Biochar: A regional Supply Chain Approach in View of Climate Change Mitigation

Viktor J. Bruckman, Jay Liu, Başak Burcu Uzun, Esin Apaydın-Varol (eds.)

Climate change poses a fundamental threat to human prosperity, and thus solutions for both mitigation and adaptation strategies are becoming increasingly necessary. Biochar offers an interesting and eco-friendly carbon sequestration solution. However, it also raises a number of questions, regarding sustainable feedstock provision, biomass pyrolysis, and biochar amendment. These questions, among various others, are addressed in this state-of-the-art compendium. Covering a broad geographical range, this interdisciplinary volume includes regional assessments of biochar systems from North America, Europe, the Near East, and Southeast Asia. It focuses on the entire biochar supply chain, from the availability and economics of biomass resources, to pyrolysis, and ultimately to the impacts on soil properties when biochar is used as a soil amendment. The combination of theory with practical examples, including case studies and experiments, makes this a valuable book for researchers, policymakers, and graduate students alike, in fields such as soil science, sustainable development, climate change mitigation, biomass and bioenergy, forestry, environmental engineering, and pyrolysis.

Keywords: biochar, climate change, soil improvement, carbon sequestration, supply chain, biomass, pyrolysis, biochar system, life-cycle assessment

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Chapter 1: Biochar in the view of climate change mitigation: The FOREBIOM experience

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Abstract

Biochar is currently one of the dominant topics in soil research, despite the fact that it is not a new discovery. It has the potential to address some of the most pressing questions humanity is currently facing, i.e. climate change, food security, energy security and environmental pollution. However, a soil system is very complex and together with the multitude of biochar production settings and nearly infinite potential feedstock resources it becomes evident that there is no single solution for these challenges available. This is specifically an issue when addressing the potentials of biochar for Climate Change mitigation via reduction of greenhouse gases (GHG). Systems approaches are needed, covering the entire supply chain and backed up with life-cycle-assessments to ensure a positive impact by using biochar as a tool for environmental management. This chapter provides a summary and brief introduction of the subsequent chapters of this book with a focus of biochar for climate change mitigation, including an economic assessment of GHG abatement costs. The FOREBIOM project will be briefly introduced and results on biochar erosion after amendment on a forest floor are presented.

Keywords: biochar, carbon sequestration, GHG emission, supply chain, climate change

Chapter 2: A supply chain approach to biochar systems

Nathaniel M. Anderson, Richard D. Bergman, Deborah S. Page-Dumroese

Abstract

Biochar systems are designed to meet four related primary objectives: improve soils, manage waste, generate renewable energy, and mitigate climate change. Supply chain models provide a holistic framework for examining biochar systems with an emphasis on product life cycle and end use. Drawing on concepts in supply chain management and engineering, this chapter presents biochar as a manufactured product with a wide range of feedstocks, production technologies, and end use options. Supply chain segments are discussed in detail using diverse examples from agriculture, forestry and other sectors that cut across different scales of production and socioeconomic environments. Particular attention is focused on the environmental impacts of different production and logistics functions, and the relationship between supply chain management and life cycle assessment. The connections between biochar supply chains and those of various co-products, substitute products, and final products are examined from economic and environmental perspectives. For individuals, organizations, and broad associations connected by biochar supply and demand, achieving biochar's potential benefits efficiently will hinge on understanding, organizing, and managing information, resources and materials across the supply chain, moving biochar from a nascent to an established industry.

Keywords: supply chain, supply chain model, logistics, climate change mitigation, product life cycle

Chapter 3: Life cycle analysis of biochar

Richard D. Bergman, Hongmei Gu, Deborah S. Page-Dumroese and Nathaniel M. Anderson

Abstract

All products including bioproducts have an impact on the environment by consuming resources and releasing emissions during their production. Biochar, a bioproduct has received considerable attention because of its potential to sequester carbon in soil while enhancing productivity thus aiding sustainable supply chain development. In this chapter, the environmental impacts of producing biochar using a holistic method called life-cycle assessment (LCA) or more generally life-cycle analysis is discussed. LCA is an internationally accepted method that can calculate greenhouse gas (GHG) and other emissions for part or all of a product life cycle. The present chapter will show how LCA can assess environmental impacts of the entire supply chain associated with all steps of the biochar system, from biomass harvesting through biochar production to soil amendment with a focus on the production stage. Exploring a biochar system from a forestry LCA perspective, a new thermochemical conversion technology developed in the United States and used to process waste woody biomass will be described. In particular, the conversion unit's environmental performance based on the LCA research conducted so far will be described. Although this chapter will present LCA mostly from a forestry perspective, non-forestry agricultural activities will be discussed.

Keywords: life cycle analysis, LCA, GHG emissions, distributed-scale pyrolysis, environmental performance, biochar system, sustainable.

Chapter 4: Systems integration in European forestry: Drivers and strategies

Saran P. Sohi

Biochar is a product with multiple functions and a range of uses, and which could be manufactured from a range of biomass types, including wood and forest residues. Economic production and use of biochar may take place within spatial boundaries that contrast greatly in total area and patchiness. At the moment, however, biochar is generally considered at a project level and assessed quite narrowly from the perspective of soil or crop effects or energy yield. This chapter presents a set of scenarios for how biomass from trees grown in different contexts might lead to production of biochar used and deployed for contrasting purposes in multiple markets. The integration required across markets and sectors is considered, distinguishing options that are more or less spatially contained (circular versus directional), with implications for environmental sustainability. Four types of forestry are considered as a source of biomass: brownfield sites, short rotation forestry, short rotation coppice and trees on amenity land. As well as forestry, horticulture, agriculture and the urban landscape are considered as consumers of biochar, often as a formulated product. The scenarios emphasize the range of opportunities that may be available, but also the complexity of the systems fit, which includes aspects of spatial logistics and questions of scale.

Key words: Biochar, forestry, systems, products, logistics, scale

Chapter 5: Biochar as an integrated and decentralised environmental management tool in the Botanic Garden Berlin-Dahlem

Robert Wagner, René Schatten, Kathrin Rößler, Ines Vogel and Konstantin Terytze

Abstract

Within the research project TerraBoGa, located at the Botanic Garden Berlin-Dahlem, biochar was explored as a mean to achieve a closed loop recycling system. The annual quantity of plant residues, as well as the potential amount of the valuable nutrient resources like urine and faeces of the employees and visitors was determined and an integrated sustainable sanitation system was developed. A carbonization plant was installed to provide energy and to produce biochar from green waste. The addition of biochar to the composting process reduced the emission of greenhouse gases and showed substantial improvements in the moisture, odour and substrate structure parameters when compared with pure compost. In all plant trials undertaken, the amendment of biochar resulted in either better or similar plant growth when compared with the plant specific standard substrates traditionally used. Biochar as an additive for horticultural substrates can reduce the use of peat up to one third without adversely affecting plant growth. The production and application of biochar as a nutrient carrier and nutrient storage medium, has a great potential to close the regional/small material cycles in conjunction with sustainable biomass and organic waste management.

Keywords: Botanic Garden Berlin, biochar system, closed loop, compost, horticultural substrate, nutrient leaching, sanitation

Chapter 6: An integrated approach to assess sustainable forest biomass potentials at country level

Michael Englisch, Thomas Gschwantner, Thomas Ledermann and Klaus Katzensteiner

Abstract

Forests are important for providing wood for products and energy and the demand for wood is expected to increase over the next decades. The potential woody biomass supply was estimated for the period 2000–2020 for stem wood as well as residues, taking into account economic, environmental and technical restrictions. Constraints reducing the availability of forest biomass were defined and quantified for three mobilisation scenarios and five wood price scenarios in order to estimate the realisable potentials. The theoretical biomass potential was estimated from Austrian forest inventory data and applying the PROGNAUS forest growth simulator. It lies between 32.7 and 38.4 million m^3 equivalents yr^{-1} over bark for the period 2000–2020. The realisable potential in Austria was estimated in a range between 23.9 and 31.1 million m^3 equivalents yr^{-1} over bark for the period 2000–2020. These potentials represent 73–84 % of the theoretical potential. Nutrient sustainability in context of whole-tree harvesting appeared to be an important constraint when considering how much biomass is realisable from forests. The attitude of private forest owners towards increased harvest of forest biomass is also of major importance for the realisable potential, given the small-scale structure of forest ownership in Austria.

Keywords: Austrian forest inventory, biomass potential, PROGNAUS, biomass mobilization, harvesting constraints, theoretical potential, forest ownership structure

Chapter 7: Sustainable biomass potentials from coppice forests for pyrolysis: chances and limitations

Valeriu-Norocel Nicolescu, Eduard Hochbichler and Viktor J. Bruckman

Abstract

Coppice forests, originating from vegetative propagation (stump stools or root suckers), are an important component of forest ecosystems worldwide. Even their economic importance has been reduced in Europe especially since the World War II, they still serve as important sources of raw materials (mostly firewood) for local communities. In addition, coppice forests could be considered as “hotspots of biodiversity”, have high habitat, historical and genetic resource values while being relatively resistant against environmental impacts such as droughts. In this context, our chapter emphasizes the main characteristics of silvicultural coppice systems (e.g., simple coppice, short rotation coppice, high coppice, coppice selection, and coppice with standards), their ecology, history and current significance in Europe. The two case studies on carbon stocks of coppice with reserves and coppice with standards in Austria are important arguments for considering coppice forests as a sustainable source of sawlogs for highly important wood products, of biomass (energy wood) that can be used for firewood as well as in pyrolysis processes.

Keywords: coppice, vegetative propagation, biomass potential, biodiversity, carbon stocks, energy wood.

Chapter 8: Towards environmental and economic sustainability via biomass industry: The Malaysian case study

Tang Kok Mun, Wan Asma Ibrahim and Wan Rashidah Kadir

Abstract

Despite the rapid industrialization of Malaysia, the agriculture sector remains one of the major economic contributors. Important crops include oil palm, rubber, sustainable forestry as well as paddy. Biomass has always been used for the upstream generation of steam and power at the milling and primary processing stage in Malaysia. The production and utilization of biochar from agro-based biomass is one of the major research areas in Malaysian universities and research institutions. The biomass sector in Malaysia has the potential to satisfy the three key pillars of sustainable development i.e. environment, business and social benefits. Biochar can be used as soil enhancer where it can be mixed into compost with other ingredients to produce high performance bio-fertilizers. The use of biochar in the urban landscape and green building sector is also being explored as it has been successfully applied for tropical rooftop greening as far back as 2004. Nevertheless, there are still challenges and gaps that need to be addressed via a combination of policy and legal instruments as well as actions and strategies with a focus on the biomass sources.

Keywords: Malaysia, biomass industry, oil palm, agriculture, bio-fuels, waste materials, policy instruments, green buildings

Chapter 9: Carbon sequestration potential of forest biomass in Turkey

Betül Uygur and Yusuf Serengil

Abstract

The role of Turkish forests to mitigate GHG emissions under the present policy incentives is evaluated in this chapter. Currently, the forestry sector is an increasing sink whereas the GHG emissions of the sectors energy, industry, agriculture and waste are increasing faster. The main drivers of GHG removals by forests are the difference between wood increment and harvest rate, and ambitious afforestation/reforestation programs. Potentially, wood biomass could supply a significant part of the energy demand and could be a substitute for fossil fuels. However, the current policy framework does not reward the implementation of such initiatives. Renewable resources constitute some 9 % of Turkey's primary energy supply, and almost half of it is provided from biomass resources. Mostly agricultural and animal wastes are collected and converted into energy in this way but the amount decreases every year in contrast with the global trend. The use of forest biomass as an alternative energy source is very limited in Turkey and there is not much support from the government on this. The biomass energy sources are emphasized in the Climate Change Action Plan of Turkey prepared in 2011 but the government failed to incentivise this with efficient policy approaches yet.

Keywords: Turkey, carbon sequestration, forest management, biomass, LULUCF sector, renewable resources

Chapter 10: Biochar production

Frederik Ronsse

Abstract

This chapter gives an overview of the key technologies to produce biochar. First, an introduction will be given to the different thermochemical conversion techniques of dry biomass (including pyrolysis) which result in char as one of the product fractions. A second part of this chapter is devoted to the discussion on how the biochar physicochemical properties result from the type of biomass feedstock used, as well as from the prevailing process conditions applied during thermochemical conversion – as some of these physicochemical properties in biochar have a major impact on the functionality and stability of biochar in soil. A major challenge for the successful deployment of biochar systems is to render its production economically profitable. Hence, this chapter concludes with an economic assessment of biochar. This last part of the chapter also emphasizes the potential increase in value creation in the biochar production process by identifying potential economic uses of co-products, including bio-oil and producer gas.

Keywords: biochar production, thermochemical conversion, pyrolysis, physicochemical properties, functionality, stability, profitability

Chapter 11: Biomass pyrolysis for biochar production: kinetics, energetics and economics

Byungho Song

Abstract

This chapter briefly introduces the pyrolysis process in terms of kinetics, energetics and economics. In this scope, firstly simple kinetic models are described for biomass pyrolysis and then the product distribution is discussed. The yields of gas, oil and char are predicted by using chemical kinetics, however it is very difficult to predict the yields of each gas species. Therefore, in this chapter, empirical correlations are used together with the elemental balances to predict the yields of gas species for reactor simulation. Also, a detailed application of the empirical relationships from Neves et al. (2011), elemental balances, and energy balance on the prediction of pyrolysis products are given for the simulation of devolatilization stage in a biomass gasification process. The production of biochar through pyrolysis process is simply described. Finally the results from the several studies on energy balances and economic feasibility for the addition of biochar application to the normal bio-energy system are summarized.

Keywords: energetics, kinetic models, product distribution, reactor simulation, energy balance, pyrolysis products, economics.

Chapter 12: Pyrolysis: A sustainable way from biomass to biofuels and biochar

Başak Burcu Uzun, Esin Apaydın-Varol, Ersan Pütün

Abstract

Biomass provides 14 % of the world's primary energy production, but it is largely wasted by inefficient and unsustainable use. To exploit the full potential of this energy source, new approaches and modern technologies such as pyrolysis and gasification are needed. Pyrolysis is the most promising thermal decomposition method for the conversion of biomass into valuable bio-products. The process produces a solid fraction (bio-char), a liquid fraction (bio-oil) and a mixture of gases. Depending on pyrolysis conditions, bio-char for soil amendment, activated carbon, carbon fibers, bio-fuels, value-added chemicals (PF type adhesives, phenolics, levoglucosan, octane enhancers, fertilizers) and gas products (hydrogen, methane, ethane and propane) could be achieved. The ratio of the products varies with the chemical composition of the biomass and operating conditions such as pyrolysis temperature, heating rate, reactor configuration, pyrolysis atmosphere, reaction time, particle size, etc. In the scope of this issue, this chapter covers the definition and sources of biomass, thermal behavior of biomass and its components, fundamentals of pyrolysis process, and effects of the process parameters on yields and composition of products. Moreover, properties of bio-oil and biochar are explained according to their utilization areas.

Keywords: biomass, thermal decomposition, pyrolysis, chemical composition, bio-oil, biochar

Chapter 13: The role of biochar production for sustainable development in Thailand, Lao PDR and Cambodia

Maliwan Haruthaithanasan, Orracha Sae-Tun, Natthaphol Lichaikul, Soktha Ma, Sithong Thongmanivong and Houngphet Chanthavong

Abstract

The majority of the rural population in Cambodia, Lao PDR and Thailand is forest dependent. Biomass fuel, predominantly fuelwood and charcoal, is the main source of energy for cooking and heating in households especially in rural areas. Traditional and simple methods to produce charcoal in combination with a range of different feedstocks leads to a wide range of achievable product qualities, production efficiencies and health risks due to emissions. Improvement in charcoal production techniques is therefore increasingly promoted. Utilization of co-products, such as pyroligneous acid, can be beneficial in agricultural and livestock production, e.g. as insecticide, antimicrobial agent and insect repellent. However, it is necessary to use them in a proper way, therefore more research and ultimately education of farmers and smallholders is needed, along with a robust quality assurance scheme. Moreover, waste from charcoal production such as charcoal dust or chunks of broken charcoal pieces can be used as biochar to improve soil properties. By increasing soil productivity and fertilizer efficiency, the region may contribute to climate change mitigation and sustainable development. This chapter gives an overview of traditional and improved kiln technologies, their characteristics and potentials for biochar production and by-product utilization are discussed in detail.

Keywords: Southeast Asia, charcoal production, traditional charcoal production, kiln improvement, pyroligneous acid, hazardous emissions

Chapter 14: Biochar applications to agricultural soils in temperate climate – more than carbon sequestration?

Gerhard Soja, Elena Anders, Jannis Bücker, Sonja Feichtmair, Stefan Gunczy, Jasmin Karer, Barbara Kitzler, Michaela Klinglmüller, Stefanie Kloss, Maximilian Lauer, Volker Liedtke, Franziska Rempt, Andrea Watzinger, Bernhard Wimmer, Sophie Zechmeister-Boltenstern, Franz Zehetner

Abstract

Biochar as a boon for soil fertility in the tropics still has to show that it is able to provide the same benefits to soils in temperate regions. Here an Austrian study with the objective to analyze the extent of benefits that biochar application offers to agricultural soils in Europe beyond its role as a carbon sequestration strategy is presented. Based on hypothesis testing, several potential benefits of biochar were examined in a series of lab analyses, greenhouse and field experiments. Three hypotheses could be confirmed: biochar can protect groundwater by reducing the nitrate migration in seepage water; biochar can mitigate atmospheric greenhouse gas accumulation by reducing soil N_2O emissions; biochar can improve soil physical properties by increasing water storage capacity. One hypothesis was only partly confirmed: biochar supports the thriving of soil microorganisms only in specific soil and climate settings. Two hypotheses were refuted: biochar does not generally provide nutrients to plants except when produced from specific feedstocks or by combining it with mineral or organic fertilizers; the cost effectiveness of biochar application is not given under current production costs if the existing benefits of biochar are not transferable to financial value.

Keywords: temperate climate, agricultural soils, carbon sequestration, N_2O emissions, nitrate migration, water storage capacity, soil microorganisms

Chapter 15: Opportunities and uses of biochar on forest sites in North America

Deborah S. Page-Dumroese, Mark D. Coleman, and Sean C. Thomas

Abstract

Biochar may be useful for restoring or revitalizing degraded forest soils and help with carbon sequestration, nutrient leaching losses, and reducing greenhouse gas emissions. However, biochar is not currently widely used on forested lands across North America. This chapter provides an overview of several biochar experiments conducted in North America and discusses the feasibility of using in-woods mobile pyrolysis systems to convert excess forest biomass into biochar. Biochar may be applied to forest sites in order to positively influence soil properties (nutrient leaching, water holding capacity), but its biggest benefit may be in facilitating reforestation of degraded or contaminated sites, and in sequestering carbon in soils. The majority of data on biochar applications on forest sites focus on seedling responses and short-term impacts on nutrients, soil physical properties and microbial changes. Long-term field research is necessary to determine water use, carbon

sequestration, nutrient use, and greenhouse gas emissions and the subsequent alteration of forest growth and stand dynamics.

Keywords: North America, degraded forest soils, mobile pyrolysis, forest biomass, soil restoration, carbon sequestration, forest growth

Chapter 16: The role of mycorrhizae and biochar on plant growth and soil quality

Ibrahim Ortaş

Abstract

Arbuscular mycorrhizal fungi (AMF) are key organisms of the soil–plant system, which contribute to the uptake of nutrients and water. AMF also play a role in the aggregation and structural stability of soil. Biochar may provide a suitable habitat or for mycorrhizal growth, which is also favorable in view of productive soils. The impact of a combination of biochar and mycorrhiza on plant growth was assessed in case studies. One of the main findings was that the biochar application alone at 40 $Mg.ha^{-1}$ did not influence growth of citrus seedlings. However, biochar and mycorrhizae species inoculation significantly increased shoot and root dry weight. In general, the contribution of mycorrhizae seemed to be higher than the biochar contribution alone and a combination performed best. This might be a result of the mycorrhizae inoculum activating the biochar when added into the rhizosphere which is a rich medium for other beneficial soil organisms. Although the relationship between biochar and mycorrhizal colonization is not yet entirely clear, the effect of physical protection of hyphae from fungal grazers might be facilitated as a consequence of the pore structure of biochar. The results also provide evidence for a competition between biochar and plant nutrient uptake.

Keywords: Arbuscular mycorrhizal fungi, soil structural stability, plant growth, mycorrhizae inoculum, mycorrhizal colonization, soil nutrients

Chapter 17: The use of stable isotopes in understanding the impact of biochar on the nitrogen cycle

Rebecca Hood-Nowotny

Abstract

The practice of applying biochar to soil could increase crop production, sequester carbon, whilst tightening leaky nitrogen cycles. Biochar has been shown to improve soil properties and even reduce greenhouse gas emissions however the underlying mechanisms which lead to yield increases and greenhouse gas mitigation, still elude us. Recent and on-going studies have demonstrated that detailed analysis of the inherent biogeochemical processes using stable isotope techniques can unravel the complex soil-plant interactions and begin to tease out the multifaceted impacts of biochar on soil processes and plant growth. Here we present a range of nitrogen isotope techniques that could be and have been used, to understand the changes in dominant processes in the nitrogen cycle following biochar addition.

Keywords: nitrogen cycle, stable isotopes, GHG mitigation, biogeochemical processes, soil-plant interactions

Chapter 18: Biochar amendment experiments in Thailand: practical examples

Thavivongse Sriburi and Saowanee Wijitkosum

Abstract

This chapter briefly summarizes the use of biochar to increase the productivity of crop yields and to improve the soil properties in Thailand. The data presented in this chapter is based on research experiments in various types of problematic soils such as infertile sandy clay soil and clay loam. The characteristics of the biochar obtained from the controlled temperature biochar retort for slow pyrolysis process are similar to those of laboratory scale produced biochar. The retort is cost-efficient and can be built easily using locally available materials and also in addition, the retort can use locally-available biomass as feedstock. The study investigated the effects on crop yield of incorporating soil with biochar in the experimental area. Both soil samples and biochar samples were collected before and after cultivation. The results showed that biochar amendment improved the soil properties in terms of organic matter, nutrients and cation exchange capacity. The yield and growth of crops increased significantly when the soil was treated with biochar. In addition, the soil properties, yield and growth of crops increased even more when the soil had been incorporated with both biochar and organic fertilizer. The combination offers a significant improvement of soil and crop yield.

Keywords: crop yields, Thailand, degraded soils, biochar retort, organic fertilizer