME?

Elaborating on the concept of technological regimes, Rip & Kemp (1998: 338) define it as a *rule-set of grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures.*

As this definition entails, gaining insights in the construction of markets follows an investigation of a broad spectrum of social actors ranging from communities of designers, users, producers, policy makers, etc. To grasp the complexity of these innovation diffusion processes, the STS-literature thus highlights the importance for *multidisciplinary unifying viewpoints, multiplicity and/or multi-level models* (See Holm et al. 2010, Sonis & Hewings 2009, Timmermans & Berg 1997).

As noted by Geels (2002) and Kemp et al. (2007), technologies thrive and operate in dynamic evolving interactions in niches of alternative technologies (e.g. biochar, nuclear energy, wind energy, biomass-technologies, etc.), which may be even more important for new radical technologies, as *radical innovations are generated in niches* (Geels 2002: 1260). By including this element in the conceptualisation of the socio-technical landscape and trying to understand the different interpretations and interdependencies within the landscape, researchers within the field of STS might add valuable data to the concept of *the wider context* when investigating new green niche technologies (Bijker, Hughes & Pinch 1987).

Perceiving green technologies (in this case biochar) as radical innovations and (niche) technological regimes can thus add to our understanding of the social shaping of green technologies and the underlying driving mechanisms.

Elaborating on these underlying mechanisms, Kemp et al. (2001: 276) highlight that *niches and entrepreneurial activity are important for the take-off of a new regime* and goes on to stress the importance of the available skills, knowledge and techniques at the given time as well as gaining the support from benefiting actors.

Smith (2003) continues in this regard by examining so-called sustainable technologies, and through the adoption of the notion of technological regimes, he suggests that social entrepreneurs represent a driving mechanism of new trends in the wider context in which *niche* technologies are concerned.

This suggestion is furthermore supported by Mair & Marti (2006: 37), who argue that social entrepreneurship, in its essence, is *a process involving the innovative use and combination of resources to pursue opportunities to catalyse social change and/or address social needs*, which, depending on the isomorphism among organisations, is an integrated part of the societal level and thus the so-called *the wider context*.

As a possible context for this, Smith (2007) finds that industrial strategies, government research and development programmes are of significant importance when trying to introduce new technologies. In this perspective, Holm et al. (2010: 127) emphasise that this also depends on *the ability to bridge between the framing of a new technology and the technological frames dominating industry and government (...). Radical technological shifts often depend on the broad network of practitioners who undertake technological experimentation, promote niche efforts and make deliberative politics to enhance new designed products, systems and so on and networks of practitioners*.

In other words, through this perspective, radical new niche technologies are very likely to originate from people with specific knowledge (e.g. agriculture, biology, engineering, etc.) and have the ability to constitute and shape constellations of relevant social groups.

This standpoint finds support in the present case study where Thomas Harttung (the Entrepreneur) states his agricultural background as a key reason for understanding the prospects of biochar and thus engaging in the technological development.

It is therefore important to take into effect the educational and/or professional background (functional fixedness¹⁰) of people engaged in the early stages of new green technologies, as it is very likely to have a determining effect on their engagement in the technological development and the framing of narratives related to the technology. As Cussins (1996) notes, technologies evoke narratives and counter-narratives and, as in the case of biochar, frames such as the intention to *'mitigate climate change'*, the *'potential to be an environmentally friendly disposal method'*, or *'increase crop productivity'*, as well as being a *'stable carbon storage'* and the *'need for further research'* - all evoke ambivalence and, in varying degrees, constitute the level of *stabilisation* and *closure* surrounding the biochar-technology. But as the scopes of these narratives are rather broad, the stabilisation on these topics should more be perceived as a stabilisation of the framing rather than a stabilisation of the specific details behind the categories.

¹⁰ Functional fixedness is the cognitive bias and inability to realise that an object (e.g. biochar) may also be used to in other ways and different contexts. For example, a person with an agronomic background may focus on biochar's ability to act as a soil conditioner, instead of focusing on biochar's CCS capabilities as a geo-engineer might focus on.

On a general note, Turnbull (2000: 56) does in this regard argue that it is not within the dichotomies of technology vs. science or practise vs. theory that the essentials of technological development are to be found, but rather in the *social and technical means by which local and messy knowledge/practices are made robust, coherent, and mobile*.

Turnbull (2000) highlights, similar as the literature on social entrepreneurship, the importance of early informal talks between the relevant social groups, and further argues that when projects have an experimental nature – as in the case of new green technologies in their infancy – innovation and learning do not flow in one direction, but instead circulate throughout networks.

One of the central ways narratives circulates throughout networks is what Turnball (2000) characterises as *small items of representational technology*, or what Lynch (1993) categorises as *equipmental complexes*. These concepts encompass material arrangements that integrate technology and science and provide distinctive phenomenal sites for not only work, but also sites in which organisation of work is established and can be translated reliably between different sites, as is the case of Barritskov (the site of BlackCarbon's pyrolysis-facility, which is also widely used for this purpose).

In continuation of this, Haraway (1991) proposed to perceive objects and artefacts as boundary objects that are configured within the context of their usage and the infrastructures of organisation within these contexts. This adds on a dimension to the concept of a wider context in that it is not only the overall structures in the socio-technical landscape (e.g. price structures, domination norms and values, political coalitions and environmental problems) that constitute this concept. The accommodation in real-life situations of new artefacts is thus also subject to translation and interpretation (see Akrich 1992).

In line with this post-structuralist perspective, Law (1994) introduces four performative *modes of ordering* that are both embodied in explicit and implicit practices and include social actors, things and social structures. Law (1994) builds on the argument of sense-making and presents the practices of categorisation, coordination and standardisation as key processes in the (re-)production of complex sites of socio-technical agency.

This argument furthermore enjoys empirical support by the proactive behaviour of the Academic Research Community and the Entrepreneur in their current attempts to create standards for categorisations pertaining to biochar production and utilisation, and coordination in regards to data sharing and attempts to narrow the interpretive flexibility on technical issues (see for example the first draft on 'Biochar Product Definition and Standard' from December 2010, International Biochar Initiative¹¹ or Sohi et al. 2009).

¹¹ <http://www.biochar-international.org/characterizationstandard>

The complex dynamics of socio-technical regime change are thus not just a result of shifting trends on a macro-level, but also shifting positions within the regime. For example, a biochar-plant is not only a result of a broader awareness of environmental issues or government subsidies for bio-electricity, it is also the result of a large array of interests and habitual practices among the relevant social groups. Examples of these different positions within the regime could include: some social groups are more interested in the agricultural benefits of biochar; some are more interested in the CCS-capabilities; some might be more interested in the biochar-process as an environmentally friendly disposal method; or combinations of the above.

The present figure illustrates this interaction between the artefact and the RSGs in the present study.

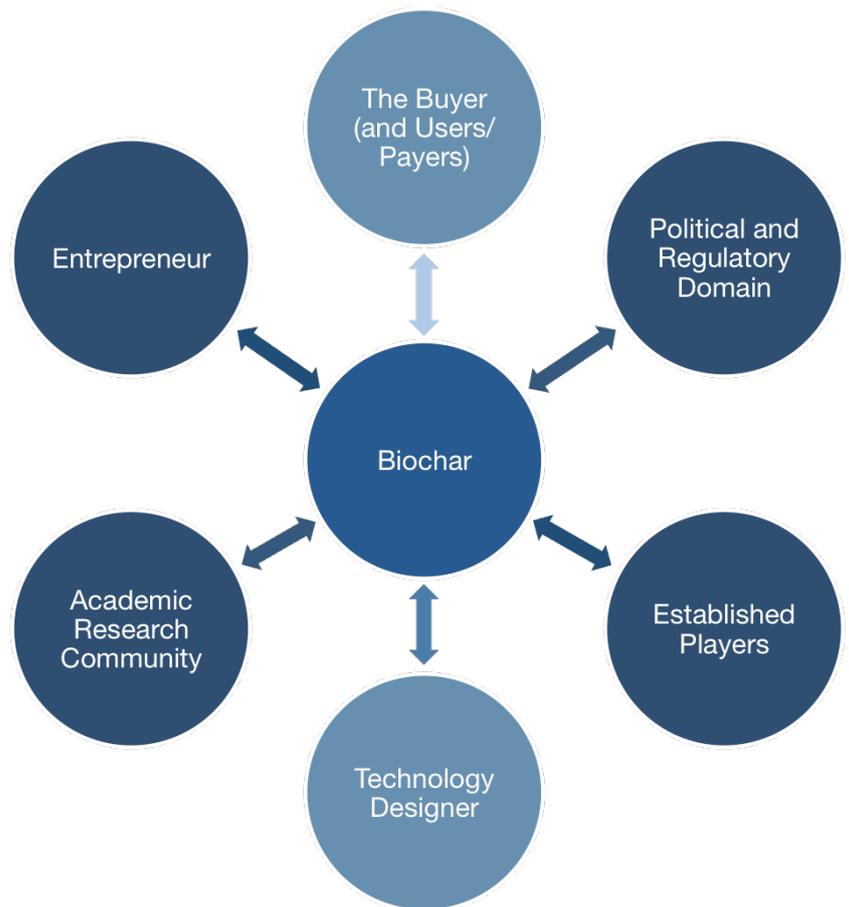


Figure 1 – A multidirectional view on the relations between biochar and the RSGs

However, this framework of actions and choices should, according to Callon (1986) as well as Bijker, Hughes & Pinch (1987), be analysed as a never-ending interpretive process. The implications of this, means that the findings presented in this thesis are only applicable to the current context and the infancy of the technology. Thus, both the importance of the different constituting issues might change and some RSGs might disappear while other (venture capitalist for example) might arise.

THE SOCIAL AND PERFORMATIVITY

Now, the above discussion of how artefacts are adopted might seem like a mixed stew with too many chefs trying to add different perspectives on how to explain that artefacts are essentially created and co-created in a social context. However, these different approaches are important to illuminate as they have profound implications for the epistemology and ontology in sociology and the explanatory status of *the social*.

The above scholars distinguish themselves by being well-placed to investigate the ontological multiplicity of the STS-field in a post-structuralist idiom, which might also be an explanation of why the term *performativity* has taken such a key role in contemporary literature.

Performativity essentially leads to analysing realities (artefacts and social actors) and representations of these realities as being enacted or performed simultaneously (Law 2008). And on an epistemological and ontological level, this consequently means that what is the focal point is not what is making realities, but rather what is doing realities (Ibid.).

Following this argument, perhaps to the extreme, Haraway (2008) argues that no single and comprehensive reality exists and that the different realities are enacted in somewhat power-saturated practices.

Subscribing to the above ideas – theories, technologies, empirical research and social relations are all co-created – will logically have far-reaching ontological and thus analytical consequences within the field, and perhaps other disciplines within social sciences.

The active use of *performativity* is a fairly new practice within the STS-field but is a game-changer in that this concept makes STS not only a descriptive research area, but also an active part of what is discovered (Law 2008).

As counterintuitive as this may sound, Law (2008: 17) goes as far as stating that *technoscience, in all its complex multiplicity, enacts worlds that are fit for its methods.*

Buying into this argument should furthermore change or erode our current conceptualisation of *the social* and *construction*. *The social* as a basic analytic category is obsolete given it is not something separate from anything else, and *construction* perhaps should be replaced by the term *enactment*, given that *construction* does not exist if enactment does not happen – which is not a given.

This has already received some attention within the STS field in recent years as some studies have focused on the importance and characteristics of enactment (see Marres 2007).

THE INTEGRATION OF THE SOCIAL ENTREPRENEUR

These recent trends within the field might prove very valuable in understanding the role of social entrepreneurs in niche technologies in their infancy, like biochar and other green technologies. Given radical innovations are generated in niches and most new green technologies (as biochar) represent niche technologies, and social entrepreneurs have a track record for driving new trends in the wider context, it is only reasonable to expect social entrepreneurs – as paradoxical as this may sound – to play a vital and inherently structural role in the development and introduction of new niche artefacts (read green technologies) through the sui generis characteristics of social entrepreneurs such as the ability to create networks and linkages between relevant social groups.

To address what this means from a theoretical perspective, it means that the premise first and foremost is that situated knowledge, and ad-hoc judgements, are the pinnacle of objectivity, and the meaning

(technical, relational, etc.) is distributed through networks, which can be expected to descend from the actions and self-reinforcing processes initiated by social entrepreneurs.

Thus, the technological development of niche technologies in their infancy should largely be seen in the context of the characteristics of social entrepreneurs and the strategic decisions made in continuation hereof.

DEFINING THE BOUNDARIES FOR INFLUENTIAL DECISIONS

To grasp the present system relevant to the biochar-technology, and define the boundaries for the immediate key decisions for this system, I have identified the most important RSGs as well as their main areas of interests/influence as the following:

Academic Research Community:

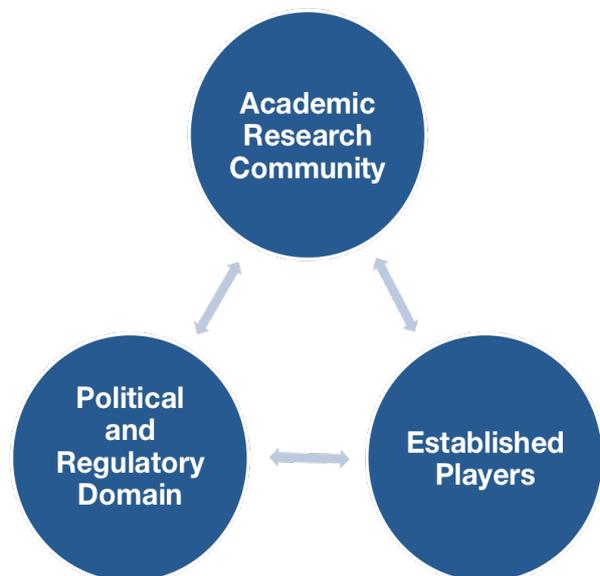
- Climate Change Management
- Application to soils

Established Players

- Development of competing energy-production
- Combustion

Political and Regulatory Domain:

- Financial incentive structures (CCS)
- Regulations



The above six topics constitute the key issues of the general perception of the economics of biochar. However, before moving on, it serves to turn attention to what currently is a barrier but if solved will very likely constitute a tipping point: the categorisation of the different types of biochar. The current lack of an adopted methodology for categorising biochar inhibits the possibility of becoming certified and thoroughly tested and understood. This barrier is furthermore related to the extremely limited supply of actual biochar, which currently inhibits research activity. When these obstacles are overcome, it is very likely to alter the proof of concept and the attractiveness of biochar (Sohi et al. 2009).

Two of the above six issues furthermore distinguish themselves as pressing key issues for the technological development (mainly pressed forward by the Academic Research Community and the Entrepreneur, but also by organisations such as Landbrug og Fødevarer and Dansk Kompetencecenter for Affald). Currently, the prospect of higher rates for biomass combustion and the potential of becoming CCS-certified seem as constituting significant issues. However, other RSGs, e.g. the Established Players and Technology Designers, also see these two issues as highly determining, which may also reflect a somewhat realistic

view among the RSGs of the time-consuming procedures of reaching stabilisation and consensus within the Academic Research Community and its areas of interests. Other social actors like Henrik Wejdling, coordinator at Dansk Kompetencecenter for Affald, also support this, as he state that *the number one challenge for biochar is the increased demand for biomass and biomass combustion*.

BIOMASS COMBUSTION AND FINANCIAL INCENTIVE STRUCTURES

The data material indicates two other key issues for determining the immediate future development of the biochar-technology: the role of combustion of biomass and possible financial incentive structures, which might also reflect the widespread uncertainty in regards to the alleged soil effects.

The market for biomass combustion is presently characterized by large-scale applications (Ravan 2005: International Energy Agency 2002), and can furthermore be divided into thermochemical and biochemical conversion technologies that both can convert biomass to heat, electricity, charcoal, oil or gas. The thermochemical biomass conversion technologies, composed of pyrolysis, gasification, direct combustion, and liquefaction¹², are worthy of further inspection, and especially the drying and pyrolysis/gasification processes that will always be the first steps in a solid-fuel combustion process (International Energy Agency 2002: 21).

Since it goes beyond the scope of this thesis to engage in a deeper discussion of the complexity of this, I will only refer to the significant increase in both forecasts and actual usage of biomass in combustion, which for example is reflected in the significant import and total consumption of wood pellets in Denmark (FORCE Technology 2010) and Grøn Energi, Klimakommissionen 2010. This development also enjoys the support of the Political and Regulatory Domain (for example, through legislation leading to higher biomass use, e.g. the EU Renewable Energy and Climate Change Package) and a wide variety of subsidies and financial incentive schemes for biomass combustion (e.g. bio-electricity) and biomass technologies (for example, Fornyelsesfonden and Energiteknologisk Udviklings- og Demonstrationsprogram).

Related legislation to the bi-products of biochar-production might also affect the economics of biochar. An owner of a power plant does for example receive public subsidies that recede for the part he uses for himself – an aspect that is relevant if large farmers or groups of farmers decide to invest in biochar-production. However, they would get indirect savings through the abolishment of public taxes, which, in 2008, accounted for a 220 øre/kWh savings¹³, and the heat-production has a comparative advantage of not having to add taxes on the heat (given the feedstock originates from renewable energy sources).

A key reason for using biomass co-firing is government support for renewable energy and the role of bio-energy in renewable electricity production. As identified by Thomas Harttung, the subsidies for electricity-production can play a decisive role in the profitability of biochar-production and thus its diffusion. Currently,

¹² Liquefaction can be defined as thermochemical conversion in the liquid phase at low temperatures (523-623 K) and high pressures (100-200 bar). As compared to pyrolysis, liquefaction has a higher liquid yield, and results in a liquid with a higher calorific value and lower oxygen content. (International Energy Agency 2002: 21)

¹³ Energitilsynets elprisstatistik for husholdninger, 2009.

the subsidies are either constituted by a specific amount per kWh or the difference between fixed settling prices and market prices. The yearly variations are partly caused by the renewable electricity-production, and partly by the subsidies to existing plants that, to some extent, are given on the market price of electricity – the subsidies decrease when the market prices rise and vice versa. However, taxes imposed on district heating distribution networks are a barrier to using biomass for district heating, which according to Dansk Fjernvarme, constitutes a commercial barrier.

THE MULTIPLICITY OF TECHNOLOGY

As the above section briefly indicates, the social shaping of a technology seems to be a cosmos with an infinite number of possible behavioural choices and interactions. To provide insights in which mechanisms that can be expected to influence the success of biochar, I will in the following try to outline some of the patterns I have noticed throughout my investigation of biochar.

By way of introduction, it serves to outline one of the most striking findings of this study, which reflects a general dismissal among the RSGs of the path creation-perspective. The vast majority (excl. the Entrepreneur and the Academic Research Community) of the RSGs reflect an understanding of technological development as an external and objective force that through a market-pull establishes a market hence actual action from their part becomes less important. Thus, most RSGs in this case study presents themselves as passive actors in a field where stabilisation and closure is primarily expected to be delivered by the Academic Research Community and the Entrepreneur.

Whether it is good old-fashioned ‘hardware’ technology or social technologies, it is key to include the social shaping of the technology to fully understand and exploit technology. To include the human mediation in ones conceptualisation of technology is also to abandon the institutionalised taken-for-grantedness of technologies, which allows for new understandings of the technologies and a continuous questioning of how actors interact with the artefacts. This position is almost solely mirrored in the attitude and behaviour of the Entrepreneur, who seems to have incorporated the same constructionist approach towards technological innovation, which seems to serve him in breaking down barriers to and among other RSGs.

Another generic trend is the continuous reconstruction of the concept of technology. It is well-known that the duality of technology is shaped by human actions and that technology also effects human actions. However, to spread light on the underlying complexity of this duality there are a few aspects that need to be illuminated. First of all, the premise is that human actions are enabled and constrained by structures that then again are a result of previous actions (Orlikowski 1992), which consequently leads to a habitual behaviour. This behaviour (norms) becomes institutionalised in the forms of structural properties of organizations, and it is within these processes the interpretive flexibility forms *the core of mutual knowledge whereby an accountable universe of meaning is sustained through and in processes of interaction* (Giddens 1979: 83).

Adding this perspective to the term *interpretive flexibility* opens up for analysing the process of interpretive flexibility by also examining the processes among and inside the RSGs, for which the data clearly indicates a need. As the data material suggests, there are not only intra-organisational forces in play, but also different rankings between the RSGs themselves in regards to who is perceived as trustworthy and who is mostly referred to. Thus, an asymmetry among the RSGs can be detected, which needs to be integrated to fully understand the concept of interpretive flexibility.

At the most basic level, no predetermined approach exists to organise the relations between RSGs (Law 1999), but building upon the abovementioned asymmetry, I will briefly conceptualise the social interaction among the RSGs by addressing the indications in the data material that points to asymmetric differences in the attributed power to different RSGs (power), the behaviour and strategic objectives within the RSGs (norms) and their interpretation of biochar (meaning).

POWER ASYMMETRY

Power asymmetry is first and foremost found among the RSGs. The different social groups all represent different degrees of strength in transformative capacity – defined as the ability to transform the material and social world through the organisational resources in interaction with other social groups. The Academic Research Community does here stand in a unique position, as the analytic artefacts *credibility* and *trust* are at a very high level, and consequently its transformative capacity. Supporting this, is the varying but low levels of commitment from the RSGs, reflect the current lack of stabilisation and consensus within the Academic Research Community. Another power asymmetry can be detected through the actions of the Entrepreneur, who has had far-reaching impacts on the vast majority of the other RSGs and distinguishes itself by initiating and persuading other RSGs into action. The transformative capacity of the Entrepreneur has for example sparked the interest in the field of biochar among some Danish scientists, established a commercial partnership between a research institution (DTU) and the Technology Designer (i.e. Sterling) as well as influenced the Danish public sphere.

NORM ASYMMETRY

Norms constitute the social practices and organisational structures through the process of legitimisation. These norms are especially relevant in the different stages and processes of technical innovation. The norm asymmetry is mainly present in social interaction within the organisational properties, such as organisational forms, competitive forces and corporate culture, and is reflected in the characteristics of the RSGs. For example, the Technology Supplier has a strategic objective to advance within the market for gasification engines, but not within the biochar-production and pyrolysis markets. This is also clearly supported by the lack of allocated manpower to the biochar-facility at BlackCarbon.

MEANING ASYMMETRY

The meaning asymmetry can be understood on two levels: internal and external. Internal meaning asymmetry takes place within the organisations where artefacts eventually get institutionalised, which basically refers to the same process of stabilisation and closure as the overall stabilisation and closure among RSGs. An example of this is the meaning asymmetry that currently exists within the Technology Supplier (i.e. Sterling). Here there is a significant distinction between the how old employees (those who had the initial contact with the Entrepreneur) and new employees perceive the importance and prospects of biochar. Event though both groups of employees are of the perception that the biochar-market is highly uncertain and the technology is still too young to say anything definitive, the older employees are more positive towards biochar than the new employees. This might be because the older employees has been influenced by the Entrepreneur and therefore has another relation to biochar or perhaps because the new employees has a more targeted focus on the organisational objectives, which in this case, is focused on the development of green engines targeted gasification.

The earlier discussed notion of time-space disjuncture might therefore also come to the fore in this context.

The three asymmetry-concepts discussed above serve in analytically addressing what the data material indicates. However, it needs to be pointed out that the above concepts are not mutually exclusive. Institutionalising means that practices become norms, and power and norms cannot be understood separately. However, the arbitrary distinction between these concepts does offer useful tools for the analytic purpose of obtaining a deeper understanding of the underlying patterns in the present context.

KEY FINDINGS

Three things are noticeable about the Entrepreneur's behaviour: how it has influenced all other RSGs by either engaging them in biochar-activities or simply raising the awareness-level; how the intentionality behind the actions of the Entrepreneur is so much more idealistic compared to other RSGs; and how it is targeted to not only solve global problems but also to offer services to local communities. These characteristics are highly unique to the Entrepreneur, but the behaviour might not as such have been possible without other key findings: a **collectively passive behaviour among RSGs** (which has provided room for the Entrepreneur to acts); the **nature of the technology** (radical innovation); and the **properties of the biochar-network** (a small-world network with relatively low connectivity).

BIOCHAR IS A RADICAL INNOVATION

Within the field of Product Innovation Management, new technological artefacts are referred to as either incremental or radical innovations. The data material also reflect this understanding and is perhaps best articulated by Hartung who describes his first impression of biochar as *“here you have a energy-technology that has a very clear carbon benefit, which I was well-equipped to understand with my agronomical background. I thought, if this is true, then we stand before a radical technology”*.

This distinction between radical and incremental innovations might arguably also provide insights in previous experiences that for example show that formal and standardised approaches are better for incremental innovations rather than radical innovations (Khurana & Rosenthal 1998); highly specialised organisations have a higher rate of radical innovation adoption rather than environments without technical specialists (Dewar & Dutton 1986); technological radicalism and differentiation has a long track record for providing competitive advantages when marketing new products; and when there exists a high degree of demand uncertainty, like in the case of biochar, a strong customer- and technology-orientation has advantages (Gatignon & Xuereb 1997).

Acknowledging biochar as a radical innovation thus provides a framework to obtain insights in the tendencies artefacts categorized as radical innovations are very likely to be effected by these.

COLLECTIVELY PASSIVE BEHAVIOUR

All RSGs show interest in the prospects of biochar, but due to the lack of stabilisation and consensus on key issues, the vast majority remains only vaguely engaged in biochar-activities. A good example of this is the lack of interest coming from one of the proclaimed key future buyers - the farmers.

According to Thomas Holst, policy-advisor at Landbrug og Fødevarer, biochar has a gloomy outlook for Danish farmers as he sees no significant agricultural benefits of applying biochar to soils and the process of producing the biochar as simply being an additional cost to farmers. However, resistance to biochar might not be as big a problem as the lack of awareness. According to Harttung, perhaps only 5 % of Danish farmers have even heard of biochar, and as long as there does not exist a financial incentive structure supported by the political domain, Thomas Holst, does not expect biochar to become adopted by the Danish farmers.

Subsequently only two RSGs (the Entrepreneur and the Academic Research Community) can be characterised as having a proactive approach to biochar-activities, while the rest remains hesitant until stabilisation and consensus on key issues has been reached.

The current hesitation and the outspoken desire to engage in biochar-activities the majority of RSGs reflects underlines the collectively passive behaviour the current market is characterised by.

The two main barriers for creating a tipping point and a momentum for others RSGs to jump on a bandwagon is (1) the **lack of categorisation of the biochar-types** and (2) the **absence of CCS-certification**.

If these barriers are overcome, it is the general opinion that the biochar-technology will take off. However, at that point, the price of biomass might constitute a new barrier since biomass combustion is very likely to have raised the price of biomass.

IT'S A SMALL-WORLD NETWORK

The results suggest that the properties of the real-world network in which the biochar-technology finds itself in, are highly characterized by a disordered and largely unaffiliated RSGs with low direct connectivity distribution. However, a few RSGs have a relative high connectivity (e.g. the Technology Supplier & the Entrepreneur), and network as a whole resembles small-world networks or the affinity group model where a few social actors within each group of high connectivity function as connectivity centres, linking the different RSGs through networking. In this regard, the Academic Research Community and the Entrepreneur facilitate the majority of the communication created and shared within the network.

The reasons behind the relative small number of social actors engaged in biochar-activities may be related to the small population of Denmark (5.7 mill.), or because of the infancy of the technology and the lack of awareness. The importance of networks for entrepreneurial companies is widely recognised and McEvily & Zaheer (1999) particularly stress the value of networks in the provision of resources and capabilities needed to compete in the marketplace.

THE ENTREPRENEUR AS A SOCIAL ENTREPRENEUR

All of the above findings might be relevant for studying the most significant finding: the striking resemblance between the behaviour of the Entrepreneur and that of social entrepreneurs. Whether the above findings are a result of the behaviour of the Entrepreneur or the above findings have created conditions under which the behaviour has been made possible, or the two have emerged simultaneously, is related to so much uncertainty and speculation that it is better left alone. However, in continuation of trends within organisational theory and social innovation, social entrepreneurship has received widespread attention over the last decade (Mair 2006). In this context, I will argue that the role of the Entrepreneur is indeed also the role of a social entrepreneur (mainly based on the idealistic intentionality behind the Entrepreneur's behaviour and the aspect of sustainability attributed to the biochar-technology).

The concept of entrepreneurship is usually seen in the capitalistic context where economic dynamism and individual creativity is promoted, and Schumpeter's *creative destruction* plays a key role. Social entrepreneurship subscribe to these characteristics but add on in regards to *the relatively higher priority given to promoting social value and development versus capturing economic value* (Mair & Marti 2006: 36). However, other scholars offer to define social entrepreneurship as being part of a complex social movement that instigates sustainable social transformation (Alvord et al. 2004), which is also an outspoken desire for the Entrepreneur.

Other definitions range from the view that *social entrepreneurship involves pursuing highly innovative approaches to addressing social problems and doing so in an opportunistic, persistent, and accountable manner* (Bloom 2009: 128) or that *the key to social enterprise involves taking a business-like, innovative*

approach to the mission of delivering community services (Pomerantz 2003: 26), such as decentralised heat- and electricity-production or disposal of organic waste.

The Entrepreneur's behaviour does in essence, through the involvement of all RSGs, try to create *a process involving the innovative use and combination of resources to pursue opportunities to catalyse social change and/or address social needs* (Mair & Marti 2006: 37).

In an attempt to understand entrepreneurship and probe the challenges of path creation, Garud & Karnøe (2001: 12) offer a similar approach but focuses on (a) acknowledging the embeddedness of action, (b) exploring temporal interconnections between processes, (c) providing a role in explanation for context and action, (d) holistic rather than linear, and (e) linking process analysis to the location and explanation of outcomes.

Relating this approach to the present data material, suggests significant correlations. The ability of Thomas Harttung, the social entrepreneur, to become engaged and embedded in the structures capable of manipulating events (e.g. allocation of public subsidies or scientific efforts) or creating events (e.g. establishing partnership between RSGs or building a pyrolysis-facility), has according to himself, only made him more *"embedded in the process of development the technology"*. This embeddedness has furthermore only been made possible due to the ability of the Entrepreneur to mobilise and manipulate processes, and thus creating temporal interconnectivity between the processes among other social groups.

Thus, the (path creating) actions of the Entrepreneur should be seen as attempts to endogenise a co-creational process between the artefact, time and the interests of the relevant social groups intended to ensure the technological development. Or said in a different way, the Entrepreneur actively and mindfully tries to navigate within the seamless web of events of which he also simultaneously tries to influence.

Failures of path creations are therefore more likely to occur when entrepreneurs are unable to create these linkages. In other words, the success or failure of a technology is not necessarily a result of the intrinsic properties of the artefact, but rather the ability to create and sustain co-creational processes.

CONCLUSION

I started this thesis by setting out to investigate who and how the technological development of a green technology was influenced by subscribing to the premise of market creation as something dynamically evolving and using Social Construction of Technology (SCOT) as the theoretical framework.

Based on this analytic approach and an exploratory case study design, I was set out for identifying the relevant social groups (RSGs), the key issues regarding biochar and the degree of stabilisation and interpretive flexibility on the various issues. However, simultaneously with this research process, I came about some surprising findings related to the patterns of knowledge distribution, the patterns of communication and the unique role of the Entrepreneur in facilitating a creational process through the strategic integration and linking of – from his perspective – social groups that can play an active role in the technological development of biochar.

Before going into depth with these findings, I will highlight the specific conditions present to the technology at hand. Specific to biochar is that it is (1) a **green technology**, (2) a **niche technology**, (3) a **radical technology**, and (4) a **technology in its infancy**. These four conditions are all important to highlight since it is these conditions that constitute the context of which the relevance of the present findings and conclusions descend.

Now, a few problems of reasoning arise when comparing the above conditions to the findings in the data material that suggests that (A) **the current network of people engaged in biochar-activities points to the characteristics of a small-world network**, (B) **most RSGs are characterised by having a collectively passive behaviour**, and (C) **the Entrepreneur adopts the behaviour of a social entrepreneur**.

Given the biochar technology currently is in its infancy, it becomes relevant to ask whether biochar may still be in its infancy either because of the collectively passive behaviour (thus also resulting in a small-world network), or the collectively passive behaviour and the small-world network precludes the infancy of the technology. However, since the data material does not provide any solid indications to these questions, I will withstand any speculative attempts to answer this, but simply turn attention to the tendency networks have to expand, which would suggest that small-world networks (and the collective passive behaviour) are premises for technological development and not vice versa. In this regard, it is interesting to note that many RSGs, and especially the Established Players, remain passive in regards to actual commercial commitments but actively surveillance the trends within the biochar-field.

Adding to the complexity of the collectively passive behaviour-phenomenon is that most RSGs subscribe to a rather deterministic understanding of technological innovation, and this combined with passive behaviour, consequently turns the passive behaviour into a self-fulfilling prophesy due to the lack of actual engagement in the creational process.

However, the importance of this may only be secondary to the importance of clarifying the role of the Entrepreneur in the process of technological development. As the data material indicates, the Entrepreneur (or the so-called social entrepreneur) not only plays a central role in initiating interest in biochar among RSGs, but also plays a crucial part in creating and sustaining the small-world network by facilitating the process of technological development.

The social entrepreneur can be characterised as a person with local knowledge (agricultural knowledge in this case), idealistic intentions (read gut-feelings), and has the capability to influence other RSGs by either engaging them in commercial activities or simply raising the general awareness through various communications forms.

Accepting that technologies in their infancy stands before fundamentally different challenges than for example mature technologies, it can be argued that social entrepreneurs play a fundamental role in the very early development stages of green technologies by having to gather enough interest among RSGs that a small-world network can be established and initial investigatory activities (e.g. field-trials and pilot-projects) can be instigated.

This then re-produces the conditions, and the situation, under which the behaviour of social entrepreneurs are made possible until either the technology matures and/or the network expands that much that the actions of the entrepreneur no longer are of significant importance to the technological development. This also brings about an interesting conclusion. The actions of social entrepreneurs are not only vital for the early phases of green innovations. They are perhaps also limited to this phase.

Bringing this aspect of time into the discussion of the process of co-creation makes it necessary to draw up the boundaries of the time-constrained elements present in the process. Given that social entrepreneurs instigate actions and create small-world networks, and the phenomenon of the collectively passive behaviour only makes sense as long as there is something to gain from other RSGs's actions (i.e. free-riding by letting other RSGs pay the costs of research and development) or the perceived uncertainty of commercial investments is too high, which suggests that if a green innovation reaches the so-called tipping point, the collectively passive behaviour would largely transform into herd behaviour, expand the network, and subsequently make the social entrepreneur obsolete to the continued technological development. This argument builds on the premise put forward by Garud & Karnøe (2003: 278) that the accumulation of inputs from multiple actors generates a momentum.

A relevant aspect when trying to explain the role of the collectively passive behaviour in this process is that biochar is a radical innovation and the level of commercial risk therefore is higher. This aspect might contribute to our understanding of both the scale and scope of the collectively passive behaviour as the transformation from entrants to (and co-creators of) a new market to consolidated players only can be expected to happen in a situation where the (analytic artefacts of) economic forecasts seems profitable.

Thus, this process of technological development instigated by the social entrepreneur can provide us with an idea of how the early stages of the emergence of future green markets may be characterized and thus how to take advantages of this. Given this case study signifies a general trend, the passive behaviour of most RSGs is only limited to the context before a prospective tipping point during which the decisive key issues reach a high stabilisation and actual commercial activities are initiated.

At the current moment, biochar has reached a relatively high degree of stabilisation in regards to being perceived as a tool '*used for mitigating climate change*', a '*potential environmentally friendly disposal method*', a '*possible CDM*', and as being a '*stable carbon storage*', '*soil conditioner*' capable of '*increasing crop productivity*'. However, even though these issues has reached a high degree of stabilisation, the content behind these rather broad labels are still too complex and has not reached stabilisation. The overall concepts and framing of biochar seem to have reached stabilisation but the details have not.

In this regard, it is important to note the pivotal role the Academic Research Community plays in the creation of knowledge and the distribution hereof, and thus the above concepts and framing. This specific RSG has the advantage of enjoying a high degree of credibility and trust among other RSGs, and consequently, has a large impact on the construction, selection and stabilisation of issues.

The interplay with this and other RSGs is important to understand hence this distribution of knowledge and framing has its focal point in this, and thus has a decisive impact on the key issues. Perhaps as a result of mix-interests among RSGs and the lack of stabilisation of the content behind the above labels, the interplay is highly characterised by all other RSGs referring to what is their own perception of the interpretive flexibility of the Academic Research Community.

In other words, there exist different continuously negotiating versions among the RSGs on what actual constitute the interpretive flexibility within the Academic Research Community. This for example becomes apparent in regards to biochar's capability as a '*stable carbon storage*'. Within the Academic Research Community there exists stabilisation and closure on the issue but different RSGs has different versions on the subject.

Adding to the complexity behind this particular phenomenon is the special characteristics of the Academic Research Community, which arguably only promotes issues that have reached a high degree of stabilisation and closure within the Academic Research Community itself (for example through peer-reviewed articles). Hence, the often-used disclaimer that '*research is needed*' in regards to biochar (though on different issues and weighed differently by different RSGs) may also lay the basis for the collectively passive behaviour and '*lack of awareness*'.

In conclusion, the present findings and arguments developed throughout this thesis point to a conceptual integration of social entrepreneurship, small-world network as well as the collectively passive behaviour to gain valuable insights in the field at hand. Additionally, to fully understand the above findings and their

correlations, it serves – when investigating technologies under these specific conditions – to perceive the technology as a market creating innovation rather than a market seeking innovation, which changes the focus from product innovation to also include process innovation.

LIMITATIONS OF THE CASE STUDY

Readers should be aware of limitations related to data sources and the measures used in this thesis. The thesis uses interviews, scientific literature and a content analysis of the Danish public sphere, which – even though tried triangulated – does not prohibit wrongful or biased data.

- The data collecting method prescribed by SCOT does not ensure any representativeness of the respondents and has no defence against blind-spots from wrongful or inadequate answers from respondent in identifying the RSGs.
- A larger sample of respondents and data material could contribute to a higher degree of certainty in the reasoning deduced from the data.
- Empirical speaking, there is the obvious problem that biochar is not yet a commercial good with end-users, which would have caused a high degree of uncertainty in the conclusions given they per definition cannot be more than qualified guesses.
- Given the importance of the social entrepreneur and interpersonal relations in this case study, the field of decision-making, strategic management as well as organisational learning could prove to provide interesting findings in regards to why certain social actors behave like they do and how concepts like ‘groupthink’ or ‘bounded rationality’ come into play. Or perhaps even more important, how much does ‘gut decisions’ influence the social entrepreneur and the process of technological development?
- Any qualitative and/or quantitative analysis cannot take account of all potential factors of relevance. Or integrate all relevant disciplines.

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APPENDIX

APPENDIX A (DATA SET A)

| Nr | Note: 5 yrs, 24.03.2005- 24.03.2010 | Search word / Biochar | Words | Header |
|-----------|--|--------------------------------------|--------------|---|
| 1 | 26.02.2010 | Økologi & Erhverv | 136 | Forskning stiller skarpt på Biochar |
| 2 | 09.02.2010 | UPN-Kymmene.com | 519 | UPM joins the Baltic Sea Action Summit with innovative research project aiming at protecting the Baltic Sea |
| 3 | 15.01.2010 | Effektivt Landbrug | 436 | Forskere: Bedre at brænde biomassen end produktion af trækul |
| 4 | 22.12.2009 | Hedeselskabet.dk | 828 | Amerikanere vil bygge flere trækulsfabrikker |
| 5 | 17.12.2009 | Information | 1235 | Geomanipulation: COP15-fiasko kan føre til kunstige skyer og skinnende planter |
| 6 | 11.12.2009 | Effektivt Landbrug | 486 | Dansker udnævnt som international klimahelt |
| 7 | 02.12.2009 | Børsen | 582 | Fem visionære klimaløsninger |
| 8 | 18.11.2009 | Information | 686 | Debat: Klima: Biochar er en fjern fremtids teknik |
| 9 | 14.11.2009 | Effektivt Landbrug | 398 | Biochar mod klimaændringer |

| | | | | |
|----|------------|---------------------|------|--|
| 10 | 10.11.2009 | Information | 1259 | Teknologisk fix: Fremtidens energisystem står i et drivhus ved Vejle Fjord |
| 11 | 15.10.2009 | Ing.dk (Ingeniøren) | 472 | Nobelprismodtager: Stands ozon, sod og HFC-gasser straks |
| 12 | 04.10.2009 | Politiken | 1383 | Portræt: Grøntsagskassemanden er en helt |
| 13 | 29.09.2009 | U-landsnyt.dk | 1925 | Ny kulsort klimabog fra FNs Miljøprogram: Det vil gå hurtigere og værre end hidtil antaget |
| 14 | 18.09.2009 | Økologisk Jordbrug | 713 | Texas-økologer gødsker med trækul og kompost-te |
| 15 | 11.09.2009 | Ing.dk (Ingeniøren) | 615 | Forskernes simple løsning på CO2-mareridtet: Biokoks |
| 16 | 11.09.2009 | Ingeniøren | 659 | CO2-lagring: Forskere vil flytte CO2 fra atmosfæren til landmandens jord |
| 17 | 03.05.2009 | Politiken | 1781 | Georg Gearløs som klimaingeniør |
| 18 | 23.01.2009 | Økologisk Jordbrug | 128 | Biochar løser det hele |
| | | Biokoks | | |
| 19 | 11.09.2009 | LandbrugsAvisen.dk | 211 | Landmænd kan få gavn af CO2 |
| 20 | 11.09.2009 | Maskinbladet.dk | 126 | Forskere foreslår lagring af kul i opvarmet halm |
| 21 | 19.04.2008 | Flensborg Avis | 450 | Biosprit aus Bäumen |

APPENDIX B (DATA SET B)

| Nr | Author(s) | Abstract | Description |
|----|---|---|--|
| 1 | S. Shackley, University of Edinburgh | Integrated Assessment of sustainable biochar systems | A sustainable biochar system is defined as one which: a) produces and deploys biochar safely and without emitting non-CO2 greenhouse gasses; b) reduces net radiative forcing; c) does not increase inequality in access to, and use of, resources; and d) provides an adequate return on investment. Systems which meet the above criteria do not exist at demonstration or commercial scale at the current time. The analysis finds that using virgin feedstocks a pyrolysis-biochar system (PBS) perform well under criteria (a), (b) and (c), but not (d). The systems are only financially viable under current conditions (i.e. assuming no agronomic and carbon storage value) if non-virgin feedstocks are used, but there is then a potential conflict with criterion (a). This analysis suggests that PBS will not develop without a change in incentives to give value to the stored carbon, except in niche areas where cheap and clean feedstocks are available and/or a high-value added product can be designed for particular agronomic applications. A gasification-biochar system (GBS) in developing countries offers a low-cost approach but is still hindered by the absence of carbon credits. |
| 2 | A. Hornung, A. Apfelbacher & S. Sagi, European Bioenergy Research Institute | Bio-thermal valorization of biomass the BtVB process at Hainhaus/Odenwald | The BtVB process – Biothermal Valorisation of (ash rich) Biomass is able to process all kinds of biomass and biogenic residues, highly flexible for different feed sizes and moisture contents. The BtVB process is coupling residues and effluents of a biogas unit to a thermal line consisting of a pyroformer (pyrolysis reactor) and gasifier as well as an algae production to generate new feedstock. Finally the minerals present in the charcoal from pyrolysis is used for sequestration and refertilisation of soils. Alternatively the biochar can be used for combustion in biomass power plants. A very efficient fertilizer cycle can be achieved by introducing algae cultivation into the process and using lignin rich residues from biogas processes. |
| 3 | E. Hodgson, K. | Biochar | Research on the chemical characterization of biomass feedstocks |

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| | Farrar, G. Gallagher & I. Donnison, Institute of Biological Environmental and Rural Sciences (IBERS) & Sustainable Energy Ltd | production and application – ancient techniques with modern technology | and the development of biorefinery systems, biochar production and utilization has now become a part of the ongoing research at IBERS. The biochar projects investigate the link between feedstock composition, biochar yield and quality, and the effect of biochar addition on soil quality and carbon sequestration potential, plant growth and yield. This is done through collaborative research projects and pilot projects that is intended to aid in bridging the gap between lab-scale and field-scale biochar production and testing. |
| 4 | W. Meredith, P. Ascough, E. Tilston, C. Snape, D. Large & M. Bird, University of Nottingham, James Cook University, Scottish Universities Environmental Research Centre | Evaluation of hydrothermal carbonisation as a method for the quantification of biochar via the testing of standard reference materials | An accurate and reproducible method for the quantification of biochar is essential if we are to assess properly its occurrence and stability in a range of environments. Currently a wide variety of thermal, chemical and optical methods are utilized which inevitably gave a range of results, as also demonstrated by Hammes et al (2007). A new approach is offered in hydrothermal carbonisation (hpy), in which pyrolysis assisted by high hydrogen pressures (15 MPa) facilitates reductive removal of labile organic matter. The high pressure and slow heating rate employed together with the presence of a molybdenum based catalyst prevent generation of secondary char as with other chemical or thermal oxidative methods. It results suggest that hpy can reduce labile organic matter to volatile products in a controlled manner, and is also able to isolate rapidly and reproducibly the most resistant biochar fraction from carbonaceous samples, independent of the environmental matrices in which it is found. |
| 5 | C. Byrne, W. Kwapinski, F. Melligan, E. Novotny, J. Leahy & M. Hayes, Department of Chemical and Environmental Sciences, University of Limerick & Embrapa Solos | Biochar produced from Miscanthus x giganteus and its effect on growth of Maize (<i>Zea mays</i> L.) | This analysis focuses on the characterization and classification of biochar, and its influences on plant growth when used as a soil amender. Biochar, from <i>Miscanthus x giganteus</i> chips was prepared in a lab-scale pyrolysis at: (a) 400°C for 10 min; (b) 500°C for 30 min; and (c) 600°C for 60 min. The best results were obtained for the biochar heated at 600°C for 60 min. Biochar heated for 10 min at 400°C suppressed plant growth, and had a significantly lower surface area than that prepared at 600°C for 60 min. The analysis concludes that in order to obtain the optimum value for soil applications of biochar it is important to establish the preparation criteria that will give rise to properties with desired effects. A classification system is needed that will indicate the values of biochar for different applications. |
| 6 | E. Lopez-Capel, Sir Joseph Swan Institute, Newcastle University | Biochar characterization prior to soil application | There is a broad range of materials that could be defined as biochar. Biochar will vary depending on the type of feedstock (crop waste, energy crop, wood chip, municipal waste, manure, etc.) and production process (mainly temperature and time) being used. Such variables may determine the use or potential use of biochar. A rapid screening technique comparing or matching biochar materials to a particular use does not exist. However, a simple scheme for characterizing biochar before addition to soils was formulated by McLaughlin at the NABC in Boulder, August 2009. The general characterization scheme breaks the biochar into a small number of constituent parts, consisting of: Moisture, Ash, Mobile Matter and Resident Matter. The paper proposes the use of thermal analysis coupled to quadrupole mass spectrometry (TA-QMS) as a valuable technique to characterize biochar before addition to soil. |
| 7 | N. Borchard, J. Siemens, A. Möller, W. | Effects on soil properties | Data on the effect of biochars from different sources on soil fertility are sparse. We determined chemical and physical properties of biochars made by flash pyrolysis, gasification and from conventional charcoal. |

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| | Amelung & J. Utermann, Institute of Crop Science and Resource Conservation, University of Bonn & Federal Institute for Geo-Science and Natural Resources | by biochar from pyrolysis, fast pyrolysis and gasification | In summary, our results suggest that gasification biochar and charcoal have a certain potential to increase soil fertility by increasing plant available nutrient concentrations, effective cation exchange capacity (in sand), or water retention. In contrast, the addition of pyrolysis biochar reduced soil pH to unfavourable levels, reduced water retention, and did not add nutrients to the soil. Considering source and type of biochar seems pivotal for assessing its potential as fertilizer or soil conditioner. |
| 8 | M. Bell & F. Worrall, Department of Earth Sciences, Science Laboratories | Biochar application to temperate soils: a carbon sink with environmental co-benefits | The study found that increasing amounts of char application resulted in: <ul style="list-style-type: none"> - Slight, non-significant increases in net ecosystem respiration. - Significant increases in dissolved organic carbon loss. - A significant decline in nitrate flux in the soil leachate. - Significant increases in soil pH, from 6.98 to 7.22 on bare arable soils with an application of 70.000 kg C/ha. Consideration of both the C sink and environmental benefits observed in this study suggests that biochar application to temperate soils should be given serious consideration. |
| 9 | L. Shaw, Department of Soil Science, School of Human and Environmental Sciences | An overview of biochar research at the University of Reading | Ongoing research projects are examining: <ul style="list-style-type: none"> - The efficacy of biochar amendment for the remediation of metal-contaminated ochre and hydrocarbon contaminated soil. - The impact of biochar amendment on the physical (water-holding/transport and radiative characteristics), chemical (biochar-soil-phosphorus interactions) and biological (plant-microbe interactions) properties and processes of tropical and temperate agricultural soils. |
| 10 | L. Brown & F. Worrall, Department of Earth Sciences, Durham University | The influence of biochar on the stability of a compost-like output | Municipal solid waste is currently laid as topsoil for landfill and other brownfield sites. However, its relative high CO ₂ flux means that this potential carbon store could be optimized. The implications of the results could see two waste materials being combined to offer a viable carbon store, a potentially important resource with global soil stocks diminishing. Furthermore, it could provide a basis for the production of biofuel crops on brownfield sites that would otherwise be unsuitable for agricultural cultivation. |
| 11 | M. Durenkamp & P. Brookes, Department of Soil Science, Rothamsted Research | Impact of biochar and substrate addition on soil microbial biomass | Soil microbial biomass can be described as the collective mass of all soil micro-organisms, e.g. bacteria, fungi, protozoa, which are essential for plant growth. Biochar may provide a habitat for microbial organisms, protecting them from predators and supplying absorbed organic compounds and nutrients. The field-research showed that biochar might have an inhibitory effect on nitrification, but do not cause large changes in soil microbial biomass, although differences were observed between used soils. |
| 12 | A. Gathorne-Hardy, J. Mercier, J. Woods & J. Knight, Centre for Environmental Policy, Imperial College | Biochar allows biomass crops to be grown on saline soils | Degraded land is a controversial term, and there is a risk that land is termed degraded so that bioenergy can be grown on it without incurring an indirect land use change-penalty (Fritsche et al 2009). Yet human induced saline soils are categorically degraded, and are an increasing problem worldwide. The potential to both sequester carbon, and also mitigate previously damaged agricultural lands will be an important tool in low-lying areas in the future. The results of the paper suggest that biochar can significantly increase germination success on saline soils ($p < 0.01$). At present the mechanism for this effect is not clear, but it is assumed that the salt ions are bound to |

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| | | | the biochar in a non plant-available form. Biochar significantly increased germination of plants in saline soils. This is expected to translate into an increased potential for agriculture in saline areas through the use of biochar, which will also give associated benefits of reduced N demand. |
| 13 | Z. Wallage, Low Carbon Innovation Centre (LCIC), University of East Anglia | Biochar production – exploring the opportunities available with biomass gasification combined heat and power | <p>In 2009, a stakeholder events demonstrated significant interest in biochar on three main fronts:</p> <ul style="list-style-type: none"> - The academic research base - Land owners/managers; and - Suppliers/manufacturers of biochar production systems <p>LCIC pursues the following basic approach with regard to biomass gasification:</p> <ul style="list-style-type: none"> - Investigate the safety and legal issues concerning the use, application storage and transport of biochar - Explore and develop a biochar supply chain network - Investigate the viability of establishing a voluntary offsetting scheme based on the sequestration of carbon via the application of biochar to soil - Develop a consultancy service centred around biochar and bioenergy production from biomass gasification CHP systems. |
| 14 | J. Fitzgerald, C. Jay, N. Hipps & C. Atkinson, East Malling Research | Assessing the effects of biochar incorporation on soil fertility and crop growth | Biochar has enormous potential for use within UK horticulture and agriculture as a method to sequester atmospheric carbon and increase soil carbon content and possibly raise soil fertility. It is potentially a useful environmentally friendly disposal method for farm and urban organic wastes as well as a product of sustainable bio-energy production. The paper finds that biochar increases moisture retention in the soil and also raised soil pH. No overall differences in yield were found in any of the crops, but there were differences in sugar and acid concentrations in strawberry fruit. |
| 15 | N. Hipps, East Malling Research | Biochar and problem waste types | Conversion from waste to biochar offers the opportunity of reducing the carbon footprint and providing a soil amendment that is beneficial to soil fertility and crop growth. |
| 16 | J. Hammon, S. Shackley, P. Brownsort & S. Sohi, UKBRC, University of Edinburgh | Life Cycle Assessment of Pyrolysis-Biochar Systems in the UK | This paper shows that pyrolysis-biochar systems (PBS) appears to offer a more efficient way to abate carbon than alternative uses of biomass feedstock, or land to grow such feedstocks. The largest contribution to PBS carbon abatement (40-50%) is from the feedstock carbon stabilized in biochar. The next largest contribution (25-40%) arises from the more uncertain indirect effects of biochar in the soil (reduced fertilizer needs, reduced N ₂ O emissions, increased soil organic matter, etc.). The carbon abatement efficiency of PBS depends, however, on the Carbon Stability Factor (CSF) of biochar, which is the proportion of total carbon in freshly produced biochar that remains fixed as recalcitrant carbon over a defined time period. The LCA suggests that the CSF remains above 0.45, PBS will outperform direct combustion of biomass at 33% efficiency in terms of carbon abatement, even if there is no beneficial indirect impact of biochar on soil greenhouse gas fluxes, or accumulation of carbon in soil organic matter. |
| 17 | A. Gathorne-Hardy, Imperial College | Full carbon accounting minimal greenhouse gas savings associated with biochar | All carbon accounting for biochar LCAs have ignored emissions from feedstock itself. One of the key justifications associated with biochar use is to mitigate climate change, but if this does not occur on a project level, then the use of biochar should be questioned. When accounting only for carbon sequestered and carbon emitted the choice of feedstock was essential for determining carbon payback periods, with straw and coppiced hedgerow feedstock giving clear |

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| | | use | carbon savings within a 20 year time frame, but tree based biochar acting as a net carbon source over 20 years. |
| 18 | R. Ibarrole, S. Schackley & J. Hammond, UKBRC, University of Edinburgh | Pyrolysis for waste treatment: a Life Cycle Assessment of biochar and bioenergy generation from different waste sources | Thermal treatment such as pyrolysis has been considered as a sustainable technology for biodegradable waste treatment as it has the potential to convert biomass into charcoal that can be used as soil fertilizer, produce green energy, and mitigate greenhouse gas emissions. At the same time, it could help local authorities to divert waste from landfills. However, it is unknown if it could compete against landfills or anaerobic digestion composting facilities in a market where these other waste treatment technologies have already been consolidated. Considering this context, a life cycle assessment of different urban and industrial biodegradable wastes generated across the UK is being performed. The first objective of this research is to compare carbon abatement, energy generation, and economical indicators obtained for these feedstocks against the existing indicators for energy crops or agricultural waste. The second objective is to compare these indicators against existent ones for common waste treatment technologies, such as landfills or anaerobic digestion, in order to analyze the potential of thermal treatment technologies as waste management strategy. |
| 19 | M. Bell & F. Worrall, Dept of Earth Sciences, Science Laboratories | CO2 implications of spreading biochar onto UK pastures (poster presentation) | The majority of research on biochar application to agricultural land is associated with incorporation into arable soil, with a large amount of this research originating in tropical climates. This means there is a need to assess the potential for biochar application other than arable if the full potential of biochar is to be achieved. A large area of agricultural land in the UK is managed as improved and rough pasture where fields are grazed and cut for hay however the soil itself is not disturbed. The lack of soil disturbance means that any addition of biochar must be undertaken without incorporating the material into the soil. This is crucial as previous research has shown significant increases in soil carbon losses with disturbance. |

BIOCHAR PROPERTIES (IDENTIFYING CHARACTERISTICS)

- Using virgin feedstock in a PBS is overall environmentally sustainable but does not currently provide an adequate return on investment (c1).
- PBS is only financially under current conditions (i.e. assuming no agronomic and carbon storage value) if non-virgin feedstocks are used but does then conflict with the environmental sustainability (c1).
- PBS will not develop without a change in incentives to give value to the stored carbon, except in niche areas where cheap and clean feedstocks are available and/or a high-value added product can be designed for particular agronomic applications (c1).
- GBS offers a low-cost approach (especially in developing countries) but is still hindered by the absence of carbon credits (c1).
- The best results were obtained for the biochar heated at 600°C for 60 min. Biochar heated for 10 min at 400°C suppressed plant growth, and had a significantly lower surface area than that prepared at 600°C for 60 min (c5).
- Gasification biochar has a certain potential to increase soil fertility by increasing plant available nutrient concentrations, effective cation exchange capacity (in sand), or water retention. In contrast, the addition of pyrolysis biochar reduced soil pH to unfavourable levels, reduced water retention, and did not add nutrients to the soil (c7).
- Char application resulted in significant increases in dissolved organic carbon loss, a significant decline in nitrate flux in the soil leachate, and significant increases in soil pH, from 6.98 to 7.22 on bare arable soils with an application of 70.000 kg C/ha. (c8).
- Biochar may provide a habitat for microbial organisms, protecting them from predators and supplying absorbed organic compounds and nutrients. Additionally, biochar might have an inhibitory effect on

nitrification, but do not cause large changes in soil microbial biomass, although differences were observed between used soils (c11).

- Biochar can significantly increase germination success on saline soils ($p < 0.01$). At present the mechanism for this effect is not clear, but it is assumed that the salt ions are bound to the biochar in a non plant-available form. Biochar significantly increased germination of plants in saline soils. This is expected to translate into an increased potential for agriculture in saline areas through the use of biochar, which will also give associated benefits of reduced N demand (c12).
- Biochar increases moisture retention in the soil and also raised soil pH. No overall differences in yield were found in any of the crops, but there were differences in sugar and acid concentrations in strawberry fruit (c14).
- The largest contribution to PBS (pyrolysis-biochar systems) carbon abatement (40-50%) is from the feedstock carbon stabilized in biochar. The next largest contribution (25-40%) arises from the more uncertain indirect effects of biochar in the soil (reduced fertilizer needs, reduced N₂O emissions, increased soil organic matter, etc.) (c16).
- If CSF (Carbon Stability Factor) remains above 0.45, PBS will outperform direct combustion of biomass at 33% efficiency in terms of carbon abatement, even if there is no beneficial indirect impact of biochar on soil greenhouse gas fluxes, or accumulation of carbon in soil organic matter (c16).

DIFFERENT HEATING PROCESSES

- BtVB (Valorisation of (ash rich) Biomass) that presumably is able to process all kinds of biomass and biogenic residues. BtVB is highly flexible for different feed sizes and moisture content, and combines pyrolysis reactor, gasifier and an algae production to generate new feedstock. The biochar can be targeted power plants (c2).
- Hypy (hydropyrolysis) is a process in which pyrolysis is assisted by high hydrogen pressures (15 MPa) that facilitates reductive removal of labile organic matter. Hypy can allegedly reduce labile organic matter to volatile products in a controlled manner and prevent generation of secondary char (c4).

APPENDIX D (INTERVIEW PERSONS)

Political and Regulatory Domain

Jannik Møller, Energy Coordinator, Regional Development Unit, Bornholms Regionskommune
 Kristian Strobech, Associate Professor/Head of New Media at Danish School of Media and Journalism
 Andreas Barkman, Head of Mitigation Group, Air and Climate Change Programme, European Environment Agency
 Birgitte Holm Christensen, Head of Department (Biomass and Waste), FORCE Technology
 Stefan Naef, Consultant, Applied Environmental Assessment, FORCE Technology
 Henrik Flyver Christiansen, Head of Section, Energy Supply, Danish Energy Agency
 Linda Bagge, Miljøstyrelsen
 Anne Grete Holmsgaard, Politician

Academic Research Community

Sander Bruun, Associate Professor, Department of Agriculture and Ecology, University of Copenhagen
 Esben Bruun, PhD student, Risø National Laboratory for Sustainable Energy
 Ulrik Birk Henriksen, Associate Professor, Risø National Laboratory for Sustainable Energy
 Henrik Hauggaard-Nielsen, Senior Scientist, Risø National Laboratory for Sustainable Energy
 Niels Bech Christensen, Senior scientist, Risø National Laboratory for Sustainable Energy
 Neil A. Hipps, Business Development Manager, East Malling Research
 Jens Frøsløv Christensen, Professor, Department of Innovation and Organizational Economics, CBS
 Adam Buchhorn, PhD Fellow, Department of Organization and Industrial Sociology, CBS
 Simon Shackley, Leader, Systems and Social Science, UK Biochar Research Centre, School of GeoSciences, University of Edinburgh
 Saran Sohi, Lecturer in Soil Science for Biochar, UK Biochar Research Centre, School of GeoSciences, University of Edinburgh
 Peter Brownsort, Post-doctoral Research Associate: Process Technology UK Biochar Research Centre, School of Geosciences, University of Edinburgh
 Alfred Gathorne-Hardy, Centre for Environmental Policy, Imperial College

Technology Supplier

Gitte Videcrantz, Program Department Manager, Sterling DK
Svend Erik Christesen, Chief Sales Officer, Sterling DK
Jesper Noes, Senior Engineer, Sterling DK

Established Players

Christian Davies, Environmental Biotechnologist, UK Project Leader, Biodomain Technology Group Projects and Technology, Shell Research Ltd
Kaj Gøtterup Nielsen, Operations Manager, Horbelev Fjernvarme
Michael Tersbøl, Head of development, Økologisk Landsforening
Jan Sørensen, Project Manager, New Energy Systems
Mike Roberts, Environmental Power International
Lise Lotte Lyck, Regulatory Affairs, DONG energy
Henrik Stiesdal, CTO Siemens Windpower
Jens Dall Bentzen, Managing Director, Dall Energy
Kirsten Henriksen, Head of Recycling, Amagerforbrænding

Biomass Suppliers

Ulrik Knaack Nielsen, head of section, Business Policy, Dansk Skovforening (Danish Forest Association)
Henrik Wejdling, Coordinator, Dansk Kompetencecenter for Affald
Inge Werther, Coordinator, Dansk Kompetencecenter for Affald

Entrepreneur

Thomas Harttung, Founder and CEO, BlackCarbon
David Hutchinson, Founder and CEO, Yorkshire Charcoal Co
Nils Peter Astrupgaard, Founder and CEO, EP Engineering

Buyers (and User/Payers)

Thomas Holst, Business Policy Consultant, Miljø & Energi, Landbrug og Fødevarer (Danish Agriculture & Food Council)
Claus Vangsgård, Consultant, Dansk Vand- og Spildevandsforening
Karin Larsen, Operations manager, Dansk Vand- og Spildevandsforening
Henrik Andersen, Technical Consultant, Dansk Fjernvarme (Danish District Heating Association)
Uffe Bro, President, Dansk Fjernvarme (Danish District Heating Association)

APPENDIX E (INTERVIEW GUIDE)

| Research question | Interview question | What data is gained | Theme |
|---|--|---------------------|-------|
| <ul style="list-style-type: none">▪ What does the respondent know about biochar?▪ What is the current position on biochar? | <ul style="list-style-type: none">○ How did your original understanding of biochar develop towards the understanding you have today?○ What do you perceive as the pros and cons of biochar?○ What made you interested in biochar?○ Which factors do you think explains the current and future | | |

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| | development of biochar? <ul style="list-style-type: none"> ○ Are you currently involved in any biochar-activities? ○ Organisational position on biochar and reasons behind this? | | |
| <ul style="list-style-type: none"> ▪ What is the respondent's relation to biochar? ▪ What are the interests of the respondent? | <ul style="list-style-type: none"> ○ How could biochar help you reach your commercial objectives? ○ How would you imagine you could use your network to strengthen your interests in biochar? | | |
| <ul style="list-style-type: none"> ▪ What can the respondent do to influence the technological development of biochar? | <ul style="list-style-type: none"> ○ In which organisations is the respondent represented? ○ Is biochar an organisational priority? ○ How much time do you spend on biochar specifically? ○ Do you consider yourself proactive or reactive in regards to influencing the development of biochar? And why is that? ○ What does the respondent do to share knowledge and best practice? | | |
| <ul style="list-style-type: none"> ▪ What obstacles do the respondent see for his interests? | <ul style="list-style-type: none"> ○ Who or what could threaten your efforts to influence the development of biochar? ○ What potential risks do you see for biochar? ○ How should biochar be regulated? | | |
| <ul style="list-style-type: none"> ▪ What could be done to make biochar more attractive for the respondent? | <ul style="list-style-type: none"> ○ Which financial incentives for biochar could support the development? | | |
| <ul style="list-style-type: none"> ▪ What could be done to make biochar less attractive for the respondent? | <ul style="list-style-type: none"> ○ | | |
| <ul style="list-style-type: none"> ▪ Who are the relevant social groups that could be expected to influence the technological development of | <ul style="list-style-type: none"> ○ Which factors are most likely to influence public perceptions on biochar? | | |

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| biochar? | | | |
| <ul style="list-style-type: none"> ▪ Who could be expected to collaborate with the respondent in his lobbying efforts? | ○ | | |

APPENDIX F (THE OVERALL RESEARCH PROCESS)

As indicated in the introductory chapter, it was my intention that this thesis would diminish the existing gap in the body of literature on green emerging technologies through a social constructivist lens, in which the underlying premise was that the development of markets evolves dynamically. In continuation of this, the thesis seeks to contribute in five different ways by: 1) providing empirical data to the field through a case study of the biochar-technology; 2) building on constructivist conceptualisation of the construction of markets for green technologies; 3) investigating the RSGs and their linkages; 4) identifying the characteristics of the collaboration among the RSGs; and 5) highlight and propose a new analytic perspective on the role of entrepreneurs (or social entrepreneurs) in the emergence of contemporary new green technologies in the field of Science and Technology Studies.

I started this thesis by formulating the following research question: **Which social actors are influencing the technological development of biochar in Denmark, and what are the characteristics of these practices?**

In order to answer this question, it is, according to Bijker et al. (1987: 30), the RSGs and their understandings (interpretive flexibility) of the artefact that play a key role in defining the way in which the artefact develops. However, whether it is *mapping controversies*, exploring *innovation journeys* or investigating where *technology meets market* or the *technological path*, these conceptual frameworks all provide vocabularies for addressing what this study essentially aims to answer.

As some of these vocabularies entails, there is within these languages provided to explain technological development an inherent expectation of conflict between the progress of new emerging technologies and existing technological regimes. An interesting note, in this regard, is that even though I, from the outset of this study, had a considerably broad and open approach, I did actually expect that the energy sector and the Established Players would play more proactive and central roles as a response to the attempt of the biochar-technology to break into their existing technological regimes. However, I soon realised that the Established Players were rather passive and the central roles instead was distributed to the Academic Research Community and the Entrepreneur. Perhaps it is symptomatic for new technologies in their infancy that it is exactly these two RSGs that are mostly engaged in the technological development, and the idea of conflict only becomes relevant when the technology reaches some stage of maturity and the technical and

scientific knowledge reaches some certitude and stabilisation (as perceived from the perspective of the Established Players), which the existing technological regimes then subsequently can react to.

And as the data material does not provide any significant indications on a clear conflict between biochar and existing technical regimes, such an assumption cannot currently be confirmed.

Lastly, a few considerations on the matter of ontology within the context of *the social*. As alluded to earlier, this study is engaged in an analysis of *the social* and thus heavily entangled in the in it. Buying into the argument that *technoscience enacts worlds that are fit for its methods* and *the social* is not something separate anything else, this thesis should also be seen as an enactment in itself. Perhaps this becomes most relevant in terms of the idea of the researcher solely as an observer, quietly observing the actions of others. Staying true to my scientific approach, this idea should be consequently be rejected by the sole reason that I myself have create knowledge and thus meaning (see Appendix F). Under these ontological conditions, the idea of being an observer should in other words, be replace be the idea of being a participant and a co-creator of meaning.

Broadly speaking, I have been entangled in *the social* throughout the research process by the sole reason of having to buy into vocabularies, which inevitable have certain biases.

I will illustrate this entanglement (in performativity) by highlighting two examples of how my choice of language has shaped the current presentation of the field of biochar.

As a relatively simple example, I have for the larger part of my research process coined the *Entrepreneur* the *Producer*. Initially, I did this because I, in my initial data-collection phase, come about a few paper from the UK Biochar Research Centre that categorised the social group as producers. Incorporating the discourses within the literature on path creation and social innovation, I subsequently changed my categorisation, which perhaps does not have the most significant effect of the study, but it is an example of how concepts and their connotations affect their contexts, and vice versa.

Secondly, I would like to turn attention to the concept of biochar. As briefly mentioned in the introduction, biochar descends from the concept of agrichar. Having bought into the discourse on biochar, I might also have bought into a discourse that is more friendly-minded towards biochar/agrichar. Even though, it is not within the scope of this study, I have noticed that somewhere around 2007 and 2008, the concept of agrichar was phased out and replaced by biochar without any apparent reason. Perhaps this is just speculation, but under any circumstances, the wording and conceptualisation of things are, as SCOT also suggests, parts of processes used for establishing stabilisation and closure, and the change from agrichar to biochar might just be an example of that.