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Cost-Benefit Analysis of the Biochar Application in the U.S. Cereal Crop Cultivation

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Capstone Project

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Abbreviations

CBA	Cost-Benefit Analysis
CO_2/CO2	Carbon Dioxide
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
NESFI	New England Small Farms Institute
PVBI	Pioneer Valley Biochar Initiative
UNCCD	United Nations Convention on Combating Desertification
UNFCCC	United Nations Framework Convention on Climate Change
USA/US	United States of America

Executive Summary

Increasing global warming and food insecurity give ample rationale for research on biochar in view of its properties: enhancement of soil fertility and crop productivity, soil water retention and carbon sequestration. As a new technology the introduction of biochar into farming faces challenges and uncertainties, which are highlighted in the report along with the policy implications.

Biochar is a type of charcoal created through pyrolysis of biomass. It is a carbonaceous substance produced with the intent to apply to soil for agricultural and environmental management. Biochar use and production can be deemed a mere business activity that should be ruled out by the market; however, due to multi-functionality of biochar properties this technology has important policy implications. Biochar can exert positive externalities, i.e. provide social benefits in the form of carbon sequestration or reduced agricultural water runoff, etc. Biochar, however, has not yet been studied in its entirety, and as such its application in some cases faces risks and uncertainty.

Biochar advocates need to give a convincing argument to farmers about the benefits of biochar application in agronomy. Apart from the considerations of pure financial costs and benefits occurred to an individual farmer, it is necessary to be mindful of the social costs and/or benefits, risks and uncertainties that a new technology may impose on people and the environment

The research aimed to review the available literature on biochar, conduct a cost-benefit analysis (CBA) of the biochar application in the US cereal crop cultivation and give a recommendation to farmers and policy-makers on biochar use. A mix of qualitative and quantitative research methods were sued to collect the data and carry out an analysis over the fall 2011 - spring 2012.

Specifically this research intended to answer the following questions: *Do private and social benefits of biochar outweigh its private and social costs? Under what conditions? Is policy needed to promote biochar?*

The study was informed by the interviews with farmers from the Amherst area; literature and document review, and personal communication with biochar researchers and stakeholders. A cost-benefit analysis (CBA) of the biochar application in the US wheat crop cultivation was conducted to identify the biochar profitability. The CBA used the field data of the Washington State research and the data from biochar studies in the northerly and tropical climates, using the formula *“Benefits - Costs > 0”* as a criterion. Expert information and the existing literature were used to identify and fill in the gaps in the CBA. Based on the factual data and assumptions the private and social costs were compared to the total benefits ensuing from the biochar application.

Private costs are measured as total costs accrued to a farmer during the purchase and field application of one ton of biochar per ha. Private benefits are measured as financial revenues a farmer gains from the increased wheat yield as a result of biochar soil treatment. This analysis is based on the biochar crop yield effect during the 1st year. It does not consider the prolonged effect of biochar on the wheat yield in the following years. Hence, the private benefits include only the revenues gained in the 1st year with hypothetical revenues ensuing from the biochar yield effects over the following 10 years.

Social costs represent the risks and uncertainties of introducing biochar as a new agricultural technology. This research, though, does not include a specific value for social costs because of the difficulty in quantifying and monetizing the potential increase of soil temperature and loss of crops, biodiversity, and social tension the society may have to pay if biochar shows adverse effects. However, the considerations for social costs are included into the CBA analysis and conclusions. The blanks are identified and filled in with the appropriate use of bounds to manage uncertainty.

Social benefits are measured as benefits accruing from the CO2 sequestration. Benefits resulting from the higher nutritional value and better soil water retention, conservation of biodiversity and higher food security (better yield predictability in the face of weather change), benefits of waste management, and the reduction of methane emissions from landfills are not included in the analysis.

The CBA findings suggest that under the current costs the biochar application in the US cereal crop cultivation does not work privately in the first year because of the high costs of biochar. The

inclusion of a multi-year biochar effect on soil fertility and crop productivity, however, can add a significant value to biochar profitability, had the field research proved a positive yield effect.

The findings demonstrate that the CO2 sequestration payments can play a very important role in biochar profitability. The carbon markets are not set up yet, therefore one way to look at biochar promotion is to consider the feasibility of introducing a policy on carbon sequestration payments, or to think of ways of reducing the cost of biochar by increasing the production scale. Meanwhile, farmers may find it profitable to use biochar for cultivation of cash crops that give a high return on investment, or on a small-scale in specific settings (greenhouses, tree nurseries, florist shops, etc.)

Governmental investments in R&D and larger scale biochar applications are required to account for a vast heterogeneity of biochar systems. In the mean time the government should introduce an "incremental" biochar policy regulating current biochar application, while promoting the information exchange among the researchers, policy-makers and practitioners.

Content

I. Introduction

Biochar is a type of charcoal created through pyrolysis of biomass. It is a carbonaceous substance produced as a soil additive for agricultural and environmental management. Biochar enhances soil fertility, retains nutrients and improves water quality; it increases crop productivity and sequesters carbon. Its unique set of properties makes it a highly attractive and potent tool to combat food shortages, generate green energy, mitigate climate change, improve agricultural outcomes. As a new technology, though, the introduction of biochar into farming faces challenges and uncertainties, which are highlighted in the report along with the policy implications.

The heterogeneity of biochar system (type of feedstock, soil, climate, crops, application method, application rate, etc.) influences agronomic and financial outcomes of biochar application. It implies that farmers need to have clear information about the agronomic effect of biochar in specific soil/crop/climates, and that they need to know the financial viability of biochar as a farming practice.

Apart from considerations of pure financial costs and benefits occurred to an individual farmer, it is necessary to be mindful of the social costs and/or benefits, risks and uncertainties that a new technology may impose on people and the environment.

The CBA presented in this report enables a comparison of private costs and benefits accruing to a farmer from the biochar application, while also considering the costs and benefits occurring to the society. The findings suggest that the inclusion of a multi-year effect of biochar on soil fertility and crop productivity adds a significant value to biochar profitability privately, while in the short-term CO2 sequestration payments play an important role in economic feasibility of biochar.

II. Background Information on Biochar

Biochar is a carbon-rich product obtained in the process of heating biomass (wood, manure or leaves) in a closed container under little or no air (Lehmann)[1]. It is produced by thermal decomposition of organic material under limited supply of oxygen, and at relatively low temperatures

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[1] Lehmann, p.1

(<700°C)”[2]. “It [biochar] distinguishes itself from charcoal and similar materials by the fact that biochar is produced with the intent to be applied to soil as a means to improve soil health, to filter and retain nutrients from percolating soil water, and to provide carbon storage”[3].

Soil studies in Amazonia discovered vast *terra preta* (dark soils) areas of the Amazon basin to be very fertile and rich in carbon. *Terra preta* is found in various soil types of the Amazon region, but all of them possess high levels of charcoal residues[4]. According to the Bruno Glaser (University of Bayreuth, Germany) study of Amazonia “an acre of terra preta soil three feet deep holds 100 tons of carbon, compared with 40 tons in adjacent soils…not improved with charcoal”[5]. Carbon contained in the biochar is stable and can be stored there for thousands years without degrading!

Biochar properties depend on a variety of elements in the biochar system: feedstock, production technology and temperature, type of soil, climate and crop, the application rate and method. It is important to distinguish between biochar, char, and charcoal[6]:

Char is “any carbonaceous residue from pyrolysis including fires”.

Charcoal is “char produced from pyrolysis of animal or vegetable matter in kilns for use in cooking or heating”.

Biochar is “carbonaceous material produced specifically for application to soil as part of agronomic or environmental management”.

Biochar production includes three main elements: production process (temperature modes, etc.), type of feedstock (rice hulls, wood chips, food-processing wastes, animal manure, municipal solid wastes, etc.) and manufacturing technology (small farm-scale units, large-scale pyrolysis, gasification and hydrothermal carbonization units, etc.). Various types of feedstock will yield different types of biochar that will give varying effects when applied to different soils and climates.

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2 Lehmann, p.1
3 http://www.biochar-international.org/biochar
4 Goodall, p.227
5 Goodall, p.227
6 Lehmann, p.127

Biomass heated under pyrolytic conditions (i.e. the heat causes the decomposition of a substance) releases gases and produces charcoal. The released gases and heat can be captured for power generation. Charcoal can be used as a fuel for barbeques, as a natural purification and filtering material, as a drawing material, a dietary supplement for gastric problems, cooking/ industrial/ automotive fuel, as a natural dehumidifier and odor neutralizer[7], and as a soil amendment - biochar.

Biochar Benefits

Food security is an acute problem for many countries of the world. The potential use of biochar as a soil amendment for improvement of soil fertility and increase of crop productivity looks, therefore, very promising. Moreover, biochar helps soil retain nutrients and water, and hence can reduce costs for irrigation and fertilizers and improve depleted soils in the long run. Biochar is a long-lasting soil additive and does not need to be added every year, which acts to its favor in comparison with agricultural fertilizers. The ability of biochar to sequester carbon puts it along with other climate change mitigation mechanisms, e.g. reforestation and afforestation, etc.

Improvement of Soil Fertility, Increase of Crop Productivity and Quality

There is evidence that porous structure of biochar is a great shelter for bacteria and fungi and a storehouse for nutrients and water that are necessary for sustained, vigorous plant growth. This is what helps improve agricultural outcomes. A social scientist from Belgium, Laurens Rademakers set up a trial in Cameroon (West Africa), where climate and soil favor two iterations of corn crops a year[8]. Through an experimental biochar application local farmers obtained doubled corn yields at the biochar-treated plots, showing that biochar had an effect of a fertilizer. And the yields were even better if biochar were applied in combination with fertilizers.

Experimental biochar research data point to long-run benefits of soil fertility - increases in crop yield, quantity and quality of biomass and improved quality of milk produced from the biochar-treated

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[7] http://www.diylife.com/2010/02/12/unusual-uses-charcoal/
[8] Goodall "Ten Technologies to Save the Planet", p.228

biomass fed to cattle; biochar showed itself instrumental in soil/land remediation (Galinato et al., Thomas, Lehmann, Husk and Major, Blackwell, Barrow[9]).

Waste Management, Reduction of Water Use for Irrigation

Waste disposal (agricultural wastes, wood residues, green urban wastes etc.) through biochar production can mitigate climate by: "reducing methane emissions from landfills; reducing industrial energy use and emissions…; recovering energy form waste; enhancing C sequestration in forests…; decreasing energy used in long-distance transport of waste"[10].

Biochar porosity is what helps it retain water and give it back to plants in dry seasons. Biochar can save water resources and reduce irrigation needs and costs. "Water—along with climate, soil fertility, the choice of crops grown, and the genetic potential of those crops— is a key determinant of land productivity. Adequate moisture in the root zone of crops is essential to achieving both maximum yield and production stability from season to season"[11]. Karhu et al. reports that the addition of biochar increased soil water holding capacity at experimental plots (in Southern Finland) by 11%[12].

Energy generation

Heat and synthesis gas are released during the pyrolysis of biomass. These can be captured for energy generation. Lehmann states that "emission reductions associated with biochar additions to soil appear to be greater than the fossil fuel offset in its use as fuel", which makes biochar an effective environmental solution[13], i.e. soil application of biochar would reduce more emissions (by sequestering carbon) than if we just burn biomass as a relatively clean fuel vs. burning coal, oil, etc.

Carbon sequestration

Biochar has a great potential for combating global warming. The photosynthesis in the plants extracts CO2 from the atmosphere and ties it into carbon-based compounds that make up the biomass; the annual amount of energy trapped by photosynthesis is five times bigger than total energy

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[9] See the list of references for a detailed bibliography

[10] Lehman, p.6

[11] Postel, p.1

[12] Karhu et al., p.1

[13] Lehmann, p.7

consumption of the mankind. Each year some 100 billion tons of carbon are converted into biomass through photosynthesis14.

The population uses only 30% of biomass – forests, crops and fuel. Dry biomass contains about 50% carbon, 5-6% hydrogen, 40% oxygen plus small amounts of minerals, etc.[15]. But all biomass whether consumed/burnt or left to decompose, gets broken down into $CO_{2,}$ methane and hydrogen sulfide which are released back into atmosphere. The concentration of these gases in the atmosphere exacerbates global warming, e.g. methane is a potent greenhouse gas with a global warming potential 70 times (per molecule)[16] higher than CO_2[17].

Pyrolyzing biomass into biochar and storing it in the soil - “carbon negative” farming – helps in removing carbon from circulation, which would otherwise be released by decaying biomass, for thousands of years. Converting biomass into biochar yields a recalcitrant compound (i.e. it has a slow decomposition), and diverts C from a fast biological cycle into a slower biochar cycle[18].

Global warming is progressing in a direct relationship to the concentration of greenhouse gases (GHG) in atmosphere. In 2005 the concentration of GHG reached 379ppm (particles per million) in comparison to 280ppm in the 18th century, prior to industrial revolution[19]. The NASA Goddard Institute for Space Studies in NYC prognoses 350ppm to be the maximum possible CO2 concentration. This is the threshold beyond which the polar and glacier ice melting increases[20].

Global average temperature is only three degrees warmer today than it was 20,000 years ago, “when there was a mile-thick mantle of ice over Manhattan”[21], therefore even one extra degree temperature increase will have a big effect on the climate.

Annual amount of GHG produced by human activities is 8 billion tons, which are released into atmosphere or are absorbed by soils, oceans, plants. Goodall posits that global warming heats up soils

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14 Paul Taylor “The Biochar Revolution”, p.7, 22
15 Paul Taylor, p.22
16 Per R.Stein and T. Wysocki
17 Taylor, p.22
18 Lehmann, p.8
19 Lehmann, p.372
20 http://www.dyarrow.org/Kansas/
21 Bates, p.2

and reduces their carbon-storing capacity, which will accelerate CO_2 emissions even more. He underlines the importance of carbon retention in the soil: “world’s soils contain twice as much carbon as does the atmosphere and about 1 trillion tons more than the world’s plants do”[22] (see Appendix D).

Biochar Critique and Uncertainties

Fire Hazard and Health Risks

Density and dustiness of biochar can represent fire hazard and health risks[23]. Biofuelwatch[24], the public-interest group, and National Resources Defense Council (NRDC) [25] emphasize the possible adverse health effects from inhaling the soot.

Of all the soil additives biochar has the lowest density. Spontaneous combustion can occur if significant amount of biochar dust accumulates in an enclosed space, or if biochar contains a big amount of volatiles. Densification and application of water, or fire retardants helps reduce the risk of combustion. Dustiness is negative for storing, transporting and applying biochar, because biochar particles can be easily flown around by wind. Biochar made from certain materials, e.g. rice husks, can contain toxic elements (rice husk-based biochar can contain toxic crystalline material)[26]. To that end, quality control mechanisms should be established to ensure health and safety precautions.

Social and Environmental Risks

(i) Land grabbing

Concerns have been voiced by the international NGOs, e.g. Biofuelwatch, the African Diversity Network, the Gaia Foundation, Friends of the Earth, GRAIN and the Transnational Institute[27] that the increased demand for biomass needed to produce biochar might pose a threat to forests and farms that are already suffering from deforestation and soil degradation.

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22 Goodall, p.237-238
23 Lehmann, p.216
24 Bates, p.173
25 NRDC, p.9
[26] Lehmann, p.216
27 Leach et al., p.13

NGOs refer to biochar advocates who say that the amount of biochar needed to combat global warming will require billion hectares of plantations, and much of these will be in Africa[28]. This will even further exacerbate the "massive land grabbing" that is already taking place for biofuels and foreign agricultural investment geared to food security elsewhere in the world, with major impacts on indigenous communities and their access to land and resources…"[29] Leach et al. at the same time point out that the scope and ways of land grabbing depends on the prior institutional, governance and environmental conditions[30]. The social aspects of the biochar technology deployment should be kept in mind when promoting the biochar production from other than the local sources.

(ii) Uncertainties of biochar systems

Biochar cannot yet be viewed as a technology tried and tested in its entirety. Sohi et al. (2009) refer to the absence of a "critical and non-prescriptive analysis of risks that might arise from the deployment of biochar…". The main arguments for such an analysis would be the irretrievability of biochar once it is added to soil; general permanence of biochar once it is in soil; and the scale and speed with which a biochar technology has to be introduced in order to effectively combat climate change[31].

Leach et al. emphasize the need to research the relationships between different kinds of biochar systems; how long biochar carbon can be stored in soils; how much carbon gets lost during transportation and handling, what effect on the climate it can have; what land-use changes may result from the increased production of biochar[32]. Lehmann proposes to research the conditions under which biochar can generate benefits, and identify the recipients of these benefits[33].

Brugges and Schahczenski call for precautionary behavior in biochar deployment: "…[E]xtreme caution is necessary when interfering with natural climate systems" because "..the intention may be

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[28] Leach et al., p.13
[29] Leach et al., p.13
[30] Leach et al., p.13
[31] Sohi et al., p.37
[32] Leach et al., p.12
[33] A citation of Kleiner, from Leach et al., p.36

one thing and the outcome another"[34], "In every deliberation, we must consider the impact on the seventh generation... even if it requires having skin as thick as the bark of a pine"[35].

A review for the "European Commission (Verheijen et al 2010) finds that 'meta-analysis of the effects of biochar application to soils and plant productivity … showed a small overall, but statistically significant, positive effect of biochar application to soils on plant productivity in the majority of cases,', but argued that 'before policy can be developed in detail, there is an urgent need for further experimental research with regard to long-term effects of biochar application on soil functions, as well as on the behaviour and fate in different soil types (e.g. disintegration, mobility, recalcitrance), and under different management practices'"[36].

There have not been many studies on the possible impact of biochar on small farmers and their farming practices; what is studied is rather the technical issues, e.g. the interaction with soil, climate, crops, etc. but not the suitability of the technology for "farmers' needs and livelihoods"[37]. Leach et al. posit that "… the history of 'transfer of technology' approaches in agriculture more generally shows that suitability, adoption and uptake frequently stands or falls on socio-technical questions – around the implications for farm labour, tenure, gender and crop control issues, as well as the dynamics of farming within a broader social setting"[38].

Farmers' Interest in Biochar[39]

To get a feel of what may be the perspectives of farmers on biochar use, five interviews were conducted with farmers who grow crops around the Amherst area[40]. These farmers did not know much about biochar, but they have heard about it from the PVBI members, NESFI, from the fellow farmers, or via attendance of agricultural conferences. In general farmers noted that "*the information*

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34 James Brugges "The Biochar Debate", p.17
35 Powepoint presentation "Economics of Biochar" by Jeff Schahczenski
36 Leach et al., p.34
37 Leach et al., p.34
38 Leach et al., p.34
[39] Information on the research design and the questionnaire are given in the Appendix B, C
40 Citations are given from the farmers' interviews

is not easy to come by", "there wasn't a viable source how to get biochar for my operations… I haven't been able to find any application rates or university studies…"[41].

The farmers stated their interest in biochar as a soil amendment that helps retain nutrients, improve water holding capacity, soil health and fertility, and plant growth: "*feed the soil, not the plants"*. Carbon sequestration was not the farmers' primary concern, though some farmers were interested in sustainability issues: "*There has been an upswell on organic [produce] from consumers… if [I] can become carbon negative, would do it anyway. It's a decent advertising point. People who buy organic food are concerned with environment and climate change"… "I want to grow all my tractor fuel…", "Sustainable agriculture would be a good thing. I've used compost already to help the soil, but I also use fertilizers".*

Farmers have not thought much about the effect of biochar on the produce marketing strategy, although they stated it would certainly be good if biochar application *"results in extreme growth…" "It may add a product that I would have available and it could be used as a promotional or marketing enhancement of the material I grow… it would be an additional point of interest".*

Farmers expressed their trust in universities because they believed universities give an unbiased opinion in contrast to the private sector: "*private sector has a motive – profits; you can't believe everything", "an organization that doesn't have a stake in the outcome…someone who does independent research, who is not involved in it [biochar business]".*

Though conducted on a small scale, the interviews with farmers give a good picture of the interests and concerns of local farmers with regard to biochar use and promotion and hence, can inform a biochar policy.

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[41] Interviews with farmers

III. Biochar in the Climate Change Legislation

Biochar propensity to be instrumental in combating global challenges – food insecurity and global warming draws a lot of attention to it as an agronomical and environmental management mechanism. Caution, however, should be taken to avoid seeing biochar applications as a compensation for current and future carbon emissions and further exploitation of fossil fuels; Paul Taylor urges to view biochar as a tool to offset the past CO_2 emissions and reduce the current climate change pace[42].

Since the industrial revolution [1850] the concentration of the CO_2 in the atmosphere has increased from 280ppm to 379ppm in 2005[43]. The Kyoto Protocol adopted in 1992 by the parties to the United Nations Framework Convention on Climate Change, set to bring about a 5% reduction in emissions against the level of 1990. The estimates, though, indicate that in order to stabilize the emissions at 550ppm level by 2050, the developed nations have to reduce their emissions by 60% below 2000 (Defra)[44]. The Intergovernmental Panel on Climate Change specifies catastrophic impacts if the level of CO_2 in the atmosphere is not stabilized at/or less 500ppm, while NASA Goddard Institute for Space Studies puts 350ppm as a threshold[45].

Sustainable solutions to climate change discussed at the Climate Summit in Copenhagen 2009 included such mechanisms as "carbon dioxide capture, sequestration at power plants and furnaces; fertilization of the oceans to stimulate phytoplankton blooms that would drop carbon to the ocean floor to become rock; and solar radiation management by means of reflectivity…"[46]. As scientists reported, none of these methods was considered possible from a geo-engineering perspective[47].

Biochar has advantages over other proposed carbon sequestration mechanisms (sequestration at plants, fertilization of oceans, solar radiation, and afforestation) in that it has a long-lasting effect, unlike the afforestation that is short-term and may lead to the shortage of land.

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42 Taylor, p. 10
43 Lehmann, p.317
44 In Lehmann's, p.317
45 http://www.dyarrow.org/Kansas/
46 Bates, p.170
47 Bates, p.170

Biochar is advocated by Lehmann as a long-term, sustainable and easily monitorable solution to mitigating global warming: "we can monitor the amount of [bio]char that is added to soil rather than having to infer the amount of stabilization that happens in soil… [bio]char's stability in soils rests on its chemical recalcitrance… from what you put in, you can predict what will remain"[48].

The UN Convention to Combat Desertification (UNCCD) approved biochar as a climate change mitigation technology[49] and submitted a paper on the "Use of biochar (charcoal) to replenish soil carbon pools, restore soil fertility and sequester CO_2" to the working group under convention indicating that " there is the need to include into the negotiation agenda of UNFCCC practical approaches such as biochar-related mitigation (CDM)[50] and other LCA [long-term cooperative action] adaptation initiatives, focusing on increased land productivity, which simultaneously takes into account the issue of climate change, desertification and biodiversity issues"[51].

The UNCCD paper outlines the following advantages of carbon sequestration with biochar[52]:

- "No competition between SOC [soil organic carbon] restoration, bio-fuels and food production". Production of biochar through pyrolysis enables sustainable carbon sequestration and renewable energy production.

- "Pyrolysis or gasification with biochar carbon sequestration". Production of bioenergy with biochar carbon storage helps in producing carbon-negative energy. Biochar can be produced by small stoves, which do not require big investments.

- "Fast SOC buildup beyond the maximum sequestration capacity". Approx. 50% of carbon is captured if biomass is burnt into biochar; whereas only 2-20% of carbon gets stored in soil as a result of humification of the above-ground biomass residues and roots.

- "Reduced deforestation". Carbon trade will foster a decrease of deforestation and will promote reforestation and land recuperation activities.

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[48] Bates, p.179
[49] Taylor, p.173
[50] CDM – Clean Development Mechanism
[51] http://www.unccd.int/publicinfo/poznanclimatetalks/docs/Submission_by_UNCCD_to_AWG-LCA_on_Biochar.pdf
[52] http://www.unccd.int/publicinfo/poznanclimatetalks/docs/Submission_by_UNCCD_to_AWG-LCA_on_Biochar.pdf

- “Easy accountability and reduced risk”. Biochar represents a big and permanent carbon sink, which is easily quantifiable, unlike the estimation of gas removals and emissions cased by the land use, land use change and forestry (LULUCF) activities.

Biochar is formally recognized as a soil amendment in Japan and there are discussions in Australia to make biochar a part of the emissions trading scheme. New Zealand is working on research and commercialization of biofuel and biochar. Fourteen countries, namely, Micronesia, Belize, Gambia, Ghana, Lesotho, Mozambique, Niger, Senegal, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe, Australia, Costa Rica have approved biochar as a climate mitigation technology[53].

The first steps of the US legislation toward biochar were paved by the US Congress Food, Conservation and Energy Act of 2008 which established a federal policy supporting the biochar production and utilization programs[54]. The act stipulates the allocation of funds for biochar research: “Grants may be made under this section for research, extension, and integrated activities relating to the study of biochar production and use, including considerations of agronomic and economic impacts, synergies of coproduction with bioenergy, and the value of soil enhancements and soil carbon sequestration”[55].

IV. Methodology

Climate change effects and the growing food insecurity give ample rationale for research on biochar in view of its physical and chemical properties: enhancement of soil fertility and crop productivity, and sequestration/storage of carbon. As a new technology, however, the introduction of biochar into farming practices faces certain challenges, uncertainties, and risks. This research aimed to answer the following questions:

Research Questions:

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[53] http://www.biochar-international.org/policy/international
[54] http://www.unccd.int/publicinfo/poznanclimatetalks/docs/Submission_by_UNCCD_to_AWG-LCA_on_Biochar.pdf
[55] http://www.govtrack.us/congress/bill.xpd?bill=h110-2419, (p.314 of the document)

- ✓ Do private and social benefits of biochar outweigh its private and social costs? Under what conditions?
- ✓ Is policy needed to promote biochar?

A mix of qualitative and quantitative research methods were used to collect the data and carry out an analysis over the fall 2011 - spring 2012. The study is based on the interviews with farmers from the Amherst area; literature and document review, participation in the meetings of the Pioneer Valley Biochar Initiative, meetings with UMass professors in the field of agriculture, water resources, economics; email and phone communication with biochar researchers and stakeholders.

To identify the biochar profitability a cost-benefit analysis of the biochar application in the US wheat crop cultivation was conducted using the field data of the Washington State research and the data from biochar studies in the northerly and tropical climates, using the formula *“Benefits - Costs > 0”* as a criterion. Expert information and the existing literature were used to identify and fill in the gaps in the CBA. Based on the factual data and assumptions the private and social costs were compared to the total benefits ensuing from the biochar application.

Operational Framework

The following definitions and measures are employed in the research: “**Cost-benefit analysis** is a method of quantitatively evaluating whether or not to implement a proposed action”[56]. Social cost-benefit analysis measures the “overall welfare impact of interventions… [it] is advocated for use in government decisions as it is more comprehensive, reflecting an intervention’s overall impact on societal welfare”[57].

Precautionary principle [is a principle that] requires a regulation of any activity that poses an unknown risk to human health…”[58]. Precautionary Principle is defined by the United Nations’ Rio Declaration (the Earth Summit, Rio, 1992) as follows: “Where there are threats of serious or

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[56] Stephen Clowney “Environmental Ethics and Cost-Benefit Analysis”, p.106
[57] Hutton et al., p.1
[58] Stephen Clowney “Environmental Ethics and Cost-Benefit Analysis”, p.126

irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation[59.]

Private costs are measured as total costs accrued to a farmer during the **purchase and field application of one ton of biochar per ha.** The data were taken from the Galinato et al. research on the winter wheat cultivation in the Washington State, US; biochar cost data were informed by the research by Thomas, Shackley et al., and personal communication with Michael Whitman, Hugh McLaughlin. Biochar application cost data were informed by the Williams and Arnott's article comparing two application methods.

Private benefits are financial revenues a farmer gains **from the increased wheat yield** as a result of soil treatment with biochar. The CBA is based on the biochar crop yield effect during the 1st year and it uses the data from the Galinato et al. research. It does not consider the prolonged effect of biochar on the wheat yield in the following years. Hence, the private benefits include only the revenues gained in the 1st year.

Social costs are the costs borne by the society and the environment and are caused by a third party directly responsible for an economic activity[60]. Social costs represent the risks and uncertainties of biochar as a new technology (possible negative interaction with the soil microorganisms, increase of the soil temperature, loss of biodiversity, social tensions, etc.).

A specific value for social costs is not included in this analysis because of the difficulty in quantifying and monetizing the potential increase of soil temperature and loss of crops, biodiversity, and social tension the society may have to pay in view of potential biochar risks and uncertainties. However, the considerations for social costs are included into the CBA conclusions. The blanks are identified and filled in with the appropriate use of bounds to manage uncertainty.

Social benefits are the benefits that accrue to the society and the environment from an economic activity of the **actors who are indirectly causing some of the benefits flow to the society and/or**

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[59] United Nations Environment Development Program, 1992

[60] Goodwin et al., 162

environment. The analysis measures the benefits accruing from the CO2 sequestration based on the data by Galinato et al., Lehmann, Maraseni et al., Stern, Boyce and Riddle, Ackerman[61]. Benefits resulting from the higher nutritional value and better soil water retention, conservation of biodiversity and higher food security (better yield predictability in the face of weather change), benefits of waste management, and the reduction of methane emissions from landfills are not included in this CBA.

Data Limitations

The available literature on biochar gives information on the biochar crop yield effects, but not much on the biochar profitability. “The cost of biochar is generally at too early a stage to accurately obtain costs of application”[62]. Most of the available research on biochar crop yield effects has been carried out in tropical climates[63], e.g. **Brazil** (Steiner et al., Glaser et al.); **Colombia** (Major et al.); **Australia** (Van Zwieten et al., Thomas[64], Blackwell et al.[65], Chan et al.); **Japan** (Kishimoto and Sugiura, Chen et al.); **Indonesia** (Yamamoto et al.).[66] Some biochar trials are available from the northerly climates: **United States (**Mikan and Abrams, Young et al., Collins[67]); **Canada** (Husk et al.)[68], but the information is still “limited for dry and temperate climates…”[69].

According to Galinato et al., “at this point, it is not possible to draw conclusions on the effect of biochar that can be broadly applied, especially in temperate regions with younger soils (compared to highly weathered soils in more tropical environments)”[70]. They posit that highly weathered soils, e.g. in the humid tropics and southeastern states of the US may benefit more from the biochar addition.

“The nature and mechanistic basis for interactions between crop, soil type, biochar feedstock, production method and application rate will have to be understood to gain predictive capacity for the performance of biochar in soil, and open the possibility for large scale deployment”[71]. “…the argument for biochar largely rests either on lab-based or short-term (2-3 year) field experiments or

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61 Please see the bibliography section for these literary sources

[62] Lehmann, p.208

[63] Lehmann, p.208

[64] Thomas, p.43

[65] Blackwell et al., p.531

[66] Galinato, Yoder, Granatstein, p. 6345

[67] Galinato, Yoder, Granatstein, p. 6345

[68] Husk et al., p.1

[69] Lehmann, p.212

[70] Galinato, Yoder, Granatstein, p. 6346

71 Sohi et al., p.33

evidence from *terra preta* soils. It is objected that such short-term research and experimentation cannot give long-term guarantees on the claimed carbon and yield benefits"[72].

The available research data are not enough to move on to a large-scale biochar application, because the biochar systems have not yet been tested in their entirety. Those systems that have been researched have not been subject to a long-term observation to see the interaction of biochar with various soils, crops, climates, etc. Such variance and uncertainty complicates agricultural, environmental and financial prognoses of the biochar application in farming.

V. Cost-Benefit Analysis of the Biochar Application in Agriculture

Parameters and Values Used for the CBA[73]

Biochar feedstock and crop: Many of the values used in the CBA are from the research by Galinato et al. on the winter wheat production in the Washington State. The type of feedstock they consider is herbaceous or woody biomass that typically contains 60-80% of carbon[74]. The wheat is known to tolerate slightly acidic soils (pH 6.-6.5); the soil pH in Washington state is in decline (currently pH 4.5)[75]. The biochar application to soil can reduce the soil acidity and bring it up to a level conducive for wheat cultivation, i.e. pH 6.-6.5.

According to Collins[76], an increase of the soil pH from 4.5 to 6.0-6.5 requires an application rate of 76.53 MT of biochar per ha. The wheat yield under pH 4.5 is estimated at 3924.44kg/ha, under pH 6.0 – 6219.44 kg/ha, that is the biochar application results in a 58% yield increase.

Using the prices of the Union Elevator (2008) at $0.28/kg of wheat, the revenues will go up from $1098.84/ha to $1741/ha as a result of biochar application[77].

Values used for the CBA:	biochar application rate: 76.53 MT/ha; crop: grain wheat; grain

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[72] Maraseni et al., p.854
[73] Detailed information on the data used in the CBA is given in the Appendix A
[74] Collins, from Galinato et al., p.6346
[75] Collins, from Galinato et al., p.6346
[76] Collins, from Galinato et al. p. 6346
[77] Galinato et al. p. 6345-6347

	wheat price: $0.28/kg

Biochar cost: biochar cost depends on various parameters, e.g. feedstock collection and transportation, production technology and temperature, production scale, distribution and handling. The absence of data on all parameters of the production system complicates the calculation of biochar economic cost.

Van Zwieten in Benjamin[78] (2008) gives an estimate of $50-200/ton of biochar. US Biochar Initiative reports the cost of biochar as $500 per ton (excl. the shipping)[79]. Shackley et al.[80] give a range of values from $0-682.54/ton of biochar[81] depending on the feedstock, pyrolysis unit costs, etc.; a zero value here stands for the assumption that biochar production makes money and hence, the biochar production cost is 0. The range of values Shackley et al. give on the wood waste biochar ranges from $91-329/ton depending on the type of storage and production facility. Hugh McLaughlin recommends using a price range of $300-500 per American ton of biochar[82]. Michael Whitman[83] gives a price range of good quality hardwood biochar as $2000/ton.

Galinato et al. use herbaceous and woody biochar in their research, therefore the range of $91-329/ton based specifically on the woody waste biochar is taken into account in this analysis. The range of $0-2000/ton is very broad. Narrowing down this range is complicated by the uncertainty about the production conditions and the feedstock types these biochar cost data stand for. I will, therefore, narrow down this range to $200-500/ton of biochar, based on the following assumptions: (i) no production costs of biochar can be equal to zero; (ii) use the frequently reported figures; (iii) focus on the woody waste biochar versus hardwood on the assumption that environmentally and socially it is more feasible to utilize woody wastes than hardwood.

Values used for the CBA:	Biochar cost: low end: $200/ton; high end: $500/ton; preferred

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[78] From Thomas, p.46
[79] http://www.biochar-us.org/
[80] Shackley et al., p.16
[81] The original value is given as £0–430 (currency conversion is based on http://coinmill.com/ GBP_USD.html #GBP=430 as at April 4, 2012)
[82] Email correspondence with Hugh Mclaughlin, a biochar production expert from Canada (Alterna Biocarbon)
[83] http://blueskybiochar.com/. Phone communication with Michael Whitman, an environmental activist and biochar promoter, California

	estimate: $350/ton

Biochar application cost: Williams and Arnott present variable economic costs of two biochar application methods – broadcast-and-disk and trench-and-fill[84] (USA, Colorado). It is important to note that ideal saturation rates of biochar in soil are not known. The cost of biochar application with a *broadcast-and-disk method* is $71.6–741.3/ha for the application rate of 6.2 –123.5 tons of biochar/ha[85]. The *trench-and-fill method* cost and application rates are: $64.2–1265.2/ha for the application rate of 12.35–185.3 tons/ha (see table 4 for more details).

At the application rate of 76.53 tons of biochar the broadcast-and-disk method will cost $485/ha; the trench-and-fill method will cost $523.57/ha. In the CBA an average cost of these two methods is used because (i) the Washington State research does not specify the application method used in the analysis; (ii) the range is very narrow.

Values used for the CBA:	Application cost: $503.57 (an average value of the two methods).

CO_2 sequestration valuation: To estimate the carbon sequestration potential of the biochar soil application, Galinato et al. posit that every ton of biochar applied to soil contains 0.61–0.80 ton of carbon, i.e. an equivalent of 2.2-2.93 ton of CO2 can be sequestered[86]. The dollar value of sequestration of one ton of CO2 is estimated at $2.93-90.83/MT of biochar (based on the market prices of CO2 offsets at the Chicago Climate Exchange and the European Climate Exchange, a range of $1-31/MT of CO2)[87].

The CO2 price range varies, with significant difference between the market-based prices and the scientifically constructed ones: $1-200/ton of CO2. Some studies reported $21/25/31/37/41 per ton of CO2; several studies referred to $50/80/85/124. Detailed information is given in the table #3.

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[84] Williams and Arnott, p.23
[85] Converted from acres based on 1 hec = 2.47105 acre, http://www.metric-conversions.org/area/hectares-to-acres.htm
[86] The correlation of molecular weight of C and CO2 is 1:3.66
[87] Galinato et al., p..6347

$1-31 per CO2 ton emitted is a low price for the damage each extra CO2 ton adds to the environment and the society; therefore it is disregarded it in this analysis and not included in the price range.

Values used for the CBA:	CO_2 sequestration value: low end - $37/ton; high end – $200/ton; preferred estimate - $124/ton. An estimate of 80% carbon/ton of biochar based on the woody biochar carbon content is applied[88]. That is, one ton biochar contains 80% carbon and hence can sequester 2.93 ton CO_2.

Explanatory CBA tables

Biochar cost scenarios

Biochar cost scenario	# of tons	cost
Low-end	1	$200.00
	76.53	**$15,306.00**
Preferred	1	$350.00
	76.53	**$26,785.50**
High-end	1	$500.00
	76.53	**$38,265.00**

Under the **low-end** biochar cost scenario ($200/ton of biochar) the cost of 76.53 tons of biochar needed to achieve a pH soil level of 6-6.5 conducive for wheat cultivation, will equal **$15,306.00**. Under the **preferred estimate** biochar cost scenario ($350/ton of biochar) it will cost **$26,785.50** to achieve the required soil pH level. Under the **high-end** biochar cost scenario ($500/ton of biochar) it will cost **$38,265.00** to achieve the required soil pH level.

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[88] Collins, from Galinato et al., p.6346

Biochar application costs

Biochar application cost	
# of tons	**cost**
1	**$6.58**
76.53	**$503.57**

Biochar application to soil can be implemented by the two methods researched by Williams and Arnott: **broadcast-and-disking and trench-and-filling**. The application of 76.53 tons of biochar with the first method will cost $485, while the latter method will amount to $523.50. The cost range is very narrow; therefore an average value is used in the CBA: $503.57.

Biochar CO2 potential

Biochar carbon sequestration potential	
# of biochar tons	**# of CO2 tons sequestered**
1	2.93
76.53	**224.2329**

The calculations are based on the estimate that every ton of biochar applied to soil contains 0.61–0.80 ton of carbon. The correlation of molecular weight of C and CO2 is 1:3.66, i.e. an equivalent of 2.2-2.93 ton of CO2 can be sequestered with one ton of biochar.

Wheat yield revenues

Wheat crop yield revenue	
# of tons	**Price**
1	$280.00
6.22	**$1,741.44**

A study by Galinato et al. discovered that a soil application of 76.53 tons of biochar for wheat cultivation results in a 58% of the wheat crop yield increase. That is, the crop yield goes from 3924.44kg/ha to 6219.44

kg/ha. With the current price of wheat at \$0.28/kg, the total revenue from the biochar treated yield will be \$1,741.44/ha.

CO_2 price scenarios

CO2 price scenario	**# of tons**	**CO2 price**
Low-end	1	\$37.00
	224.2329	**\$8,296.62**
Preferred estimate	1	\$124.00
	224.2329	**\$27,804.88**
High-end	1	\$200.00
	224.2329	**\$44,846.58**

Application of 76.53 tons of biochar will sequester 224.23 tons of CO2. If the market price for the CO2 equals \$37, the total value of the CO2 sequestration is \$8,296.62. With the CO2 price at \$124/ton, the total value of the CO2 sequestered is \$27,804.88. Pricing the CO2 at \$200/ton, the total value of the sequestration will go up to \$44,846.58.

CBA Findings and Conclusions

Low-end scenario				
	Costs	***Benefits***	***Profit***	
Social		*\$8,296.62*		*biochar cost \$200/ton,* *CO2 price \$37/ton*
Private	*\$15,809.57*	*\$1,741.44*		
Total	*\$15,809.57*	*\$10,038.06*	***- \$5,771.51***	

Preferred estimate scenario				
	Costs	***Benefits***	***Profit***	
Social		*$27,804.88*		*biochar cost $350/ton,* *CO2 price $124/ton*
Private	*$27,289.07*	*$1,741.44*		
Total	*$27,289.07*	*$29,546.32*	***$2,257.25***	
High-end scenario				
	Costs	***Benefits***	***Profit***	
Social		*$44,846.58*		*biochar cost $500/ton,* *CO2 price $200/ton*
Private	*$38,265.00*	*$1,741.44*		
Total	*$38,265.00*	*$46,588.02*	***$8,323.02***	

In the low-end biochar cost scenario ($200/ton of biochar and $37/ton of CO2) the use of biochar incurs an economic loss of $5,771.51. Biochar use gains profitability with the increased CO2 price of $124/ton regardless of an increased price of biochar at $350/ton. The net profit will be $2,257.25. Biochar application becomes even more profitable at $200/ton of CO2, which offsets the biochar cost at $500/ton. This scenario will yield a profit of $8,323.02.

Biochar is said to have long-lasting soil benefits, i.e. it does not need to be added to soil each year, as is the case with many agricultural fertilizers. With research data on the biochar crop yield effects, e.g. over the time-span of 10 years, it would be possible to more precisely calculate the total private benefits. Assuming that each next year after the first application biochar gives a soil effect reduced by 4-5% from the first one, and so each year on, the revenue table may look like this:

Hypothetical Revenues from Biochar Yield Effect over 10 Year Time-Span:

Year	**Baseline revenue**	**% increase**	**Increased revenue**		**Revenue difference**
1	1098	54%	1690.92		592.92
2	1098	50%	1647		549
3	1098	45%	1592.1		494.1
4	1098	40%	1537.2		439.2
5	1098	35%	1482.3		384.3
6	1098	30%	1427.4		329.4
7	1098	25%	1372.5		274.5
8	1098	20%	1317.6		219.6
9	1098	15%	1262.7		164.7
10	1098	10%	1207.8		109.8
				Total revenue difference	**3557.52**

Hypothetically over the next 10 years of the biochar application it is possible to get additional $3,557 from the increased crop yield, which will make the overall biochar profitability much higher. The cost-benefit analysis shows that under the current costs the biochar application in the US cereal crop does not work privately. This happens if high costs of biochar at $350 or $500/ton get offset by the high price for the CO2 sequestered at $124 or 200/ton.

Since carbon markets are not yet set up, one way to look at the biochar promotion is to consider the feasibility of introducing a carbon policy stipulating the carbon sequestration payments, or thinking of ways to reduce the cost of biochar by increasing the production scale. For the biochar use in agriculture to be economically feasible in the first year of application, the costs of biochar have to become significantly lower, i.e. given the private benefits of $1,741.44 from the wheat yield of 6.22 tons, the cost of biochar would have to cost no more than $23/ton. However, the inclusion of a multi-year effect of biochar on soil fertility and crop productivity adds a significant value to biochar profitability privately, and offsets initial high costs of biochar.

One more factor influencing the biochar profitability is the type of a crop the biochar is applied to. Wheat is a very cheap agronomy crop ($0.28/kg) and it does not give a high return on investment. With cash crops (like squash, broccoli, sweet corn that can be sold at a higher price)[89], biochar profitability may be much higher.

The CBA conclusions would be incomplete without accounting for possible social costs that might incur with the biochar use. The difficulty in quantifying and monetizing possible social costs did not make it possible to include the value for social costs into the calculations, and this may have affected the research results. To that end, the need in further R&D is emphasized in the policy recommendations section.

VI. Policy Implications and Recommendations

Research findings from academicians and practitioners in different parts of the world prove an amazing combination of biochar properties that promise humanity a way out from the dire situation of today. Food and energy insecurity, polluted air, water, overexploited and depleted soils; high

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[89] Professor of Agriculture, UMass-Amherst, Masoud Hashemi

concentration of greenhouse gases in the atmosphere could be reduced and optimized through the intelligent use of biochar. Biochar, though, can represent certain risks (fire hazard, environmental and health risks), which can be neutralized through an informed and mindful approach to biochar production and application cycle. Safety and precautionary measures taken, biochar production and application represent an environmentally friendly and local solution to sustainable development.

There is mounting evidence of the positive impact the biochar can play in environmental management, e.g. mitigate climate change and contribute to food security. However, most biochar studies are short-term and lab-based, and do not account for the vast heterogeneity of biochar systems (a correlation between the types of feedstock, soils, climates, crops, application rates and methods, suitable farming practices etc.). The risks and uncertainties related to the introduction of biochar in agriculture (irretrievability once in soil, permanence, interaction in the soil, etc.), stipulate the need for more research and regulation of current attempts to apply biochar in the field.

Recommendations to the US Government

1. **Fund biochar research**. More R&D and larger scale applications are required. Biochar production, specification and handling protocols should be developed to prevent possible health, social and environmental hazards. Institutional and regulatory frameworks need to be set up to address social and environmental issues.

2. **Introduce an "incremental" policy and regulate current biochar application**. A precautionary approach to public policy should be exercised. The introduction of biochar into agriculture should be implemented first for those variables/biochar systems that have already been tested in field settings and have been found not to have any negative effects. Lessons learnt from the previous transfers of agricultural technologies (social and gender issues, etc.) should be taken into account when designing a biochar policy.

3. **Design a subsidy for the CO2 sequestration with biochar**. The policy should make it clear that carbon sequestration is not a compensatory mechanism to justify excessive fossil fuel use. Payments for the CO2 sequestration should be smaller than the price that CO2 emitters pay for

one ton of CO2 emissions. This margin will allow covering the administrative costs for carbon monitoring and accounting.

To avoid a possible double carbon accounting, the policy should outline the recipients of the CO2 sequestration payments: producers, or consumers, i.e. farmers. The policy should contain a regulatory and monitoring mechanism to avoid potential food insecurity arising from the excessive use of biochar to the detriment of a crop yield in order to get more revenues from the CO2 payments (in cases where payments for CO2 sequestered can give higher revenue than private benefits from the increased crop yield).

4. **Promote information exchange among researchers, policy makers and practitioners**. Establish a database that would serve as an exchange platform for researchers and practitioners. The cases of biochar application that have been found suitable for particular situations and objectives should be described in detail and promoted among biochar stakeholders. This would also stimulate the demand for and supply/production of biochar.

   A feasibility of introducing the biochar chain-of-custody (health and environmental standards of the biochar production, distribution and handling) should be studied. A comprehensive information/outreach campaign is required to disseminate the information about biochar effects among the farmers' community. This could be done in collaboration among the research institutions, universities, and farmers' associations.

Recommendations to Farmers:

From a private perspective, the biochar application for wheat cultivation based on the data from the Washington State research proves economically viable over a longer time-span. Therefore, the prolonged yield effect of biochar should be taken into account when making a private decision about its application. The economic feasibility of biochar will increase once the production scale increases reducing the cost of biochar, and once the CO2 payments get introduced. While this is not the case, the use of biochar can be considered:

(i) To cultivate crops that prove profitable under a long-term biochar yield effect analysis.

(ii) To cultivate cash crops that give a high return on investment.

(iii) On a small-scale in specific settings (greenhouses, tree nurseries, florist shops, etc.)

Farmers should actively seek information on biochar from the farmers' associations, and related organizations and collaborate with a broader circle of biochar stakeholders.

VII. Potential for Further Research

Future research should investigate the parameters affecting biochar costs and come up with clear indications of values. A quantification and monetization of social benefits and potential costs resulting from the biochar application (reduction of irrigation/improvement of water quality, fertilizer use reduction, increase of food security, biodiversity conservation, climate change mitigation, and possible adverse effects) is needed to better inform a public policy.

A long-term research on the biochar crop yield effect as applied to different crops is needed. This will enable conducting a comparative study on the crop yield effects, costs and benefits of biochar versus other agricultural fertilizers that will be helpful for private and policy decisions.

The qualitative research of farmers' opinions was conducted on a small scale, and a larger sampling size would be required to embrace the perspectives of farmers more fully. An in-depth stakeholder analysis revealing the interests and positions of various stakeholders (foresters, wood processors, environmentalists, policy-makers, researchers, municipal authorities, etc.) on biochar as a new agricultural technology will also yield useful information for policy-makers.

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IX. Appendices

Appendix A. Tables on the CBA Input Data

Table 1. Biochar Cost and Benefit Parameters, and Values

Type of feedstock	Crop intended for	Biochar cost, $/ton	Biochar application rate	Biochar Application Cost	Anticipated crop yield increase	Anticipated revenue from the crop yield	C content of biochar feedstock	CO2 sequestr ion potential when applied soil	CO2 sequestrati value, $
Herbaceous or woody biomass	Wheat	$50-200/ton (Van Zwieten in Bejamin, 2008) From Thomas	76.53ton/ha	Application rate of 76.53ton/ha the broadcasting application method will cost $485. The trench-and-fill method:	From 3924.44kg/ha (ph 4.5) to 6219.44 kg/ha (ph 6) 58% increase	Grain wheat price $0.28/kg, Union Elevator, 2008, from Galinato et al.) Soil ph 4.5 revenue $1098.84/ha Soil ph 6.0	60.5-66.7% and 74.5-80%	2.2-2.93ton of CO2 is sequestered for every ton of biochar applied[90]	Every ton of biochar can sequester 2.2-2.93 ton of CO2. I use 2.93ton of CO2 sequestered based on the 0.80 carbon content of wood waste

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[90] Galinato et al. p.6346

				75.53 ton/ha of biochar will cost: $523.5		revenue $1741.44 /ha			biochar. Multiply it by the price of CO2 to get the value of the CO2 sequestration.

*fertilizer use is not taken into account

Table 2. Biochar Application Costs[91]

Broadcast-and-disk method	Trench-and-fill method	Comments/Assumptions
$29-44-72-158-300/acre for application rate of 2.5 – 5 – 10 – 25 – 50 tons/acre Prorated per ha[92], the application rate per ha is: 6.2 - 12.3 – 24.7 – 61.8 – 123.5 tons/ha And the cost of biochar will be $71.6 - 108.7 – 177.9 – 390.4 – 741.3/ha	$34 – 85 – 171 – 341 – 512[93] for an application rate of 5 - 12.5 – 25 – 50 – 75 tons/acre Prorated per ha, the application rate per ha is: 12.35 – 30.9 – 61.8 – 123.5 – 185.3 tons/ha And the cost of biochar will be $64.2 – 210 – 422.5 – 842.6 – 1265.2/ha	These figures are based on a study by Williams and Arnott[94]. They cover only variable costs (capital costs are ignored, and the biochar cost is also disregarded). Ideal saturation rates of soil with biochar are not known.

Table 3. CO2 price range

Market-based price	**Info Source**	**Comments**
$1-7.40/ton CO2	Galinato et al.[95]	Chicago Climate Exchange, 2008
$17-31/ton CO2	Galinato et al.[96]	European Climate Exchange, 2008
$1-31/ton of CO2	Galinato et al.[97]	this price range is based on the Chicago Climate Exchange and the European Climate Exchange
Scientifically-constructed price	**Info source**	**Comments**
$21 per ton of CO2 in 2010	Ackerman[98]	An Obama Interagency Working Group has approved a “central” estimate of $21 per ton of CO2 (2010). The proposed SCC value is based on the three economic

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[91] Williams and Arnott, p.27-28

[92] 1 hec = 2.47105 acre, http://www.metric-conversions.org/area/hectares-to-acres.htm

[93] The cost is given based on the trenches 2 feet deep, and at trenching and application rates of 15 feet per minute (Williams and Arnott, p.23)

[94] Williams and Arnott, p.23-28

[95] From Galinato et al. p.6347

[96] From Galinato et al. p.6347

[97] From Galinato et al., p.6347

[98] Ackerman, p. 2

		models, FUND, PAGE, and DICE. All three are based on erroneous assumptions (value the lives of people saved from warming based on their per capita incomes; higher range of estimates is ignored and it is assumed that developed nations will adapt to climate change at near-zero cost; it is assumed that most people will prefer a warmer climate. The discount rate the working group has used was 2.5 to 5% per year.
$5-80 per ton of CO2 in the year 2030	Boyce and Riddle[99]	Intergovernmental Panel on Climate Change (IPCC) (2007) “Summary for Policymakers,” in Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmmental Panel on Climate Change, p.19. Available at www.ipcc.ch/SPM040507.pdf.
$37/ton CO2	Maraseni et al.[100]	Estimate taken from Lehmann, J.A. A handful of carbon’, Nature. 2007
$37/ton of CO2	Lehmann[101]	Under this study the biochar sequestration and bioenergy from pyrolysis becomes economically viable under this price.
$41-124 per ton of CO2	Ackerman	The UK first put the social price on carbon and now it values CO2 based on its mitigation costs. The range is $41-124 with a central estimate of $83[102].
$50/tCO2	Boyce and Riddle[103]	A study by the MIT Joint Program on the Science and Policy of Global Change thinks such a price is needed to reduce emissions by 80% by 2050, “with the price gradually rising to $730/tC by that year (Paltsev et al., 2007)” (Boyce and Riddle, p.9). $730/tC is $202/ton of CO2.
$ 25-85 per ton of CO2	Stern Review, from Lehmann[104]	Stern, N. The Economics of Climate Change: The Stern Review (Cambridge Univ. Press, Cambridge, 2007).
$200/ton of CO2	Boyce and Riddle[105]	Boyce and Riddle use this estimate based on the MIT study and the one by Barnes and Breslow (these authors in turn refer to the studies collected in the Energy Journal by scientists trying to deduce the carbon price needed to achieve Kyoto Protocol targets. The carbon price range given is $20-400 per ton (Weyant and Hill, 1999).

Appendix B. Research Design on the Farmers’ Stance on Biochar

The purpose of my research on biochar has been to learn about biochar as a technology that has important environmental, social and economic policy implications. Specifically, I intended to get a picture of where biochar stands on the international and US arena, and what the Massachusetts legislative status quo on biochar is. My aim has also been to identify the themes, interests, concerns

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99 From From Boyce and Riddle, p. 9

[100] Maraseni et al., p. 854

[101] Lehmann, “A Handful of Carbon”, p.2

[102] Ackerman, p. 2

[103] MIT Joint Program on the Science and Policy of Global Change, from Boyce and Riddle, p.9

104 Lehmann, p.2

105 Boyce and Riddle, p. 9

and attitudes of farmers with regard to biochar. The farmers' level of knowledge, understanding and perception of the biochar use and production, as well as the factors affecting the farmers' interest in the biochar application.

The population under a qualitative study were farmers from the Amherst area regardless of the size of a farm and type of farming (organic vs. non-organic). The criteria for selection of farmers were: (i) farm ownership and (ii) cultivation of vegetable crops, in contrast to dairy farming businesses only, (iii) some knowledge about biochar.

I applied a purposive and chain sampling strategy to come up with a selection of farmers for interviews (I contacted specialists of the New England Small Farms Institute (Belchertown) and members of the Pioneer Valley Biochar Initiative). I also visited the Amherst Farmer's Market. This process resulted in four in-person interviews and one phone interview with local farmers.

Appendix C. Interview Questions for Farmers

1. Tell me please about your farming experiences. When you started, what's the scope of your farming, what crops you grow, what difficulties you experience.
2. Have you heard of biochar? If yes, where from? What do you know about it? (was it easy for you to get that information? Is it readily available to farmers?)
3. Is biochar technology interesting to you?
4. Do your farmer-colleagues know of biochar? Have they ever applied it on their fields?
5. Which properties of biochar are you most interested in? least interested in and why?
6. What are the main driving factors be for you to apply biochar?
7. Does application of biochar in your farm to grow produce change your marketing strategy? How?
8. Say, the government is giving carbon credits to farmers for biochar application in their fields. Will it be a sifnifican impetus for farmers to start using biochar?
9. Would it stimulate your use of biochar if this technology were accepted and supported by state regulators? What policies do you think would be helpful?
10. Do you feel an information/knowledge gap with regard to biochar? where would you be willing to receive information sessions/trainings? What entity should it be to provide the services thereof?
11. Tell me what you think about the climate change. Do you believe in it? (Can you say if you feel its impact on your activities?)
12. Please describe your preferred option of biochar production and give your rationale for it: a centralized manufacturing unit (with farmers contributing organic wastes and then receiving/buying a share of biochar), a mobile pyrolysis unit (with multiple farmers having access to it), or a farm-scale unit you own and use on your farm?

Appendix D. Carbon Content by Types of Carbon Sinks

Type of a carbon sink	**Carbon amount content by Chris Goodall**	**Carbon amount content by the Parliamentary Library of the Government of Australia**[106]
Soils	1.6 trillion tons	The ocean is the largest carbon sink on earth, which has been decreasing with the increase of anthropogenic CO_2 emissions.
Plants	0.6 trillion tons	

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[106] http://www.aph.gov.au/library/pubs/climatechange/responses/mitigation/carbon.htm#ocean

Oceans	No indication	Researchers estimate that carbon content of oceans before the industrial revolution was “60 times as much carbon as the atmosphere and 20 times as much carbon as the land vegetation and soil”[107].
Atmosphere	0.8 trillion tons	

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[107] http://www.aph.gov.au/library/pubs/climatechange/responses/mitigation/carbon.htm#ocean