CURRENT STATE AND FUTURE PERSPECTIVES OF BIOCHAR APPLICATIONS IN FINLAND

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ABSTRACT

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Abstract

Biochar applications are attracting considerable attention as they offer economically feasible and environmentally sustainable solutions. Biochar has already been researched in Finland for around a decade but only recently its economic potential has been discovered and the market of biochar has started to emerge. Previous research has mainly focused on the pyrolysis-process, characterisation of biochar and potential applications, rather than analysing biochar's market and economic potential. Thus, the aim of this study is to fill the existing knowledge gaps by exploring the current state and future perspectives of biochar in Finland through investigation of the main driving factors, challenges, and opportunities for various biochar applications.

The data in this qualitative study was collected through thematic, semi-structured interviews. In total ten experts in the biochar field were interviewed during June-August 2017. According to the research findings, several biochar applications have a significant potential in Finland and the market is estimated to grow in the upcoming years. Currently, there are ongoing projects and experiments in the following biochar applications: cultivation, animal agriculture, soil and gardening, and urban areas. The research findings suggest that in the future biochar will achieve a strong position in the gardening and green building sectors, in particular in composting, green roofs, seedbeds, filtering and managing storm water and urban runoff. Research findings indicate that application-specific drivers such as economic feasibility and local benefits drive biochar market development. On the other hand, lack of practical research results, varying quality and type of biochar, low public awareness, broad and unclear definition of biochar ("biohiili"), lack of external funding for biochar producers, and the need for sophisticated yet affordable biochar production technology are indicated as the main challenges influencing the adoption of biochar.

Keywords
biochar, diffusion, innovation, bioeconomy, environmental technology, sustainable development, carbon sequestration, climate change

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TIIVISTELMÄ

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Tiivistelmä

Kiinnostus biohiiltä kohtaan lisääntyy jatkuvasti, sillä biohiili tarjoaa taloudellisia ja ympäristön kannalta kestäviä ratkaisuja. Biohiiltä on tutkittu Suomessa noin kymmenen vuotta, mutta vasta viime aikoina sen taloudellinen kannattavuus on tunnistettu. Aikaisemmat biohiileen liittyvät tutkimukset ovat keskittyneet lähinnä pyrolyysiprosessiin, biohiilen ominaisuuksiin sekä biohiilen potentiaalisten käyttökohteiden tutkimiseen. Biohiilen markkinatilannetta ei ole vielä Suomessa tutkittu, lukuun ottamatta biohiilen käyttöä energiantuotannossa (biohiilen poltto), mikä on kuitenkin rajattu tästä tutkimuksesta. Tämän työn tarkoitus on tutkia biohiilen käytön nykyistä tilannetta ja sen tulevaisuuden näkymiä Suomessa, sekä tunnistaa tekijöitä jotka edesauttavat biohiilen käyttöönotossa. Lisäksi tarkoitus on tunnistaa haasteita ja mahdollisuuksia liittyen erilaisiin biohiilisovelluksiin.

Tutkimusmetodiksi valittiin laadullinen tutkimus, joka toteutettiin puolistrukturoituina teemahaastatteluina. Yhteensä kymmenen asiantuntijaa osallistui tutkimukseen ja heitä haastateltiin kesä-elokuussa 2017. Tutkimuksessa selvisi, että biohiilimarkkinat Suomessa ovat alkaneet muodostua ja yritykset ovat löytäneet useita taloudellisesti kannattavia tapoja hyödyntää biohiiltä. Tällä hetkellä Suomessa on käynnissä tai käynnistymässä useita biohiileen liittyviä projekteja, joissa biohiiltä kokeillaan eläintuotannossa, viljelyssä, kaupunkialueilla, maanparannuksessa ja puutarhasektorilla. On ennustettu, että tulevaisuudessa biohiili tulee olemaan merkittävässä asemassa puutarhasektorilla ja viherrakentamisessa. Erityisesti biohiilen käyttö kompostoinnissa, viherkatoilla, kasvihuoneissa, kasvualustoissa, suodatuksessa ja huleveden hallinnassa nostettiin esille. Tutkimuksessa selvisi, että biohiilen käyttöönottoa edistävät erityisesti sen taloudellinen kannattavuus ja paikallisesti saavutetut hyödyt. Biohiileen käyttöönottoa hidastavia tekijöitä ovat esimerkiksi vähäiset käytännön tutkimustulokset, biohiilen vaihteleva laatu, tietoisuuden puute, biohiilen määritelmien moninaisuus, biohiilen valmistajien rahoituksen puute, sekä puute kehittyneestä ja kohtuuhintaisesta biohiilen tuotantoteknologiasta.

Asiasanat
biohiili, diffuusio, innovaatio, biotalous, ympäristöteknologia, kestävä kehitys, hiilensidonta, ilmastonmuutos

Säilytyspaikka
Jyväskylän yliopiston kauppakorkeakoulu

FIGURES AND TABLES

LIST OF ACRONYMS

CO_2 = Carbon dioxide
EBC = European Biochar Certificate
ETS = Emission trading scheme
EU = European Union
EVIRA = Finnish food safety authority
FBA = Finnish Biochar Association
GHG = Greenhouse gases
Luke = Natural Resource Institute Finland
PAH= Polycyclic aromatic hydrocarbons
REACH= Registration, Evaluation, Authorisation and Restriction of Chemicals
Tekes = Finnish funding agency for innovation
UNFCCC = United Nations Framework Convention on Climate Change

CONTENTS

1 INTRODUCTION

Biochar is a solid product which contains a large amount of carbon and it can be produced from several types of biomass, such as wood, leaves and manure (Lehmann & Joseph, 2009: 1). According to Vuori & Kangas (2017) from a climate and resource point of view, it is preferable to use biomass which is otherwise difficult to be utilized or is considered to be waste, such as small-diameter trees, energy crops, waste from sawmills and other industry side streams.

Biochar has several physicochemical properties which determine its characteristics, such as capability to hold nutrients, air, heavy metals, organic chemicals, and water. Moreover, biochar can also be favourable for microorganisms. The characteristics of biochar can be affected by raw material selection, production conditions, such as temperature and length of the pyrolysis process. In addition, different additives and enrichment processes can be used to adjust the characteristics of biochar depending on its use. (Vuori & Kangas, 2017) According to Schmidt & Wilson (2014), there are over 55 potential uses of biochar. Due to the various potential uses of biochar, researchers believe that biochar applications will significantly increase in the future (Draper, 2016).

Rapidly growing human population and climate change have contributed to several global problems, such as decreasing food security, declining agricultural production, water scarcity and fuel crisis (Komang & Orr, 2016: 5). Biochar can mitigate several of these problems, for instance, biochar can help farmers to increase productivity of farm lands and simultaneously decrease environmental footprint of farming practices by replacing chemical fertilizers, herbicides and pesticides. Moreover, biochar can play role in waste management as different waste materials can be utilized as raw materials for biochar production. In addition, biochar can be used in soil remediation and soil improvement to deal with contaminated and unproductive areas and brownfields. Finally, biochar creates new sustainable industry with economic opportunities which can benefit the whole society. (British Biochar Foundation, 2017) After reviewing existing literature on biochar applications it is apparent that so far, the main research focus has been on pyrolysis-process, characterisation of biochar and potential applications (Appendix I), rather than analysing its market and economic potential.

1.1 Objectives of the research

The aim of this research is to study the current state and future perspectives of biochar applications in Finland. As different stakeholders, such as customers, companies and scientists have only recently begun to explore the economic potential of biochar Finland the published information on that topic is limited. Thus, the objective of this study is to add to the small body of literature on this topic by compiling information from various sources and professionals. The research results will provide a good understanding of the current situation of the biochar market in Finland and are intended to have a positive effect on the overall market development of biochar. The research is conducted in cooperation with the Natural Resources Institute Finland (Luke) and is tailored to meet the organisation's needs.

Main research question:
What is the current state and future perspectives of biochar applications in Finland?

Sub questions:
What are the current challenges in potential biochar application areas and what opportunities biochar can provide?
How does the business environment affect the biochar market and what are the key enabling factors for further market development?

1.2 Definition of biochar

Some of the common definitions of biochar include the definition by Wang et al. (2012):

> *"an umbrella concept which covers all solid thermally degraded biomass products produced in the process of pyrolysis, including torrefaction and hydrothermal carbonization with different features and applications"*

And the definition by the International Biochar Initiative (2012):

> *"Biochar is a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment. Biochar can be used as a product itself or as an ingredient within a blended product, with a range of applications as an agent for soil improvement, improved resource use efficiency, remediation and/or protection against particular environmental pollution, and as an avenue for greenhouse gas (GHG) mitigation."*

The main difference between these two definitions is that the definition by the International Biochar Initiative (2012) excludes combustion of biochar, while the definition by Wang et al.'s (2012) does not. For the purpose of this study, the definition by the International Biochar Initiative (2012) was chosen.

Due to the broad definition of biochar, other terms, such as charcoal, biocoal, torrefied pellets, torrefied wood, green coal, black pellets, biocarbon and black chips are also used in literature. Even though there is no clear difference between these terms, most of them are used in combustion related context. Moreover, companies who sell biochar to end-consumers often promote the product as "terra preta soil" instead of biochar. On the other hand, in Finnish language biochar is usually translated into "biohiili", which in addition to the usual biochar applications, covers also combustion. Therefore, the definition by Wang et al. (2012) is more suited to describe the term "biohiili". In addition to "biohiili", other terms in Finnish language include: puuhiili, grillihiili, TOP-pelletti, and torrefioitu biomassa. Most of these names represent a special type of biochar which is used for combustion.

2 THEORETICAL FRAMEWORK

The first part of this chapter introduces the concept of biochar. It includes sub topics, such as biochar origin, production process, main characteristics, usage, drivers and the current situation of biochar applications in Finland. Biochar introduction is followed by presenting the diffusion of innovation theoretical framework by Rogers (2003), which sheds light on how, why and at what rate the innovation is adopted. The chapter continues with a PESTEL examination of the biochar environment in Finland. The purpose of PESTEL analysis is to investigate the role of the external macro-environment which could be used as guidance in strategic decision-making (Bensoussan & Fleisher, 2012: 187-189).

2.1 Introduction to biochar

Biochar applications as soil amendment starts over 2500 years ago, when biochar was used by native Indians to fertilize small plots of land in highly infertile soils in the Amazon. This technique was known as "Terra Preta" (Wayne, 2012). These Terra Preta soils have been reported to remain exceptionally fertile in comparison to surrounding soils, even after many centuries. This extraordinary finding has brought considerable attention to biochar's capability of long-term microbial activity and carbon sequestration (Komang & Orr, 2016: 3-5). The picture below is from an area in Amazon and it illustrates the significant effect of biochar on soil over time.

Figure 2.1 Terra Preta soil versus usually discovered soil in Amazon (Glaser et al. 2001)

2.1.1 Production

The most common way to produce biochar is the so called *slow pyrolysis* process where biochar is heated in an almost or completely oxygen free environment to 300-700˚C (Lehmann & Joseph, 2009: 1). The optimal temperature for biochar, which is intended to be used as soil amendment is 500-600˚C. When produced in temperatures lower than 500˚C, biochar does not last long in the ground. On the other hand, biochar production in temperatures above 600˚C, will significantly decrease biochar's capability of absorbing and keeping nutrients (Vuori & Kangas, 2017). The main raw material which is used to produce biochar in Finland is wood from forest industry side streams (Tiilikkala 2013, Vuori & Kangas 2017). Other possible raw materials that could be utilized for biochar production are all animal and plant-based materials. For instance, utilization of animal bones and manure for biochar production will result in a type of biochar that contains large quantities of nutrients (Tiilikkala 2013).

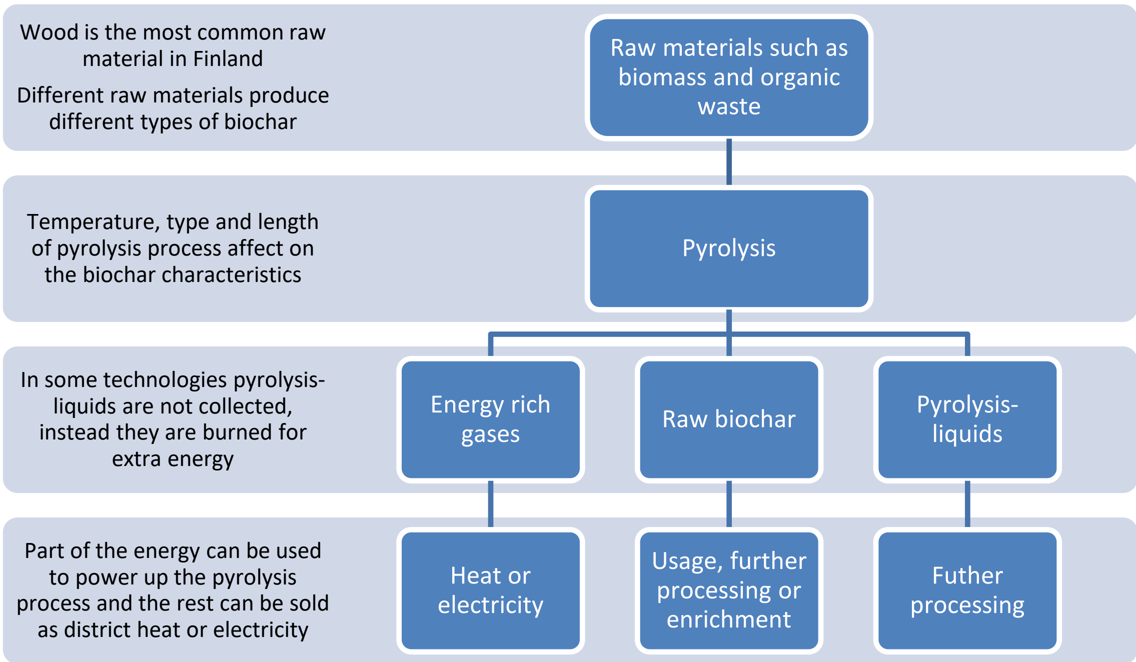

Figure 2.2 Biochar production process and by-products

The figure above illustrates the biochar production process. Biochar is only one of three products from the pyrolysis process, the other two by-products are pyrolysis-liquid and energy rich gas. The type and quality of these by-products significantly depend on the pyrolysis conditions such as biomass, pressure, temperature, time, and heating (Komang & Orr, 2016: 2-3, Vuori & Kangas, 2017). Pyrolysis-liquid can be further processed and utilized as fuels, pesticides, and fertilizers. For instance, pyrolysis-liquid is currently being utilized in production of biodegradable covers, which are used in agriculture. Research results related to herbicide control are very promising. Pyrolysis-liquids from the pyrolysis process have huge potential, but further research is needed before these can be widely utilized. (Vuori & Kangas, 2017)

2.1.2 Characteristics of biochar

Additional physical, chemical or biological activation of biochar upon pyrolysis may be needed in order to improve its properties and further on use in different applications. For instance, biochar could be first used in compost, where it gets enriched from the beneficial nutrients and microbes and later on used as a long-term fertilizer in soil amendment. Other substances that could be used for biochar activation are manure, mycorrhizal, iron oxide and ozone (Vuori & Kangas, 2017). Biochar is often referred as charcoal which is used in soil amendment. However, biochar differs from charcoal in two notable ways. Firstly, charcoal is mainly used for combustion, whereas biochar is designed to be applied to the soil, where it improves soil's properties, stores carbon, or filters percolating soil water (Lehmann & Joseph, 2009:1). Secondly, the aim of biochar production process is to achieve well-developed porosity and absorption capacity which enable interaction between water, nutrients and microbes in the soil. In contrast, charcoal production does not necessarily develop such characteristics, since the product is to be used in combustion. Hence, charcoal production process is unfavourable for biochar production unless it is modified. (Taylor, 2010: 135)

2.1.3 Major drivers of biochar applications

There are several ways to apply biochar and new ways are continuously being discovered. Among the high number of drivers for biochar applications which vary depending on the applications, at least five are recognized by the international community and they are frequently being discussed. These drivers are illustrated in figure 2.3 below.

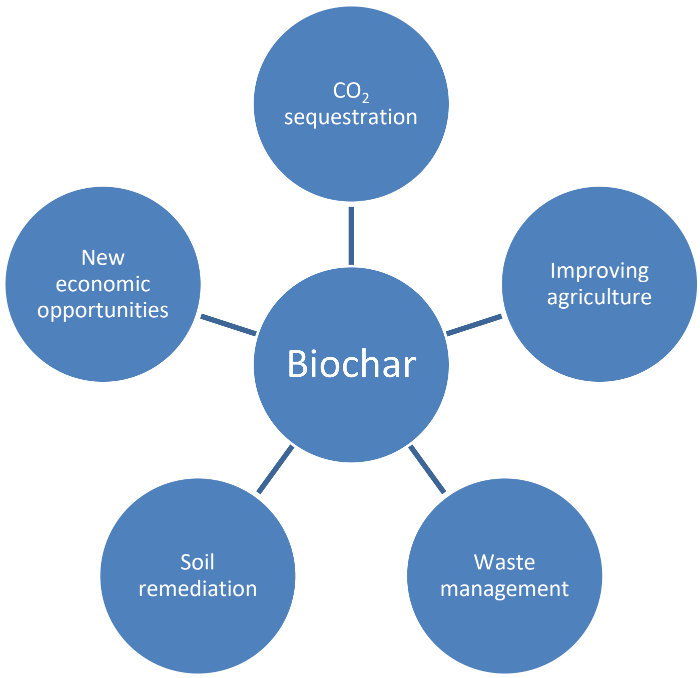

Figure 2.3 Major drivers for biochar applications

1) *CO_2 sequestration*

Biochar helps to mitigating climate change (Lehmann & Joseph, 2009: 5), as when applied to soil, large amount of carbon contained in the biochar is not released back to the atmosphere for 100-3000 years (Tiilikkala 2013, Schmidt & Wilson 2014, International Biochar Initiative 2016). For instance, biochar applications can help governments and local authorities to move towards lower carbon communities and economies while meeting international, national and local GHG emission targets (British Biochar Foundation 2017, Draper 2016). Interestingly, biochars capability to safely store carbon does not provide economic value and thus, it is viewed as added value, rather than as the main purpose of the product (Draper, 2016).

2) *Improving agriculture*

Biochar applications on farmland increases productivity of crops and improves local sustainability, national food security, national commerce and export. Furthermore, biochar helps decreasing the environmental footprint of farming practices, which are considered to have one of the largest environmental footprints on the planet. Additionally, applied biochar reduces the need of chemical fertilizers, herbicides and pesticides. which have negative effect on the environment. (British Biochar Foundation, 2017) Furthermore, biochar applications in animal agriculture, for instance as animal feed supplement is beneficial as it increases herd health for poultry, cattle, fish and hogs and decreases the usage of antibiotics, which have negative impact on environment and human health (Schmidt et al., 2016).

3) *Waste management*

Biochar could be used as a waste management solution, as it effectively utilizes end-of-life biomass, such as forestry and agricultural residues, sewage sludge and animal manure. (British Biochar Foundation 2017, B4SS 2017) For instance, in order to avoid emissions from decomposition of forestry and agricultural waste, this waste could be turned into biochar (International Biochar Initiative, 2016).

4) *Soil remediation*

Biochar could be used to recover contaminated areas and brownfields as it increases soil fertility and improves growth of crops, trees and other flora. In addition, it improves ground's capability of handling drought and flooding. Biochar can also decrease the amount of heavy metals and other pollutants in the soil and prevents them from getting into water bodies. (Schmidt & Wilson 2014, Hagner 2016).

5) New economic opportunities

Biochar creates new markets and industries (British Biochar Foundation, 2017) while providing financial and social benefits (Lehmann & Joseph, 2009: 5). In addition to biochar applications in soil amendment biochar has significant potential in several other applications and allows for different cascading uses. For instance, one scenario in which biochar is first utilized in the water treatment and then applied for soil amendment is currently being experimented by the Ithaka Institute, the Rochester Institute of Technology and Cornell University. So far, the experiments have demonstrated that biochar is not as efficient as activated carbon, but it can play role in waste water treatment (Draper, 2016). Another example of cascading use of biochar is to indirectly apply it to the soil. For instance, researchers believe that biochar can replace significant part of the so-called carbon black, which is used in several products such as tires, rubber shoes, dry batteries, inks and other types of products which are currently disposed in landfills. Adding biochar to these products will not only help in storing carbon but it will also absorb toxins and increase biodegradability in the landfills. (Draper, 2016)

2.1.4 Biochar in Finland

The biochar field in Finland has already been researched for around a decade. Among other topics, biochar research has focused on soil amendment, carbon storing, pollution, effects on soil properties, field trials, green roofs, plant growth, effects on yields, pore structure, chemical and physical properties. The full list of biochar studies published in peer-reviewed journals and related to soil amendment are included in Appendix I

During the last two years biochar has gained considerable amount of media publicity in Finland. The published articles have been related to biochar and climate change mitigation (Kulmala 2016), biochar production benefiting old peat production sites (Niemi 2016), plans to establish new biochar production units to Mikkeli (Kyytsönen 2016) and Parikkala (Väisänen & Kaipainen 2015). Biochar's capability to filter storm water in the urban centres has also gained media publicity and it is one of the key uses of biochar. Currently Luke has ongoing research projects related to biochar and storm water with six Finnish cities: Helsinki, Turku, Jyväskylä, Kaarina, Kuopio and Salo (Ala-Siurua, 2017). There is also an ongoing project related to utilizing biochar in fur farming, where a mixture of peat and biochar is used to significantly decrease the odour, nutrient and GHG pollution. Currently, the manure from fur facilities is considered as hazardous waste. The aim of the project is not only to significantly improve the environmental footprint of the farms, but also to find a way to enrich the biochar which can be later used as organic fertilizer (Tyhtilä, 2016).

In the city of Nurmes, there is an ongoing project to establish green industrial area for sustainable bioeconomy companies in order to help Nurmes to achieve it's carbon neutral targets. The idea of this industrial area is to build highly efficient area where output of one company can be used as input of another. One of the significant actor in this area would be a biorefinery which produces significant amount of pyrolysis-liquids which would be further processed inside the industrial area and biochar/biohiili (Finnish definition, includes biochar utilization in combustion). (Nurmes, 2017) Biochar or biohiili would be used not only to replace coal in combustion but also other applications such as soil amendment. The annual production of this biorefinery in the beginning would be approximately 35 000 – 41 000 thousand kilograms and the capacity could be increased up to 100 000 thousand, the estimated cost of this refinery is around 43 million euros (YVA, 2015). It has been estimated that this biorefinery would directly employ around 30 people. However, the indirect effect of this factory is more significant, as it would contribute to up to 300 more jobs in the area since raw material would be purchased locally, and there would be more jobs related to raw material production, and transportation. In addition, biochar production could create a market and unlock the potential of small diameter trees which currently have low economic value (Haapalainen, 2013).

The current situation with the green industrial area in Nurmes is that at least four companies have moved their operations to the area and more are expected to come (Sievälä, 2017). However, the biorefinery has experienced a delay and has not yet started its operations to the area. The city of Nurmes has also received funding to establish railway connection to the industrial area and improve other logistical infrastructure around, the construction work is planned to be done during 2018 (Kuittinen, 2017). Another biochar production factory which is planned to be established in Mikkeli has been estimated to double the usage of energy crops and small diameter trees. Currently the market for these types of wood has been declining in the region but this factory significantly improves the situation. Moreover, this factory will significantly increase the demand for these types of materials while creating new jobs directly and indirectly. (Vironen, 2016)

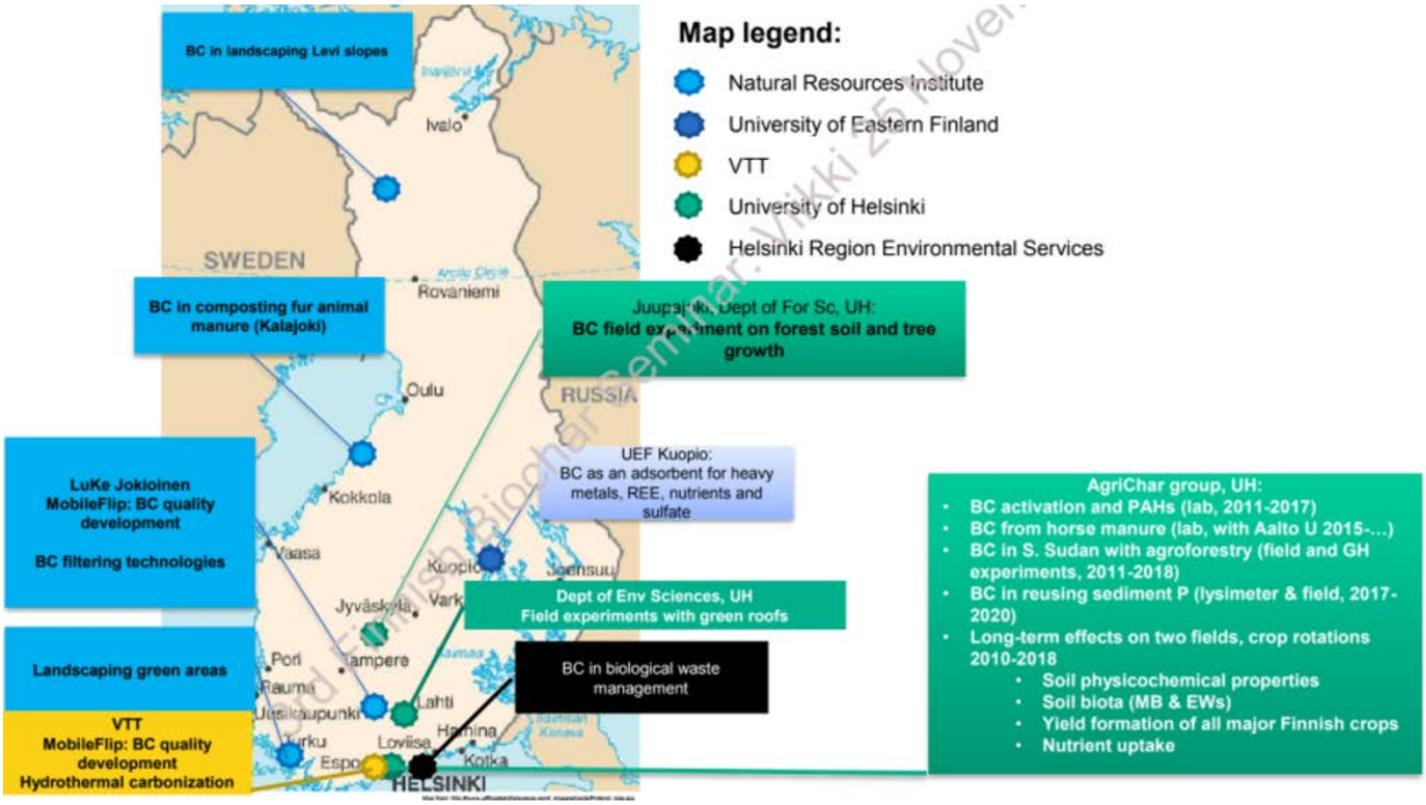

Figure 2.4 Ongoing biochar research in Finland (Tammeorg, 2016).

The map above was presented in the 3rd Finnish Biochar Seminar on 25 November 2016 and it illustrates the ongoing biochar research in Finland.

2.2 Diffusion of innovations

The major challenge related to different innovations is that even if the innovation provides obvious advantages, it might be ignored and not adopted. This is caused by the gap between what is known and what is actually being used. From the time the innovation becomes available it might take a long period of time, even years until it will be widely adopted. (Rogers, 2003: 1) Challenges related to adoption of innovations were already identified long time ago. In 1903 a book named “The Laws of Imitation” was published by Gabriel Tarde, a French judge who observed his society through legal cases. The book aimed at exploring why some innovations in form of industrial processes, mythological ideas or words spread, while other are forgotten. It took several decades until the importance of diffusion research and the work of Gabriel Tarde was recognized. The number of diffusion studies started to increase after Bryce Ryan and Neal Gross (1943) published a diffusion study related to hybrid corn, and the actual break-through in diffusion research happened during 1960s (Rogers, 2003: 43). Currently, the diffusion of innovations theory by Rogers is one of the most widespread and used model to study the innovation process (Sherry & Gibson, 2002).

Rogers (2003) defines diffusion in the following way:

> *"Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas"*

The following four main elements are recognized from the definition of diffusion: *innovation, communication channels, time,* and *social system*. The first element of the definition is *innovation* and it refers to an idea, object or practice which is viewed as new by the potential adopter, no matter of the actual time of discovery. (Rogers, 2003: 11). The second element is *communication channels* and it refers to mass media and interpersonal communication. Mass media channels such as television, radio, and newspaper are more effective in informing larger audience of potential adopters. On the other hand, interpersonal channels, such as face-to-face conversations are more beneficial in creating or changing individual's attitude towards the innovation. In the innovation-decision process, which is described below, mass media channels could be seen as more important in the knowledge stage, while interpersonal channels are more important at the persuasion stage. (Rogers, 2003: 18-19). A "Special type of communication" refers to the conversation which is driven by the newness of the innovation and where communication is based on the information that is exchanged throughout several cycles of communication. This type of conversation could be triggered, for instance in the situation where a consultant recommends an innovation as a possible solution. (Rogers, 2003: 6)

The last two elements of the definition are *time* and *social system*. It is important to consider the time aspect during the diffusion research in order to understand at what rate the innovation might develop. (Rogers, 2003: 20) The social system refers to the innovation stakeholders, such as informal groups, organizations, companies, and individuals. These stakeholders can be unrelated but connected by a joint problem and engaged in solving and achieving a common goal (Rogers, 2003: 23). As the diffusion happens inside a social system, the latter has a great influence on the diffusion process by determining the level of innovation amongst individuals. (Rogers, 2003: 24)

2.2.1 **Innovation-decision process**

The innovation-decision process is a process in which individuals move through five different phases: knowledge, persuasion, decision, implementation, and confirmation. (Rogers 2003: 168). The process is illustrated in the figure below.

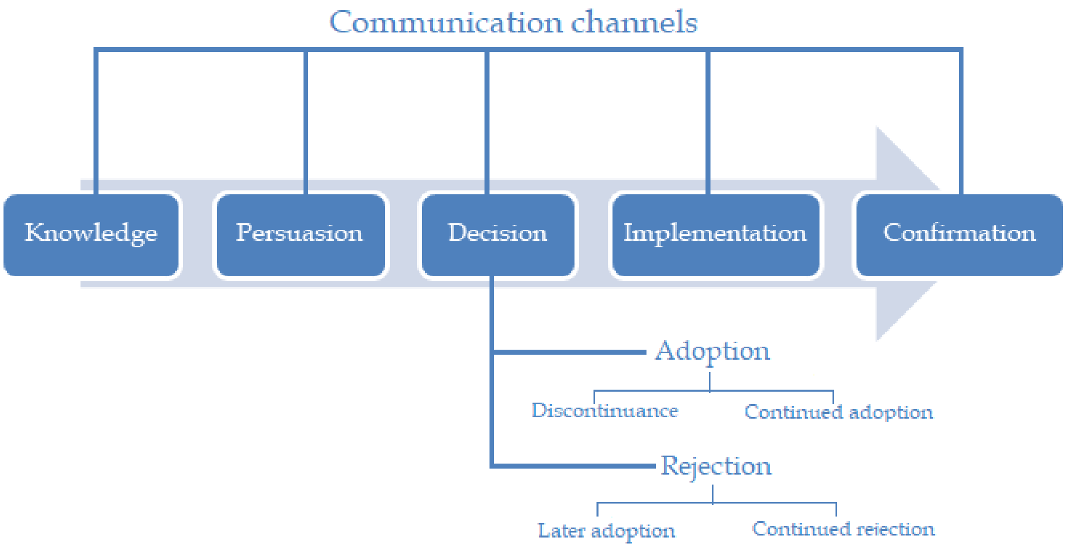

Figure 2.5 Phases of the innovation-decision process (Rogers, 2003: 171)

In the *knowledge phase*, the individual is introduced to the innovation and gain a general knowledge on the subject. There are three types of knowledge which individuals seek. Firstly, awareness-knowledge which is, information related to the existence of the innovation. Secondly, how-to-knowledge, which is, information related to how to correctly use the innovation. Thirdly, principles-knowledge, which is, information related to how the innovation is functioning and why does it work. Providing this information is essential for individuals, in order to avoid misuse of the innovation which can cause discontinuance. (2003: 171)

In the *persuasion phase*, the individual has already gathered general knowledge about the innovation and has formed a positive or a negative attitude towards the innovation. However, the attitude does not automatically lead towards rejection or adoption of the innovation. (Rogers, 2003: 174). During the persuasion phase, the individuals are interested more precisely about the product attributes and they are also dealing with the uncertainty related to the innovation. Individuals beliefs and opinions are highly influenced by social reinforcements, such as colleagues and friend's evaluation.

During the *decision phase*, the individuals choose to either reject or adopt the innovation (Rogers, 2003: 177). Innovations who have the possibility of being tested before making the final decision are adopted more quickly because most of the individuals want to gain personal experience before making the final decision. Rejection of innovation can occur during any of the phases of the innovation-decision process. According to Rogers (2003: 178), there are active and passive rejections. Active rejections refer to the situation where an individual has tried or used the innovation and decided to either not adopt it or discontinue the usage. On the other hand, passive rejections occur when an individual does not even consider adopting the innovation. The phase sequence of the innovation-decision process can also be knowledge-decision-persuasion instead of knowledge-persuasion-decision.

During *implementation phase*, the innovation is put into practice and uncertainty related to the outcomes of the innovation might still pose a threat during this stage. The adopter of the innovation might still require assistance during this stage to decrease the uncertainty related to the consequences. During this stage, the innovation-decision process ends since the innovation is no longer perceived as new. During the implementation phase, reinvention might occur. Reinvention refers to a process where the user of the innovation changes or modifies the innovation during the process (Roger, 2003: 179).

In the *confirmation phase*, the individual has already adopted the innovation and is now looking for support for the made decision. In this phase, the individual is trying to avoid negative and conflicting messages about the innovation, and instead is looking for positive messages which support the made decision. Discontinuance might occur at the confirmation phase for two reasons. Firstly, the individual might find another innovation to replace the current one, and this is called replacement discontinuance. Secondly, the individual might be dissatisfied with the innovation, either because of its performance or because it did not meet the needs of the individual. (Rogers 2003: 189)

2.2.2 **Factors affecting the rate of adoption**

According to Rogers (2003: 230), the innovation-diffusion process can also be described as an uncertainty reduction process. Rogers (2003: 219) identifies five most essential qualities related to uncertainty and innovation: *relative advantage, complexity, compatibility, observability* and *trialability.* These qualities are not just dealing with the uncertainty, but they are also used to predict the rate at which the innovation will get adopted (Rogers 2003: 221). The rate of adoption is defined by the number of individuals that have adopted the innovation during a certain period. The most important quality in determining the rate of adoption is relative advantage. In addition to these qualities, innovation-decision type (decision of innovation made collectively or personally), social system, communication channels, and change agents might contribute to the predictability of the rate of adoption.

Relative advantage investigates how advantageous or necessary the innovation is from individual's perspective. The key factors of relative advantage include affordability, convenience, satisfaction and social-prestige. In some cases, relative advantage is understood as competitive advantage (Rogers 2003: 229). *Complexity* aspect investigates how difficult is for the individuals to understand and use the innovation. Simpler ideas are more frequently adopted than complex ones, which require guidance or new skills. *Compatibility* investigates whether the innovation is compatible with the existing values, needs and past experiences of the potential adopters. Even though compatibility seems similar to relative advantage, it is conceptually different. *Observability* deals with how visible the innovation and the benefits related to it are to other individuals. Good experiences and results from an innovation can stimulate adopters to spread the word and encourage other people to adopt the innovation. The last quality is *trialability* and it refers to the degree to which the innovation can be experimented, for instance, uncertainty related to the innovation can significantly be decreased if the innovation could be tested and experimented with by the individual who is considering adopting the innovation on a larger scale. (Rogers 2003: 240, 257-258)

2.3 Business environment

Business environment could be divided into four different layers. The inner layer is internal environment, which refers to an individual company or an organization. Surrounding the internal environment is the operating or market environment, which refers to markets, such as, competitors, customers, partners, and suppliers. The third environment is the industry or sector. It is formed by all the companies or organizations which produce the same product or service. Last and the broadest environment, surrounding all the other environments is the macro-environment. (Johnson et al, 2008: 54) The figure below illustrates the different layers in the business environment.

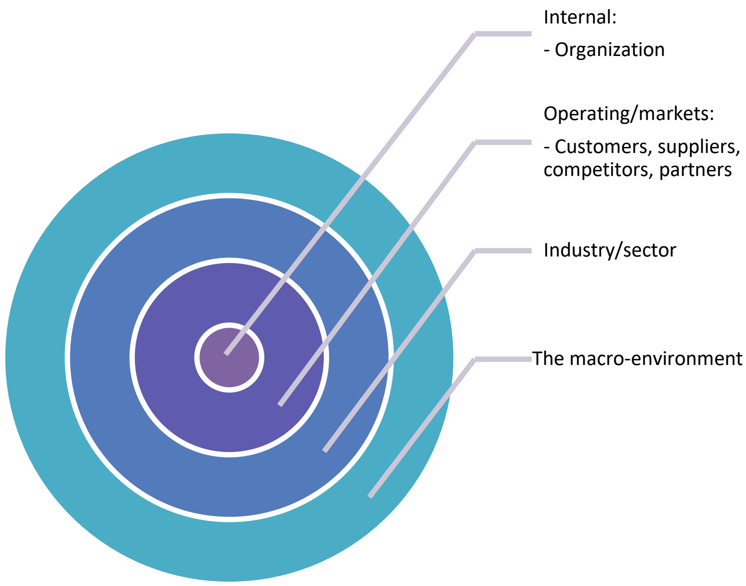

Figure 2.6 Different layers in business environment (Johnson et al, 2008: 54, Bensoussan & Fleisher, 2012: 187)

In this research, the macro-environment will be analysed through PESTEL (political, economic, social, technological, environmental, and legal) analysis. PESTEL is a tool which can be used to recognize key factors which influence competitiveness of industries and companies (Bensoussan & Fleisher, 2012: 187). The political factors refer to the role of governments, while the economic dimension highlights different macro-economic aspects, such as business cycles, exchange rates, and economic growth rates. The social dimension examines factors, such as demographics, culture, and population. On the other hand, the technological aspects in PESTEL refer to the development of e.g. nanotechnology and internet. The last two dimensions are environmental and legal. While the former refers to issues, such as waste and pollution, the latter deals with the investigation of legislation and its influence on companies (Johnson et al, 2008: 55). Thus, PESTEL analysis helps in identifying the key factors influencing companies or industries from the outside. The results of PESTEL analysis can be used in several ways, such as, strategic decision-making and business planning (Bensoussan & Fleisher, 2012: 187-189).

Overview of the biochar business environment in Finland

The political environment for biochar applications in Finland could be viewed as an opportunity rather than a threat. Finland has significant forest resources and the development of bioeconomy, cleantech solutions and circular economy are among the key areas endorsed in the Programme of the Finnish government (Hallituksen strateginen ohjelma, 2015). For instance, the government is paying special attention to different value-added forest-based products which are not only seen as a solution to global problems, but also such products are expected to create new jobs and increase the share of exports. Among the top themes in cleantech solutions are the concept of protecting and improving the environmental status of the Baltic sea by decreasing the pollution from agriculture. However, the global benefits associated with biochar applications are not yet officially recognized by the policymakers. For instance, biochar is neither mentioned in the newly published report "Wood-Based Bioeconomy Solving Global Challenges" (Ministry of Economic Affairs and Employment, 2017), nor are there direct policies to support its consumption (Hagner, 2016).

Hagner (2016) suggests that biochar has a high potential in Finland, especially in composting, soil amendment (natural parks and gardens), agriculture and filter technologies. However, economic viability is highlighted as the main challenge for biochar applications. Biochar does not receive any government support in Finland and is not even recognized within the EU emission trading scheme (EU ETS) as a practice which would mitigate greenhouse gases. Hanger estimates that utilizing biochar at large scale in soil amendment, without governmental intervention is almost certainly economically unprofitable in the current situation.

For harnessing the maximum benefit of biochar in terms of climate change mitigation, it should be officially recognized as a carbon offset product or as a climate change mitigation strategy by UNFCCC and it should also be included under the EU Emission Trading Scheme (Hagner 2016, International Biochar Initiative, 2011). Up to date, the legislation relevant to biochar consumption is scarce. For instance, the whole word biochar does not occur in the fertilizer product legislation, which also concerns soil amendment substances. According to the Finnish food safety authority EVIRA, there has not been insurmountable issues with regulation and biochar. European manufacturers of biochar have jointly created a scientifically based certificate called The European Biochar Certificate or EBC. The certificate aims at monitoring the quality of biochar in terms of heavy metals and PAH compounds. (Vuori & Kangas, 2017)

3 RESEARCH METHODOLOGY

3.1 Research strategy and approach

This research intends to study the current state and future perspectives of biochar applications in Finland. The weight is put on recognition of the main driving factors, challenges, and opportunities for biochar applications. The main challenge throughout the research was the availability of relevant information, as biochar is currently a small but developing field. For this reason, qualitative, semi-structured thematic interviews were conducted at the early stage of the research process. According to Saldana et al. (2011) qualitative research is *"an umbrella term for a wide variety of approaches to and methods for the study of natural social life"*. Qualitative research, such as semi-structured thematic interviews emphasizes words over quantity, it concentrates on inductive approach and aims at generating theory rather than testing it (Bryman & Bell 2011: 27). Semi-structured thematic interviews are usually described as an informal approach which encourages friendly discussion and the objective is to gain insights on interviewees' opinions and views. (Marshall and Rossman, 2006). As suggested by Salmons (2015), the main questions central to the study were initially prepared prior to the interview process, and were later adjusted, so that new follow-up questions were formed based on the responses of the interviewees'. According to Guest et al. (2014), thematic interviews which are conducted at the early stage of the research about little-known phenomenon can also be called exploratory interviews. During the process of exploratory interviews, the interviewer learns more about the topic and develops a better understanding of what questions to ask, how, and from whom to ask them. Therefore, the content of the interviews was driven by what is being learned after each phase. As recommended by Creswell (2013: 32), during the interview process, data collection was done in the participant's setting and it was analysed inductively. The data was then transformed into a more meaningful and relevant form.

3.1.1 Data collection

The potential respondents were invited to participate in the interviews via an e-mail. In case they did not respond back they were contacted by phone after a few days. Seven out of eleven potential respondents answered the e-mail from which one refused to be interviewed. Four out of eleven answered the phone call and the interview was organized through phone. All communication, including the interviews themselves were conducted in Finnish language. In total ten participants in the field of biochar were interviewed for this research. Out of the ten interviews, seven were conducted via video conference, while three were conducted through phone. The length of the interviews varied between 45-70 minutes. Interviews were conducted during June-August 2017.

The interview process started by contacting and interviewing three biochar specialists, they themselves suggested other knowledgeable potential respondents for the research. This method is also known as snowball sampling and it is very useful, especially in situations when it is hard to reach the right people who have the needed information (Patton, 2002). All interviewees were highly cooperative and provided several suggestions for potential interviewees. In order to gain extensive knowledge on the research topic, actors with different roles related to biochar were chosen for the interview, such as biochar producers, consultants, and researchers.

List of the interviewees:
- Researcher at Luke
- Research professor at Luke
- Representative from a project which aims at establishing large scale biochar production unit
- CEO of biochar based environmental technology company
- CEO of a company which is specialized in development of biochar production technology and which is also producing biochar
- CEO of a company which is producing biochar and offering different biochar based solutions, for instance related to infrastructure
- CEO of biochar production company
- Landscape architect specialized in biochar
- Consulting engineer specialized in biochar
- Leader of the biochar research group at the University of Helsinki and Chairman of the Finnish Biochar Association

3.1.2 Content of the thematic interviews

Before the interview process started 3 main and 10 sub themes were formed. Under these themes several essential sub questions were designed. List of themes:
- Business environment of biochar
  - Political
  - Economic
  - Social
  - Technological
  - Environmental
  - Legal
- Current state and diffusion of biochar
  - Competitive advantage
  - Complexity
  - Trialability
  - Observability
- Suggestions for improvements

In the invitation e-mail which was sent to the interviewees, these themes were highlighted as a content for the interviews. Moreover, it was emphasized that the interview process is flexible and that interviewees are free to express their views related to these themes and that there is no certain amount of questions which will be asked. Before the start of the interviews, each respondent was briefed on the objectives of the research. The content of the interview was constantly adjusted during the interview process and new follow-up questions were formed. The following three main factors determined the selection of questions for each participant: already gathered answers, the background and knowledge of the interviewee. This approach allowed for a broad data collection, while recognizing the key points and simultaneously deepen the knowledge of these key points.

3.1.3 Data analysis

Major challenge in qualitative research is the handling and analysing the large amount of collected data (Bryman & Bell, 2011: 572). According to Miles (1979), qualitative data can be described as an "attractive nuisance" because the data is valuable and attractive but highly difficult to be analysed. One of the most popular ways to analyse qualitative data is through conducting a thematic analysis. According to Bryman & Bell (2011: 571) thematic analysis is rather vague definition as searching themes as an activity can be found in several different qualitative data analysis approaches. Furthermore, Bryman & Bell (2011: 571-572) suggests that business researchers often refer to coding when they talk about thematic analysis. Thus, thematic analysis, or coding was chosen for the data analysis in this study.

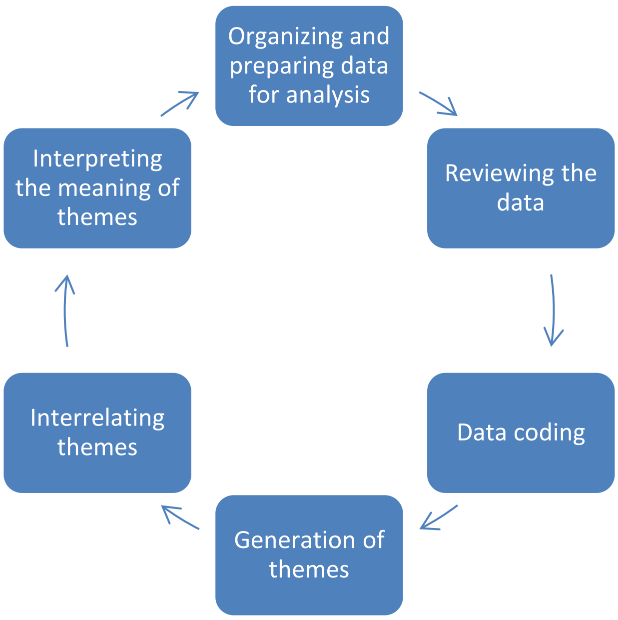

Figure 3.1 Process of data analysis (Creswell, 2013: 197-201)

The figure above illustrates the process of data analysis used in the current study. The process began with *organizing and preparing the data for analysis* through translation and transcription of the interviews. The second step was *reviewing the data* and it involved reading through the gathered data in order to form a general understanding on the data and its overall meaning. In the third step *data coding*, chucks of data were highlighted by key words, which represented certain categories. The fourth step was *generation of themes,* where coded data was categorized into themes, which were formed prior the interview or into newly formed themes. During the fifth step *interrelating themes,* the description of themes was advanced and divided into topics, which can be found from the next chapter, 4 Research findings. In the final step - *interpreting the meaning of themes,* the author has analysed and interpreted the most important aspects of the study, which are presented in Chapter 5 Conclusions. (Creswell, 2013: 197-201)

4 RESEARCH FINDINGS

According to the research findings, the first biochar samples for research purposes in Finland were provided already in the end of the 2000s to different research institutes and universities. Since then, there has been a continuous improvement in the biochar field and the demand for biochar has gradually increased. However, the increase has been significant in percentages rather than quantities. Some of the respondents suggested that Finland should take the role of a producer and an exporter as biochar offers significant export opportunities. It was further indicated that during 2017, a Finnish biochar company BioCore Oy (former RPK Hiili Oy) has delivered considerable amounts of biochar not only to the Finnish market but also to the Swedish markets. For instance, the city of Stockholm is currently using around 1000-1500 tonnes of biochar annually in several projects related to green building and storm water management. The city alone is one of the most significant purchasers of biochar produced in Finland. However, the interviewees pointed out that the benefits of biochar applications in Stockholm are based on the statements made by the city rather than on scientific evidence.

The interviewees highlighted that the active advertisement of biochar applications by the city of Stockholm has increased the interest of Finnish municipalities in possible biochar applications. Even though the respondents emphasized that biochar applications are still in an experimental phase in Finland, there are strong signs that the demand will grow significantly. For instance, increased awareness amongst Finnish municipalities has not only brought some new projects but has also lead to renegotiation of existing projects in a way that biochar is included. The interviewees identified lack of credible and practical research results related to certain biochar applications in Finland as the main obstacle for wider biochar utilization. According to the research findings, there is a need for research in practical environment on biochar applications in stormwater and urban runoff management and seedbeds. Thus, it could be concluded that availability of practical research results would significantly reduce the uncertainty related to biochar and contribute to its widespread utilization.

According to the research findings the drivers for biochar applications vary according to the type of application. Currently, biochar applications in Finland are based on different experiments and trials in agriculture, gardening, green building, soil amendment, water treatment, and mining industry. The interviewees pointed out that the biochar consumption in Finland is generally low, as the market for biochar in Finland is currently developing. The findings suggest that in the future, biochar will achieve a strong position in the gardening and green building sectors; specifically, the areas of composting, green roofs, seedbeds, filtering and managing storm water and urban runoff. For instance, in the consumer market, there are already several products which include biochar. These products are related to composting, seedbeds, planting soil, and summer flower soil. Even though they contain different amounts of biochar, they might not be advertised as biochar. Another quality of biochar is speeding up the composting process and simultaneously improving the quality of compost, which is also enriching the biochar with nitrogen, phosphorous and microbes. The compost could further be utilized as a long-lasting fertilizer.

4.1 Biochar applications in Finland

According to the interviewees, the potential biochar applications in Finland could be categorized into four areas: animal agriculture, cultivation, soil and gardening and urban areas. The main drivers for biochar applications are related to locally achieved benefits and economic feasibility.

Animal agriculture

Biochar can be used in several ways in animal agriculture. For instance, in litter bedding, biochar can be first used to absorb nutrients and decrease odour and then applied as a long-lasting soil fertilizer. In some cases, animal manure is considered to be hazardous waste and it is seen as a cost and a liability. By adding biochar to this manure, for example, through litter bedding, this manure would enrich biochar and turn it into a valuable soil fertilizer. Another way to utilize biochar in animal agriculture is to apply it in outdoor areas, where it acts as a sponge and prevents the nutrient pollution created by the animals to be washed into water bodies. According to the research findings, using biochar as an animal feed supplement is extremely beneficial as it improves the digestive system of the animals, prevents different livestock diseases and decreases the usage of antibiotics.

Cultivation

The interviewees underlined the connection between continuous farming practices in Finland with the decreased carbon content in the fields, which in turn has contributed to increasing the usage of chemical fertilizers. The pollution problem could be alleviated by increasing the usage of biochar in agriculture, however in some cases, the cost of biochar poses an obstacle for the widespread utilization. The interviewees underlined the connection between continuous farming practices in Finland with the decreased carbon content in the fields, which in turn has contributed to increasing the usage of chemical fertilizers. Utilizing biochar on the fields for few years would not only recover their carbon content and decrease the consumption of fertilizers, but it would also decrease the amount of nutrients escaping to water bodies. In addition, catching escaping nutrients with biochar application to farm lands was outlined as an excellent way to enrich the biochar, which could later be returned to the fields and used as long-lasting fertilizer.

Moreover, applying biochar to greenhouses is on the rise because it is cost-effective and economically feasible.

Soil and gardening

Some of the respondents emphasized the importance of biochar applications in rural areas and forests, where biochar can be used to improve poorly growing forests, cleaning contaminated land and recover unproductive and/or abandoned lands. Biochar applications in such areas would not only store carbon in the soil, but it would also increase the carbon sinks of forests. For instance, old peat production sites are continuously releasing CO_2 to the atmosphere. By utilizing biochar-based solutions on old peat production sites will not only have environmental benefits, such as decreasing CO_2 emissions, but also economic value, as the nutrients added to the soil will enable the old peat fields to be put back in use, for example, for growing crops such as willow. However, large areas of soil require high quantities of biochar, which drives the costs upwards and currently it is one of the barriers related to biochar applications on lands.

According to the research findings, biochar can be used for soil improvement and compost additive in the gardening sector. Adding around 3-7 percent of biochar to the compost, biochar decreases the nitrogen levels, improves the quality of compost and speeds up the composting process. After the process, the compost can be applied as a long-lasting fertilizer for soil improvement.

In addition, the interviewees pointed out the role biochar could play in decreasing the environmental impacts of mining operations, such as gold extraction. Biochar is capable of filtering waters in the soil and it could be used for filtering mining waters. It can also be utilized in landscaping old mining areas.

Urban areas

As the leading reasons for the interest of Finnish municipalities in biochar applications, the respondents pointed out biochar capability in filtering storm water and its associated benefits in green building. For instance, by utilizing biochar in trees' seedbeds, municipalities are able to increase the lifetime of the trees and decrease the maintenance cost. Renewing trees in the urban centres can cost up to several thousands of euros per tree. Moreover, when biochar is applied in seedbeds, not only will its ability to absorb nutrients be enhanced but it will also make the whole structure of the seedbed stronger and longer lasting. Biochar can also be used as an important component in building green roofs, where it reduces the weight of the structure while increasing the absorption of nutrients and water.

Increasing precipitation due to climate change and urbanisation are brining several new problems to the society, such as flooding, storm water and urban runoff, which overload the sewage systems and waste water treatment facilities. As highlighted by the respondents, solving these problems by rebuilding the sewage system or increasing the capacity of water treatment facilities is complicated, expensive and unsustainable. With biochar-based solutions, not only it is possible to ecologically solve these problems, but also to benefit from them by increasing the green areas in the cities and creating more pleasant living conditions. The interviewees acknowledged that there are currently several biochar related projects across Finland and most of the largest cities are participating. They also emphasized that the scale of the projects starts to be quite significant, for instance, an area of around 100 trees, green areas or one to three-hundred-meter-long street in the city.

The interviewees highlighted that in certain applications, biochar is utilized together with potentially unsustainable products. For instance, in green building, biochar might be used in a mixture cement, macadam, or other materials which can cause negative environmental impacts. However, researchers who are currently investigating biochar capabilities in green building are mostly using recycled or waste materials which can be viewed beneficial from environmental point of view. The table below summarises the potential biochar application areas in Finland, the current challenges these areas are facing (without the application of biochar), and the benefits and opportunities biochar applications can provide.

Application area	**Current challenges of the application area**	**Benefits and opportunities of utilizing biochar in the application area**
Animal agriculture	- Livestock diseases - Odour - Leaking nutrients - GHG pollution	- Increasing wellbeing of animals - Decreasing environmental impacts such as GHG and odour - Utilizing manure and leaking nutrients to enrich biochar - Decreasing the need of antibiotics
Cultivation	- Chemical fertilizers - Eutrophication - Drought and flooding - Decreasing carbon content on the fields	- Decreasing the need for chemical fertilizers - Recovering and improving fields - Decreasing the environmental impact - Recycling nutrients - Balancing water levels - Increasing crop yields
Soil and gardening	- Contaminated and abandoned land - Poorly growing forest - Unproductive land	- Decreasing environmental impacts of mining operations - Improving lands, increasing growth and carbon sinks
Urban areas	- Stormwater and urban runoff problems - Maintenance costs related to trees, parks, and other green areas in the cities	- Managing stormwater and urban runoff biologically - Decreasing flooding - Increasing green areas and the number of trees in urban centres

Table 4.1 Benefits and opportunities of utilizing biochar in certain application areas

4.2 Business environment of biochar in Finland

4.2.1 PESTEL analysis

Political and legal

In the current situation, political and legal environments are not perceived by the respondents as factors which would significantly prevent the overall development of biochar market in Finland. On the other hand, it was mentioned that in some specific situations political and legal environment might create barriers. For instance, even though Finnish municipalities are highly interested towards biochar applications, they might have to go through long and slow decision-making process and it might take up to several years until the decision is done. It was highlighted that the Finnish Food Safety Authority (EVIRA) has allowed biochar applications in food production. Moreover, biochar can be freely used in composting and according to EU legislation it does not require special standardizing. In addition, rapid innovation in the biochar concept is outpacing current legislation and leaving gaps both on a national and international scale.

The interviewees noted that biochar produced from animal manure does not currently have a market permit in Finland as companies have not even applied for such a permit. Concerns were also raised in relation to the potential impact of REACH regulation on biochar, since officials in Finland have not made official statement about how this regulation affects biochar applications. For example, in Sweden and the United Kingdom, the officials have stated that biochar is an organic soil conditioner and it is exempted from the REACH regulation. Another concern identified by the respondents is the fertilizer legislation, as certain biochar enrichment processes might increase the level of polycyclic aromatic hydrocarbons (PAHs).

The main legislative barriers identified by the interviewees are related to the commercialization of pyrolysis-liquids. Pyrolysis-liquids are by-products of biochar production process and are currently categorized as artificial toxins under the EU's Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) -regulation. The respondents underlined that outside the EU, pyrolysis-liquid based products are already on the market. For instance, in Australia such products are used as herbicide in farming and as insect repellent, in Asia and North-America there are different pyrolysis-oil based product on the market as well.

Nevertheless, in some cases, legislation might motivate biochar applications. For instance, agricultural subsidies require that cows have access to certain amount of land and these areas should be secured in a way that environmental pollution is avoided. This is a good example on how agriculture subsidies can indirectly motivate biochar applications. Another possibility is for biochar manufacturers to apply for investment subsidy for biochar production unit from Finnish Funding Agency for Innovation Tekes. The funding can be up to around 30% of the total investment, but it might take over a year before a decision is reached. Currently, there are no direct subsidies related to the utilization or production of biochar. The respondents highlighted that the lack of subsidies is not an obstacle for biochar business as biochar production is profitable even without subsidies, however it is limiting the utilization of biochar. For instance, it is not feasible to utilize biochar in farming of certain crops, such as wheat. On the other hand, utilization of biochar for more valuable crops, such as strawberries is economically feasible in the current situation.

Economic

The research findings revealed that currently the global biochar market measured in kilograms is around one million tons and it is growing around 20-30 percent annually. Even though the Finnish biochar market is estimated at one thousand tons annually, this number includes also biochar used for combustion. Out of the total amount, only around 20% of the biochar in Finland is used for soil amendment. On the other hand, within Finland the demand for biochar exceeds current production capabilities. This situation has lead the price of biochar to increase to around 700-800 euro per ton when it used to be 300-400 euro. Furthermore, based on the plans and projects related to biochar in Finland, it is evident that the market of biochar in Finland will grow. In 2016 the demand for biochar has exceeded the production mainly due to an increase in the amount of different experiments. However, both, demand and production of biochar are relatively small currently. According to the respondents, the biochar market in Finland will increase at least 10-fold during the next 5 years, which would not be as significant as it sounds. According to the research findings, there will be a clear increase in the biochar production in Finland already during 2018 by at least 10 000 tonnes /annually as more production has been planned to be established during 2018 and 2019. Furthermore, a sudden sharp increase in demand can be expected if a major industry such as mining adopts biochar.

The respondents highlighted that in addition to domestic markets, biochar offers significant export opportunities and there is a large demand for Finnish biochar internationally. The abundance of high quality raw materials for biochar production in Finland at a very competitive price, makes it economically profitable to export the product for instance to Central Europe, where even after transportation costs the biochar price will still be highly competitive. It was also highlighted that biochar could potentially be exported even beyond Europe to Africa and

Asia as biochar properties are especially visible on sandy soils, where the major problems are drought and lack of nutrients.

Currently, Finland is exporting various semi-processed biomass products with limited economic value, such as pulp. The development of the biochar market can significantly increase the economic value of Finnish forest reserves. For instance, due to the currently low economic value of certain wood types (energy crops and small diameter trees), the majority of forests owners utilizing their forests for economic purposes, feel that they do not receive a fair compensation. However, if biochar production increases, it would also increase the price of these wood types and higher the overall value of forest resources. The starting price of biochar is already multiple times higher than pulp, while enriched and different special grades of biochar can be tens of times more valuable than pulp. Moreover, the value chain of the forest industry is not only a source of income for the Finnish government, but also it is a major employer especially in rural areas, where job creation is usually challenging.

Social

The research findings revealed that currently biochar has high social acceptance rates in Finland, and there have not been any issues in this aspect. Society's attitude towards biochar is described by the respondents as either positive or neutral. However, it was highlighted by the respondents that the general knowledge of biochar in Finland is still very low, as there are only few decision makers who are familiar and interested in the concept of biochar, while different environmental organizations have not yet expressed their opinion. Nevertheless, the increasing media publicity and different biochar related projects are raising public awareness. For instance, some of the respondents mentioned that during summer of 2017 biochar was actively marketed in various events across Finland and it has been estimated that currently around 100 000 people in Finland are aware of biochar. According to the research findings, it will take around 3-5 years until the concept of biochar will be widely understood in Finland.

Lack of awareness of existing biochar producers was identified as a problem potential biochar adopters face. For instance, one significant international consulting company which is also operating in Finland has struggled to find biochar producers in Finland. One way to overcome this barrier and improve the flow of information is for biochar producers to invest in marketing and provide reliable and extensive information about their operations, environmental impacts, and types of biochar they offer. Respondents representing Finnish biochar production companies stated that they are planning to significantly increase the availability of information related to their biochar products and invest in marketing.

Technological

The choice of technology for biochar production has a significant effect on the overall profitability. According to the respondents, biochar manufacturers are required to provide a wide category of several types of biochar in order to survive on the biochar market in long run. This requires sophisticated biochar production technology capable of producing several types of biochar for different uses, in large quantities, efficiently, and without compromising the quality. Moreover, manufactures are required to have access to a wide range of raw materials and possess extensive knowledge of biochar enrichment processes. In addition, the manufacturers should be able to utilize the by-products of biochar production process. For instance, commercialization of pyrolysis-liquids would significantly affect the cost structure of biochar production and decrease the price of biochar, making it possible to be used in areas where the price is currently the only obstacle.

The research findings indicate that currently the market is missing affordable biochar production technology which can efficiently produce high quality biochar. One reason for this is that there is still lack of research related to biochar as a product and those who develop the technology are unsure about what kind of technology exactly is required. The current available biochar production technologies differ significantly from each other, and it is unclear which one is the best. Biochar production machinery capable of producing large amounts of biochar is very expensive and the cost range is from several millions to tens of millions of euros. In addition to the technology, various types of biomass, such as energy crops and specific wood species produce very different biochar. Thus, the respondents highlighted the importance of knowing the end use of the biochar prior to the production process. In that way, the feedstock could be adjusted according to customer's needs which will also regulate the price.

According to the research findings, current biochar technology is often a modified and improved version of existing charcoal production technology. Even though production technology can still be developed, it was not considered to cause significant short-term risks to the current biochar producers. Lower amounts of biochar can also be produced by different alternative methods, for instance by using Kon-Tiki, which is a type of fireplace which pyrolyzes biomass into biochar. Different alternative methods to produce biochar have been used around the world for centuries. In developing countries these alternative methods offer inexpensive way to produce biochar which can be used in cultivation and soil improvement. Even though some good results have been achieved with these alternative methods there are still some challenges, such as environmental sustainability, varying quality of biochar and utilization of by-products.

Environmental

According to the interviewees, biochar applications are associated with significant environmental benefits. For instance, biochar production is environmentally friendly if pyrolysis-liquids are collected during the production process, excess energy is utilized and gases from the pyrolysis are prevented from releasing in the atmosphere. Moreover, in Finland there are several sustainable sources of raw materials for the production of biochar, such as side streams of forest industry, energy crops, and other biomass which are currently viewed as waste and have no economic value. Higher demand for biochar would not only increase the value of these raw materials and create new markets for them, but it will also encourage forest owners to maintain and clean their forests as brushwood and other small diameter trees would have an economic value. Thus, the respondents concluded that biochar production in Finland is environmentally sustainable.

According to the research findings, life cycle assessment is an important tool when assessing the environmental footprint of biochar production. Biochar's environmental benefits are related to nutrients recycling, climate change mitigation and adaptation. In addition, biochar can play a role in circular economy, for example in waste management.

Respondents highlighted that certain ways of utilizing biochar provide significant environmental benefits but are hardly economically viable. For instance, these include but are not limited to CO_2 sequestration by utilizing high quantities of biochar in soil, improving water bodies contributing to a cleaner Baltic sea, and recovering abandoned lands, such as peat production areas which continuously release CO_2 to the atmosphere. Thus, by providing financial support, governmental and regional actors could enable these biochar applications and simultaneously contribute for the achievement of various climate and environmental targets.

Table 4.2 below summarises the key points of the conducted PESTEL analysis.

PESTEL	Challenges	Drivers	Comments
Political	- Slow decision making - Finnish officials have not made official statement about whether biochar is affected by the REACH regulation	- Municipalities are interested in biochar applications	- Political environment does not significantly prevent the overall market development
Economic	- Commercial biochar production requires large investments	- Availability of inexpensive raw materials - Increasing the value of forest resources - Driving economic growth and job creation - Export opportunities - Economic potential of biochar by-products	- It has been suggested that Finland will have a role of a biochar producer and exporter
Social	- Lack of awareness of biochar	- Increasing awareness through media publicity, biochar projects and marketing activities	- Environmental organisations have not taken a stand about biochar yet
Technological	- Lack of affordable and efficient biochar technology on the market - Varying quality of biochar - Barriers for technology producers due to lack of biochar related research	- Growing body of biochar related research - Increasing demand of biochar accelerates the development of biochar production technology	- Biochar production technology should be adjustable and operational on several different raw materials
Environmental	- Environmental impacts of uncertified biochar - Certain biochar applications which can produce significant environmental benefits are not economically feasible	- Sustainable production of biochar - Biochar can play a role in waste management as it can be produced from different organic materials - Certain biochar applications contribute for the achievement of climate and environmental targets	- Subsidies or other economic instruments are required in order to enable certain biochar applications and maximise the climate and environmental benefits related to it
Legal	- REACH regulation preventing commercialization of pyrolysis-liquids - Certain enrichment processes of biochar	- Biochar applications approved in food production and composting - Market for pyrolysis-liquids based products outside the EU	- The legal environment does not significantly prevent the overall market development

Table 4.2 Summary of PESTEL analysis

4.2.2 Enabling factors for biochar market development

Financing

Despite the growing demand and positive prospects of biochar, one of the main barriers underlined by the respondents is the availability of external funding for the biochar producers. The research findings indicate that the lack of funding has considerably slowed the development of the Finnish biochar market. Support from policymakers was also indicated as a key enabling factor given the fact that the biochar market is still emerging, and it is difficult for biochar producers to obtain loans or attract investors. For instance, the government could support Finnish biochar companies, all of which are currently SMEs, through financial instruments, such us governmental loans or investment subsidies.

Standardisation

The respondents underlined that even though the concept of biochar is easy to explain and understand, there is a possibility that improper usage of biochar could result in a negative outcome. Among the factors listed by the interviewees are wrong type of biochar, poor quality of biochar, misuse by the user, or external factors related to the specific usage of biochar. For instance, there is a high risk in applying biochar on fields during spring season as it might absorb large amounts of water and nitrogen and make the soil unfavourable for growing any plants. In the current market situation, one of the challenging factors pointed out by the respondents is the need to familiarize oneself with each biochar manufacturer as the biochar quality varies significantly depending on the production method. According to the research findings, possible solution to that problem would be the introduction of several new usage-specific standards similar to the European Biochar Certificate (EBC). Having biochar standards and certificates in place will not only facilitate and simplify the process of purchasing biochar, but it will also ensure safe usage and guarantee high quality and sustainable production. Furthermore, compliance and adoption of biochar standards, such as EBC would drive the technological development of efficient biochar production equipment and proper utilization of by-products.

Practical experience

According to the research findings, the current utilization of biochar is primarily owing to the excitement and adventurous spirit of various innovators in Finland, such as researchers and other curious people, who are utilizing biochar for experimental purposes. Such an experimental attitude is a win-win scenario both for the biochar producers and users. By actively searching for pilot customers who are willing to experiment with biochar, the manufacturers can significantly reduce the uncertainty related to their biochar and the customer gets a chance to test the product before making the final buying decision. The testing time varies depending on the biochar applications and while in some cases, the results are visible almost immediately for instance, in soils ability to absorb water, sandy seedbeds, nutrients absorption, increase of microbes, in others, such as, modifying soil properties and increasing yields, it might take several years until the desired results are achieved. The interviewees pointed out that currently there are several large ongoing projects related to biochar applications with different industries and it is very likely that these projects have the potential to drive a large-scale adoption and future demand for biochar.

In order to improve the situation, interviewees suggested that the public sector, for instance, municipalities, would take an active role by increasingly participating in different pilot projects and experiments. Not only this would guarantee certain level of demand for biochar producers, but it would also provide valuable experience and encourage other actors to adopt biochar. Furthermore, the respondents emphasized the importance of collaboration in various biochar projects between municipalities, companies and researcher. Such collaborations would enable researchers to actively participate in the project planning phase and collect valuable scientific information about applications, as there is still a lot to be understood about biochar from scientific point of view. Companies would benefit as all statements about the biochar qualities would be validated by research institutes and/or universities. It was further highlighted that scientists can also work confidentially and only validate the results. Biochar applications which are done in a real environment instead of a test environment are seen significantly more credible. Thus, enabling collaborations between biochar researchers and municipalities and/or companies creates a win-win situation for all the parties involved and contributes to the biochar market development.

Scientific research

The respondents emphasized that even though there is a considerable amount of existing biochar research, the field is so broad that there is still a great need for further research related to identified biochar characteristics, biochar enrichment process, and biochar absorbing properties, in particular nutrient absorption of phosphor, heavy metals, nitrogen and pesticides. In addition, research related to biochar technology and market research is also required. Availability of scientific research results would significantly contribute to the biochar market development. For instance, it was highlighted by the respondents that Finnish authorities require extensive studies related to pyrolysis-oil before it can be utilized in sectors other than combustion. These studies are very costly, as the price might reach several hundreds of thousands or even millions of euros. Even though Finnish biochar companies are already funding several research projects, their resources are limited as they are currently SME's and the market of biochar is just emerging. It was further indicated that policymakers could assist through financial support or by increasing funding related to biochar research.

Internationally, the biochar field is continuously developing and in the past three years significant amount of information related to best practices of biochar application has been published. The respondents highlighted that certain research results from other countries could be utilized as a basis for the biochar applications in Finland as well.

Clear and well-communicated definition

Another challenging factor identified by the respondents is the ambiguous definition of biochar. In Finnish language, biochar is known as "biohiili", however, the term "biohiili" has much broader definition than the English term biochar and causes several misunderstandings, as it is often connected as a type of wood which is used for combustion, which is not the purpose of biochar. Hence, there is a strong need to develop the terminology of biochar in a way that it could be easily connected to the right application and communicated without causing misunderstandings. The recently established Finnish Biochar Association (FBA) attempts to bring clarity to the market actors by welcoming everyone interested in the topic of biochar to join the association. As part of its operations, FBA is organizing different events, such as workshops, which are more practical and aim at educating people about biochar applications, and seminars, which have more scientific approach. The web-page of FBA[1], acts as a database for information related to biochar. Thus, FBA plays an important role in increasing biochar awareness and communicating clearly the concept of biochar through publications in various channels, such as mass media channels, corporate web sites and social media.

[1] www.suomenbiohiili.info

The table 4.3 below summarises the key points of the enabling factors for biochar market development

Factors	Challenges	Opportunities	Suggested incentives
Financing	- Companies struggle to get funding	- Investing opportunities	- Governmental loans or investment subsidies
Standardisation	- Varying quality of uncertified biochar - Improper usage of biochar	- Standards such as International Biochar Initiative (IBI) and European Biochar Certificate (EBC) can help in ensuring the quality, sustainability and proper use of biochar	- Developing new, application specific standards
Practical experience	- Lack of practical experience related to biochar applications - Certain biochar experiments take years to be completed	- Decreasing uncertainty through finding innovators to experience with biochar applications - Scientific validation of practical experiences	- Public sector could contribute to the market development by increasingly participating in different pilot projects and experiments - Stakeholder collaboration
Scientific research	- Great need for further scientific research - The cost of research required for commercialization of pyrolysis-liquids	- Internationally recognized research results - Research can contribute to the market development of biochar	- Support from the policymakers for conducting biochar research
Clear and well-communicated definition	- Complexity and broadness of Finnish biochar definition "biohiili"	- Clearly communicating the biochar concept and definition through the activities and publications of the Finnish Biochar Association	- Increasing the awareness of biochar by utilizing mass media channels

Table 4.3 Factors influencing the development of biochar industry

5 CONCLUSIONS

5.1 Summary of the study

The main purpose of this study is to explore the current state and future perspectives of biochar applications in Finland through investigating the main drivers, challenges, business environment and key enabling factors for biochar market development. The data for this study was collected through qualitative thematic interviews. In total ten biochar experts with different backgrounds were interviewed. Biochar has already been researched in Finland for around a decade but only recently its economic potential has been discovered and the market of biochar has started to emerge. 2017 has been reported to be the first year when considerable quantities of biochar have been utilized in Finland and during the next five years the utilization of biochar is estimated to experience a rapid growth. According to the research findings, there will be a clear increase in the biochar production in Finland already during 2018 by at least 10 000 tonnes /annually as more production has been planned to be established during 2018 and 2019.

Despite the expected growth, the interviewees pointed out that the current biochar consumption in Finland is generally low and is mainly driven by different trials and experiments by innovators and researchers. Thus, it is not the biochar consumption in Finland which the domestic biochar producers are relying on, but the significant export opportunities. For instance, the city of Stockholm has already a long history in biochar applications and is currently not only recognized as one of the major purchasers of biochar produced in Finland, but also as a forerunner in the adoption of different biochar applications. According to the research findings, the promotion of biochar applications by the city of Stockholm in the form of instruction guidelines and guided tours has significantly contributed towards increased interest from Finnish municipalities in different biochar applications. However, the benefits associated with biochar application in Stockholm are not scientifically approved due to the lack of proper research. Currently in Finland, municipalities, companies, universities and institutes are having increasing number of projects and research related to biochar applications in various fields such as: animal agriculture, cultivation, soil and gardening, and urban areas. The research findings suggest that in the future biochar will achieve a strong position in the gardening and green building sectors, in particular in composting, green roofs, seedbeds, filtering and managing storm water and urban runoff.

The political and legal environments are not perceived by the respondents as factors which would significantly prevent the overall development of biochar market in Finland. The main legislative barriers are related to utilization of pyrolysis-liquid, which is the by-product of biochar production process. Even though the potential of pyrolysis-liquid in several applications was greatly highlighted during the interviews, authorities require an extensive amount of research before a wider commercialization could be considered. In addition, certain biochar enrichment processes might be affected and limited by the fertilizer legislation.

Findings related to the technological environment suggest that there is a great demand for sophisticated, affordable and efficient biochar production technology. The choice of technology for biochar production has a significant effect on the overall profitability. According to the respondents, biochar manufacturers are required to provide a wide category of several types of biochar in order to survive on the biochar market in the long run. This sets a requirement for biochar technology that is able to process several different raw materials in controlled and monitored environment, while utilizing the by-products, such as excess energy and pyrolysis-liquid. However, it was pointed out that the lack of research of biochar as a product creates limits for biochar technology companies to design the right technology.

The research findings revealed that the current rates of social acceptance of biochar in Finland are estimated to remain high in the future, especially with the plans of the government for the development of the forest economy. Moreover, in Finland there are several sustainable sources of raw materials for the production of biochar, such as side streams of forest industry, energy crops, and other biomass which is currently viewed as waste and have no economic value. Thus, the widespread uptake of biochar has the potential to increase the value of forest resources and create significant amount of new jobs in rural areas.

The lack of funding is indicated as one of the main economic barrier and factor slowing the development of the biochar market in Finland, especially given the fact that all biochar producers are SMEs. Other challenges slowing the development of the market are the lack of credible and practical research results which are applicable for the Finnish conditions. The respondents put an emphasis especially on research related to biochar application in urban areas, such as seedbeds, stormwater and urban runoff management. As a solution to the varying quality of biochar types, the respondents suggest the adoption of certification and standardisation system, which will also ensure the sustainability of biochar. Furthermore, stakeholder collaboration in biochar projects, e.g. between biochar producers, municipalities and / or companies and researchers is of great importance for the biochar market development.

The respondents highlighted that the general knowledge of biochar in Finland is still relatively low among decision makers and society. In order to mitigate this problem, it has been suggested that the companies should take an active role in increasing awareness. Another challenging factor identified by the respondents is related to biochar's definition. In Finnish language biochar is known as "biohiili", however, the term "biohiili" has much broader definition than the English term biochar and causes several misunderstandings. Thus, organisations, such as the Finnish Biochar Association (FBA) have a central role in creating knowledge, organising events, such as workshops, which are more practical and aim at educating people about biochar applications. The key research findings are summarised in Table 5.1 below.

Biochar applications in Finland	PESTEL analysis	Enabling factors for biochar market development
• Biochar market in Finland is emerging • Current biochar demand is driven by different trials and experiments related to animal agriculture, cultivation, soil & gardening, and urban areas • Biochar is estimated to achieve a strong position in com-posting, green roofs, seed-beds, filtering and manag-ing storm water and urban runoff	• Political and legal environment does not significantly limit the overall development of biochar market • Biochar provides export opportunities • Biochar by-products and enrichment processes offer business opportunities • There is a demand for sophisticated, affordable and efficient biochar production technology • Biochar production is environmentally friendly • Availability of inexpensive and sustainable raw materials	• Financing biochar production • Utilizing current biochar standards and developing new in order to secure the quality of biochar and decrease the misuse • Increasing practical pilot projects and experiments • Stakeholder collaboration • Increasing the availability of scientific research results • Increasing awareness of biochar • Developing terminology of biochar in a way that it could be easily connected to the right application and communicated without causing misunderstandings

Table 5.1 Summary of the key research findings

5.2 Discussion

Previous biochar studies in Finland has mainly focused on topics such as biochar applications in soil amendment, carbon storing, pollution, effects on soil properties, field trials, green roofs, plant growth, effects on yields, pore structure, chemical and physical properties. The purpose of the current research is to add to the body of literature of biochar studies by investigating potential biochar applications from a market-centred perspective.

The current paper applies the diffusion of innovations theoretical framework by Rogers (2003) in order to investigate the future perspectives of biochar applications in Finland. Rogers (2003:1) points out that the major challenge related to the adoption of innovations is the gap between what is known and what is actually being done. This is also recognized as one of the key challenges in the biochar adoption process. While biochar has been known for a long time and some of its capabilities, such as improving soil fertility has already been recognized several thousands of years ago, only recently the biochar field has started to rapidly develop. Even though biochar research in Finland started in the beginning of 2000s, the biochar market started to form in 2017 and it is expected to grow in the next few years following a boost in demand and production of biochar, which will provide for significant export opportunities.

According to the reviewed literature, the most potential biochar application fields in Finland include composting, soil amendment in natural parks and gardens, agriculture and filter technologies (Hagner, 2016). The current study confirms that composting and filter technologies are one of the most potential biochar application fields. In addition, research findings suggest that green roofs, seedbeds, filtering and managing storm water and urban runoff (partly related to filter technologies) are also among the most potential application areas. Biochar utilization in these areas has attracted the attention of various stakeholders, such as researchers, producers and potential adopters as these area could provide a large number of benefits and economic opportunities.

Based on the literature, it could be concluded that the business environment for biochar in Finland is neutral or even positive since the development of forest-based bioeconomy, cleantech solutions and circular economy are one of the key areas for Finnish economy and also endorsed by the government (Hallituksen strateginen ohjelma, 2015). While this research identified several enabling factors for biochar market development, it did not find factors which would completely prevent the development of biochar such as strong political opposition or legal restrictions. Moreover, despite the usual challenges related to the market entry of new innovations the findings indicate significant market potential and growth for the biochar market in Finland.

According to Rogers (2003:221) the five factors affecting the rate of adoption of innovation are relative advantage, complexity, compatibility, observability and triability. The research findings revealed that certain biochar applications related to cultivation, animal agriculture, soil, garden, and green building can be affordable, convenient and satisfactory. These three factors are described by Rogers (2003: 229) as the factors determining the relative advantage. On the other hand, Hanger (2016) highlights that biochar applications providing significant environmental and carbon storing benefits and opportunities, such as large-scale applications on fields to increase crop yields, are currently hard to be implemented due to lack of economic incentives.

The second factor determining the rate of adoption is the complexity, which deals with how difficult it is for the individual to understand the innovation (Rogers 2003: 257). The research findings revealed that complexity varies among different applications. For instance, biochar applications related to soil fertility, green roofs or compost can be easily communicated and understood, while more demanding applications such as seedbeds or stormwater management require more orientation. Biochar's production and enrichment processes and climate change mitigation properties might as well be difficult to be understood.

The third factor affecting the innovation adoption rate is compatibility which refers to how well does the innovation fits the values, needs and past experiences of the potential adopters (Rogers, 2003: 240). The findings of the current study suggest that currently there are no issues related to compatibility of biochar in Finland. There is generally high social acceptance of forest-based innovations and such innovations has been endorsed by several decision makers. The interviewees indicated that the attitude towards biochar applications has been positive or neutral. The fourth factor is observability and it refers to how visible the innovation and its benefits are to other individuals. This factor is of significant importance as good experiences and results can stimulate others to utilize the innovation (Rogers, 2003: 258). The research findings confirmed that observability is highly important in the process of diffusion of biochar. For instance, the positive biochar experiences in the city of Stockholm raised interest from several Finnish municipalities that are currently implementing a number of biochar projects. If the current projects are successful, not only this will decrease the uncertainty related to the benefits of biochar, but it will also increase awareness and encourage others to try biochar.

The last factor is trialability which investigates how easily the innovation can be experimented with (Rogers, 2003: 258). According to the research findings, one of the strengths of biochar is that it can be easily tested. Testing the product and its qualities is particularly important for potential consumers and it serve as basis for making the final decision for large scale adoption. In fact, the majority of current biochar projects in Finland are in an experimental phase and biochar producers are increasingly looking for customers who are willing to test their products. The research findings revealed that experimenting with small quantities of biochar is relatively inexpensive and the longevity of the test period depends on the desired results. For instance, some benefits such as soils ability to absorb water can be achieved almost immediately, while others such as increasing yields or achieving certain soil properties might take up to several years.

Many other studies indicate that major drivers of biochar applications include CO_2 sequestration (Lehmann & Joseph 2009: 5, Tiilikkala 2013, Schmidt & Wilson 2014, International Biochar Initiative 2016, British Biochar Foundation 2017), improving agriculture (British Biochar Foundation 2017, Schmidt et al., 2016), waste management (British Biochar Foundation 2017, B4SS 2017, International Biochar Initiative 2016), soil remediation (Schmidt & Wilson 2014, Hagner 2016), and new economic opportunities (British Biochar Foundation 2017, Lehmann & Joseph 2009: 5, Draper, 2016). While these drivers were also recognized in the research findings, the application-specific drivers, such as economic feasibility and local benefits were identified as the main driver for biochar market development. For example, applying biochar on green roofs could increase its ability to absorb nutrients and water while making the whole structure lighter which allows for building green roofs on weight sensitive roofs. Another example is that adding biochar to compost would significantly improve and simultaneously reduce the composting time which is particularly beneficial in the context of Finnish weather conditions.

5.3 Validity and reliability

Validity and reliability are essential characteristics of any research and refer to author's consideration regarding data collection, data analysis, data interpretation and presentation of research findings. (Merriam, 2009: 209-210) According to Firestone (1987: 19) in qualitative studies it is easier for the author to demonstrate the credibility of the conducted research, as there are enough details available for the readers to validate author's conclusions. Merriam (2009: 213) points out that there are two key issues related to qualitative research which are addressed through internal and external validity. Internal validity refers to how accurately the research findings match the reality, while external validity refers to the generalizability of the research results. Several researchers such as Maxwell (2005: 105) argue that the reality can never be captured as it is relative and can never be proven. Nevertheless, there are several strategies which can be used to decrease the gap between the research findings and reality (Merriam, 2009: 215). Furthermore, qualitative research is often criticised for having small and non-random sample. This in fact is the whole purpose of the qualitative study as the research objective is to understand particular issues in depth, rather than investigate which is true out of many (Merriam 2009: 224).

Several factors have influenced the validity and reliability of this study. Firstly, the research was conducted in co-operation with Luke who provided guidance and assistance throughout the research process. Secondly, since the topic is about an emerging innovation, the research results refer to the diffusion process which will take place in the future. Thirdly, the data was collected through unstructured thematic interviews, which allowed for flexibility and adaptation of the questions depending on what has been learned so far and interviewees background. All the interviews were conducted in Finnish language and when referring to biochar during the interviews the term "biohiili" was used. Before the interview started, terminology was explained in order to avoid misunderstandings between different biochar definitions.

Fourthly, the research process has been transparently presented and described in detail, which allow the reader to form an opinion about the validity and reliability of the study. For instance, the interviewees were selected carefully in order to collected reliable and valid information. In addition to scientific research, several media articles were used as a source of information for this study. Even though relying on media articles could be criticised. Not only such data provides valuable insights on the public perspective and awareness of biochar, but also it is important factor in determining the market development of biochar, since publicity has a major impact on the adoption of innovations. Lastly, the research findings were sent back to the interviewees for respondent validation and the feedback provided was taken into consideration before the final publication of this work.

5.4 Limitations and suggestions for future research

Biochar research in Finland has been mostly focused on the pyrolysis process, biochar applications and characteristics. However, the field is lacking economic and market-based research. Even if certain biochar application provides significant benefits, it might still be ignored and not adopted for reasons, such as lack of profitability. Therefore, the attempt of this study was to recognize out of many different biochar applications, those which are currently the most discussed and interesting from economic point of view as they have higher potential to be adopted in the near future. As this study did not focus on specific applications in particular, possible topics for future research include a market research based on one or few biochar applications, which were recognized as the most potential in the current study. This would allow for the conduct of an application specific market analysis, where different variables could be taken into consideration.

During the data collection phase of the study, some respondents raised concerns regarding biochar's environmental impacts and sustainability, especially in relation to the feedstock. Exploration of this topic would also provide good ideas for future research. Possible topics include but are not limited to the rate of sustainable biochar production depending on the selection of raw materials and application specific Life-Cycle-Assessment studies. Other possible research area identified throughout this study is the export potential of Finnish biochar. In addition, biochar production technologies offer completely new business area and opportunities and it would also require own research. Thus, it could be concluded that currently the biochar market is still emerging in Finland and there is a strong need for further research, which will increase both the knowledge in the field and the rate of adoption, while decrease the uncertainties.

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APPENDICES

Appendix I

List of studies adapted from the AgriChar research group of University of Helsinki (2017). The list is containing biochar studies which are related to soil amendment and are conducted in Finland

2011

- Karhu, K., Mattila, T., Bergström, I., & Regina, K. (2011). Biochar addition to agricultural soil increased CH4 uptake and water holding capacity–Results from a short-term pilot field study. *Agriculture, Ecosystems & Environment*, 140 (1), 309–313.
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2013

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2015

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