PYROLYTIC CHAR IN CLIMATE MITIGATION AND SOIL IMPROVEMENT: POSSIBLE TECHNICAL AND ECONOMICAL SCENARIOS TO UTILIZE BIOMASS IN HUNGARY

GEMESI, Zsolt – PhD. Student of the Doctoral School of Economics and Business Administration of SZIE,Godollo, associate of the RFH, Regional Development Holding, Budapest
FOGARASSY, Csaba – Associate Professor of School of Economics and Social Sciences, head of research group, SZIE, Godollo
LUKACS, Akos – PhD. Student of the Doctoral School of Economics and Business Administration of SZIE, Godollo, Climate Advocate of the British Council, Budapest
HOLLO, Gabor – PhD. Student of the Doctoral School of Economics and Business Administration of SZIE,Godollo, associate of the FVM, Ministry of Agriculture and Rural Development, Budapest
CRUSE, Richard M.– Professor, Iowa State University, Department of Agronomy, Ames, IA, USA

Abstract

Hungary is well-endowed with renewable energy sources, but most renewable energy strategies are only able to offset CO_2 emissions from avoided fossil fuel use. One promising renewable energy production process that lowers atmospheric CO_2 is intermediate pyrolysis producing syngas, bio-oil and biochar. Biochar, has the potential to mitigate climate change, improve soils and reduce environmental pollution. Applied to soils, it improves physical and chemical properties crucial for sustained production and higher yields. The technical and economic feasibility of such an approach has been studied and is well documented in literature. It is necessary to evaluate how this technology can be adopted in Hungary to maximize the environmental and socio-economic benefits. Information is provided about the next phase of research that will be conducted to test relevant hypotheses. To promote this approach, which offers manifold environmental and economical benefits, novel technological options and progressive carbon emission trading possibilities are recommended.

1. Introduction

The purpose of this review is to present the most recent information available in literature, relevant to the environmental and economical ramifications of the application of biochar to soils in Hungary, and to assess the possible technical and economical scenarios for biomass utilization.

The successful models of sustainable modern societies are hinged on three key factors: access to and the uninterrupted supply of safe food, decarbonized energy and clean water. The first two are related to biomass production, which is the output of complex systems that involve multiple factors. Of these, the most critical and common links are soils and climate. Both are non-substitutable inputs and at the same time are determinants of agricultural production. On the one hand, agriculture requires productive soils and predictable climatic conditions. On the other, growing demand for food, feed, fiber and energy from biomass creates incentives for farmers to utilize their resources in ways that secure their success, which is best measured by profits. This often incentivizes practices that may reduce soil fertility with a concomitant decrease in yields, and increased environmental pollution. It is thus crucial to identify technology options that offer sustainable answers to address the question of how to provide food, feed and energy to a growing population.

While food security (availability, access, utilization) and access to clean water is not a major problem yet in Europe, it will play an important role in future policy. On the other hand energy is and will remain a crucial issue. According to the European Environmental Agency[1] the bioenergy potential is still largely unexploited and this industrial sector is expected to have the highest growth rates in coming years. If the climate and renewable energy targets are to be met, by 2020 at least 16-17 percent of the EU's energy needs will be covered by agriculture, including dedicated crops, residues and wastes.

Biomass is the most abundant source of renewable energy in Hungary. The amount of biomass that is economically available for energy production could provide up to 20% of the total primary energy supply (TPES) in Hungary[2]. Various conversion pathways exist, whereby the chemical energy stored in biomass can be released to produce heat, liquid fuels or combustible gases[3]. During fuel combustion, the carbon (C) captured by plants in the vegetative period is released back into the atmosphere. This form of energy production, together with solar, hydro and geothermal energy is more sustainable than if fossil energy sources were used and will help society to reduce CO_2 emissions. In the case of complete biomass combustion the process can be considered C neutral at best, since the amount of C emitted during combustion is captured by plants during vegetative growth. However none of these technologies will reverse climate change.

2. Technology options

A technology derivative of the thermo chemical conversion platform is carbon negative i.e. C is removed from the atmospheric pool in the process. The technology, called pyrolysis, is one of many to produce bioenergy[3]. The process involves the combustion of carbonaceous materials in the absence of oxygen yielding combustible synthesis gases (syngas), bio oils, which are sources of energy[4] and a carbon rich, extremely porous solid byproduct called biochar (Figure 1). Syngas can be converted to power, and the bio-oil can be used to replace crude oil derivatives for green chemistry, pharmaceuticals, or liquid fuel production[5]. The net energy balance of the process is positive by a large margin, as only about 15% of the process energy is needed to operate the pyrolyzer[6]. If the decay-resistant charcoal is returned to the soil, soil organic carbon (SOC) stocks may increase, with measureable reduction of the atmospheric C pool. Agricultural soil carbon sequestration (ASCS) has been analyzed and found technically and economically feasible with due consideration of permanence, leakage and additionality[7]. Utilizing this technology and the carbon negative energy derived from it may not only avoid further contributions to climate change but actually reverse the process by capturing atmospheric C and sequestering it in soils in an environmentally and economically sound process.

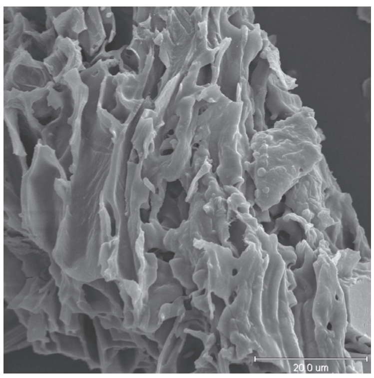

Figure 1. Scanning electronmicroscope image of charcoal. (Courtesy: Best Energies)

In the Charcoal Vision, Laird[6] presents a viable technology option for biomass processing through a distributed network of fast pyrolyzers, ideally mobile units[8]. This system has many advantages over stationary conversion facilities or any other biomass conversion platform. Such fast pyrolyzers rapidly heat pre-dried biomass (water content at 10%V) to an optimum temperature range of 450-550°C [9]. This thermal transformation results in bio-oil, syngas and char (60:20:20% of mass respectively). These systems are designed to utilize the process syngas to provide power for operating the pyrolyzer. Benefits of a distributed energy system involve elements such as infrastructure, logistics and equipment. Pyrolyzers are scalable pending the volume of local biomass sources and distribution. This minimizes transportation costs, which are high per unit of energy gained[8]. Mobile units offer even greater advantages. Pyrolyzers are relatively flexible regarding the inputs, cleanliness during harvest is not as problematic as in the case of e.g. 2nd generation ethanol production. Most biomass suitable for pyrolytic conversion can be harvested with existing farm equipment. Further research is needed to identify how such a distributed system can be adapted to conditions prevailing in Hungary and the type of equipment that is suitable for spreading and incorporating the charcoal into the soil.

3. Economical aspects

The economics of energy production are inevitably tied to the world market price of crude oil. However, recent volatility of crude prices makes it very difficult to create reliable macro-economic models that project into the near future. It is therefore increasingly difficult to make decisions on investment in the energy sector. Information, predictable policies and long-term incentive systems are needed if policy makers wish to engage the business community in addressing the environmental and climatic challenges with economically viable solutions. This section will attempt to highlight some of the key issues relating to the above.

The benefits in connection with lower transportation costs and optimized logistics in general have been addressed. Several C costs have been taken into account[9] that are associated with biomass production, transport, pyrolysis itself, and land application of biochar. Calculations taking all relevant C costs into account suggest that the energy balance is very favorable, with approximately 3–9 kg C energy yield for every kg C energy invested, even with the proposed use of biochar as a carbon sink instead of an energy source10. These calculations suggest that pyrolysis offers comparative advantage over other biomass transformation platforms and yields 3–9 times more energy than is invested in generating the energy. At the same time, about half of the C is sequestered in soil.

From a capital expenditure perspective pyrolyzers are relatively less capital intensive when compared with the cellulosic ethanol platform, and financing can be solved with the involvement of local stakeholders. The distributed network of pyrolyzers will create jobs and bring new entrepreneurial opportunities into rural communities. If the supply chain, from production, through harvesting and storage, including energy consumption is organized locally, a greater portion of the revenue generated by the supply chain can be retained by those communities[6].

Some of the key economic questions in connection with pyrolysis of biomass are related to the inadequate incentive measures that would create drivers for farmers to produce and apply char to soils. If the value chain does not take into account the environmental and climatic benefits, charcoal will be seen as a diversion of inputs, hence less profits. The incentive of applying charcoal to soils to increase yields and decrease costs associated with fertilizer will be relatively small and long-term. Given the proportion of own operated farms to leases, for many farmers this is not a viable economic model. One solution would be to incentivize the pyrolyzer operator to make bio-char and the farmer to apply it to the soil. This incentive could be secured in the form of compensation through emission trading of carbon credits and offsets. Currently contracts for soil sequestration of carbon are discounted on grounds of uncertainty about permanence and leakage. Project-based contracts for carbon sequestration involving biochar application to soils have the potential to be high-value contracts, because the amount of C sequestered is quantifiable. Project based approaches to mitigation are increasing in the US[7], and most recently in the EU, under the collective name: project based Green Investment Scheme – pGIS. The bases of such contracts are protocols, developed to handle technical issues in project-based accounting systems for greenhouse gas reductions. To ensure wider acceptance of these protocols, the relevant numbers, including the actual use of the bio-energy in e.g. transportation or household sectors need to be substantiated and better data are needed for fertilizer savings, biochar stability, and greenhouse gas emissions using a wider range of scenarios.

4. Environmental benefits

4.1. Improved soil fertility

Through effort to maximize profits, bio-energy producers will strive for maximum removal of biomass from agricultural land, especially in the case of short term leases. This may lead to soil degradation, with negative effects on productivity, wildlife habitats, and off-site pollution[12]. The coupling of pyrolysis with organic carbon recycling may address this problem. Trials have demonstrated that about half of the organic carbon can be returned to soils, with a quantifiable improvement in fertility[11].

Recent research has shown that applying biochar to agricultural soils may have multiple benefits. Highly productive soils have been shown to contain considerable amounts of charcoa[6]. Other studies have shown that charcoal in highly stable form has remained in soils under humid tropical conditions for hundreds of years[12]. The anthropogenic soils of the Amazon, Terra Preta de Indio, have sustained Indian tribes for centuries. It is hypothesized that the natives have gradually built up the carbon-stock in small plots, collecting charred wood and other organic residues. Initial studies of soil samples from these locations show that charcoal may have been responsible for the fertility of these plots.

Subsequent trials and in-depth analysis of the properties of charcoal on stability, nutrient retention and water retention have demonstrated that char is resistant to decay[11,13] it has a superior ability to retain nutrients and agricultural chemicals[14] and improves certain physical properties of soils. Stability, and to the same extent rapid decomposition of some portions of biochar are caused by its heterogeneous chemical nature and the particulate form[15]. Nutrient retention is the result of the larger surface area, higher negative surface charge and greater charge density relative to soil organic matter. The retention of nutrients also reduces leaching and the pollution of water resources. The relatively low density has the capacity to increase macroporosity of high clay soils, resulting in improved hydrologic properties, better aeration and root penetration. Charcoal also increases the ability of sandy soils to retain more water and nutrients. In summary the environmental benefits are threefold: (1) climate change mitigation, (2) soil improvement, (3) reduction of environmental pollution. In addition to these positive aspects biochar also leads to higher crop yields in some situations as demonstrated by test trials[11].

From the above it seems that using pyrolysis in combination with land application of charcoal, i.e. the biological sequestration of carbon and renewable energy production need not be considered as alternatives, but as part of a coherent and concerted climate change mitigation and energy strategy.

4.2. Climate Change mitigation

The contribution of agricultural production to greenhouse gas (GHG) emissions is well documented[16]. The role of livestock in global warming may be much greater than previously thought. At the same time, the climatic implications i.e. carbon-neutrality of green energy are well demonstrated in numerous studies and life cycle assessments. Given that policy is shifting focus to biorenewables, and as this may create competition for land, there is growing concern about the potential impacts on this natural resource base. For sustainability, these impacts need to be assessed and suitable actions and measures need to be implemented that alleviate the harmful environmental and undesired socio-economic impacts. If sustainability issues are not addressed, this may not only create unnecessary stress on soil and water resources, but may also reduce the beneficial impact of renewable energy use on climate change.

The most significant and apparent effect of combining pyrolysis with charcoal application to agricultural soils is the net withdrawal, or capture of atmospheric CO_2[9]. Carbon in CO_2 assimilated by plants through photosynthesis is converted to biochar. As new CO_2 is fixed by plants, the biochar burial becomes a net sink of C. An achievable level of typical C recovery is around 50%[15]. The time scale over which decomposition of biochar occurs in most soils is very long compared to other SOC forms.

Past research indicated that biochar bio-energy not only results in the net sequestration of CO_2, but that soil applications of biochar was found to decrease emissions of the two greenhouse gases that have a significantly greater global warming potential. In greenhouse experiments, nitrous oxide (N_2O) emissions were reduced by 80% and methane (CH_4) emissions were completely suppressed with biochar additions of 20 g kg-1 to a forage grass stand[17].

5. Discussion and recommendations

The principal argument supporting the application of charcoal as a C sink is that of the major global C sinks, soil and terrestrial vegetation are the only ones that humans are able to influence. By adding charcoal to soils C can be stored with residence time > 100 years[13]. Modest additions of biochar to soil were found to reduce GHG emissions by up to 80%[17]. The co-benefits on soil fertility are also significant. Numerous studies examined the co-benefits of charcoal, including yield effect[6], increased availability of nutrients, and water retention[11]. Result show that less fertilizer is needed, and charcoal prevents the leaching of nutrients into drains or subsurface water.

For Hungary the region of Sand Ridges (Homokhátság) located between the Danube and Tisza rivers offers the most promising opportunities. This dustbowl area, traditionally known for horticulture, faced increasing difficulties in past decades. A complex program including increased SOC via biochar application and an irrigation system based on rainfall management and canalization could bring about an agro-economic revival. Supporting policy measures could result in a win-win situation, where sustainable agriculture can flourish.

To test these hypotheses, and to address questions in connection with soil application of biochar we will combust locally grown bioenergy crops, including: Miscanthus sinensis, Agropyron elongatum, Zea mays (L) in pyrolyzer reactors operated by Chemical Research Institute of the Hungarian Academy of Science and by the Agricultural Engineering Research Institute. Following laboratory analysis of the biochar small scale tests will be conducted on soil samples from the Sandy Dunes Region to test the hypothesized beneficial impact on soil properties. Char will be incorporated into soil samples of the Research Institute for Soil Science and Agricultural Chemistry (RISSAC).

Summary

In summary, applying charcoal to agricultural soils is hypothesized to have several positive impacts[11]. It increases the sorption of nutrients, reduces leaching, and improves physical properties through lowering bulk density in clayey soils, while improving water and nutrient retention in sandy soils. The aggregate effect is higher crop yield. The pyrolytic process generates carbon negative energy which can replace petroleum based transportation fuels and also decreases the level of CO_2 in the atmosphere, by sequestering C in soils. If applied in regions afflicted by degraded soils this may have added economical and social benefits[6].

In this review we presented the technical and economical feasibility of a pyrolysis energy production system in Hungary. We assessed the beneficial environmental impacts and concluded that biochar application to soils has the potential to improve soil fertility and reverse climate change. Therefore it is recommended to continue research to address critical questions before supporting the wider deployment of the system described in the Charcoal Vision[6].

Such actions require the concerted efforts of scientist, stakeholders and policy makers on an EU level. A welcome step in this direction is the international biochar initiative, which needs more policy support and stakeholder involvement in European member states.

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