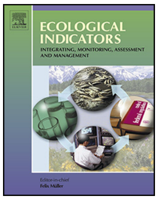
Ecological Indicators 51 (2015) 139–145

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Pyrolysis and biochar potential using crop residues and agricultural wastes in China

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ARTICLE INFO

Article history:
Received 17 April 2014
Received in revised form 1 June 2014
Accepted 30 June 2014

Keywords:
Pyrolysis-based electricity
Biochar
Greenhouse gas emissions
Soil amendment
Agricultural wastes

ABSTRACT

This preliminary study examines the feasibility and applications of pyrolysis and biochar in China to understand issues about bioenergy generation, agricultural cost savings and enhancement of atmospheric quality. Multiple agricultural and animal wastes are analyzed and quantitative measures of economic and environmental benefits are provided. The Poyang Lake, one of the most important clean water lakes in China, is examined to see how pyrolysis and biochar applications can be beneficiary to farmers and society in terms of the economic and greenhouse gas values. Rice straw, corn stover, poplar, orchard wastes, animal wastes and open pasture wastes are primary feedstocks for fast and slow pyrolysis. The results show that both fast and slow pyrolysis are profitable under current situations where corn stover-based pyrolysis yields the highest economic benefits but that of animal wastes-based can offset more GHG emissions. Rice straw yields a loss but it can still be a potential choice since the material is the most popular in study area. Sensitivity analysis is provided to understand the changes of economic and environmental benefits under various market conditions and the results indicate that in general, significant profits of pyrolysis and biochar application bring additional margin of safety and therefore, pyrolysis and biochar does not incur a loss unless input costs increase more than 53% to 64%.

1. Introduction

Sustainable development of economy and environment is one of the most important issues for modern development because it involves both current and future generations. Governments have been finding ways to achieve this goal where clean energy is a potential technology since it provides renewable energy and mitigates climate shift. Among all renewable energy technologies, pyrolysis is one attractive alternative because of its carbon negative property. Pyrolysis involves heating biomass in the absence of oxygen, which decomposes feedstocks into bio-oil, bio-gas and biochar. Bio-oil and bio-gas can be used to generate electricity while biochar can be either used to generate electricity in the pyrolysis plant or hauled to the cropland as a soil amendment (Lehmann et al., 2006). When biochar is burned, it is merely an energy source. However, when biochar is blended with fertilizers and applied on cropland, it is able to enhance crop yield, increase water and fertilizer efficiency and store carbon in a more stable form (Lehmann et al., 2003; Chan et al., 2007). Therefore, pyrolysis and biochar application not only brings renewable energy, but also provides potential economic and environmental benefits. China has been an agricultural country for a long time and hundreds of million people have still engaged in agricultural related sectors. Poyang Lake, one of the largest freshwater lakes in China, fosters more than 10 million populations and plays an important role in environmental sustainability and bio-diversity. More than 5 million populations residing around the lake engage in agriculture, imposing an immediate and potential environmental degradation such as eutrophication due to the significant amount of fertilizers applications. Moreover, incomes of Chinese farmers are low compared to other industries and the government has been putting great efforts to enhance their living standard for decades. To achieve these economic and environmental goals, pyrolysis is one potential technology. With pyrolysis and biochar applications, farmers can enjoy economic benefits from energy production and yield enhancement while the society has access to the lake and ecosystem with better quality. For pyrolysis can be a feasible way of achieving multiple objectives, it must be economically profitable, otherwise it will be discarded. However, if the environmental benefits outweigh the economic loss, development of pyrolysis could still be a desirable method. This study investigates the net economic and environmental impacts of pyrolysis using crop and animal residues including poplar, corn

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http://dx.doi.org/10.1016/j.ecolind.2014.06.043
1470-160X/

stover, rice straw, animal wastes, orchards wastes and open pasture wastes. Specifically, the study examines the follow issues:

(a) Net electricity production and per kW h cost from poplar, corn stover, rice straw and agricultural wastes.
(b) Potential revenues from sale of pyrolysis energy.
(c) Net economic benefits from onsite biochar application.
(d) GHG effects under lifecycle analysis (from feedstock collection to onsite biochar application).
(e) Potential social effects and policy implications.

The study makes a contribution by providing information on economic and environmental effects from pyrolysis using multiple feedstocks and agricultural wastes, which can be useful for future environmental and agricultural policy decisions.

2. Background of pyrolysis and biochar

Pyrolysis is the chemical decomposition of organic materials by heating in the absence of oxygen. During pyrolysis, biomass is converted into three products:

(1) A liquid product called bio-oil, pyrolysis oil or bio-crude.
(2) A solid charcoal product that can be used in a range of applications, including use as a soil additive (and in that use is commonly called 'biochar') or as a source of energy in the conversion process.
(3) A non-condensable gas product containing carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4) and higher hydrocarbons, which is called 'biogas', 'syngas' or 'pyrolysis gas'.

Two types of pyrolysis are predominantly used in biochar production: fast and slow, where the differences depend on their heating rate and heating duration. Slow pyrolysis yields more biochar and less bio-oil while fast pyrolysis produces more bio-oil and less biochar (Lehmann and Joseph, 2009; Sohi et al., 2010). Wright et al. (2008) indicate that fast pyrolysis yields about 15 percent biochar, 70 percent bio-oil and 13 percent syngas. Ringer et al. (2006) indicate that under slow pyrolysis, about 35 percent of the feedstock ends up as biochar, 30 percent as bio-oil and 35 percent as syngas. In both cases, the bio-oil can then be cleaned and further processed to produce higher-quality fuels (Czernik and Bridgwater, 2004), used to produce electricity, or it can be refined to produce chemical feedstocks such as resins and slow-release fertilizers. Each of these is a potential source of value. Although per ton of raw bio-oil has less energy because of water, alkali, sulfur and other chemical components (Diebold et al., 1999; Ruth, 2003; Energy Information Administration (EIA), 2004), chemical engineers are able to clean and upgrade bio-oil to meet the specification for certain petroleum-based distillate and residual fuels (Scahill and Amos, 2003). Moreover, many forms of organic material can be utilized in pyrolysis and produce biochar, including crop- and forestry-waste products, urban-yard wastes, industrial biomass by-products, animal manures and municipal sewage sludge. While biochar was initially viewed as a source of energy, it can be used for water purification, gas cleaning, or for charcoal in home cooking. In addition, it is a potential source of several valuable environmental and agronomic benefits (discussion in Lehmann and Joseph, 2009; Lehmann et al., 2003, 2006; Lehmann, 2007a; McCarl et al., 2009; Kung et al., 2013).

The use of biochar as a soil additive has been proposed to simultaneously mitigate anthropogenic climate change, improve soil fertility and enhance crop production (Glaser et al., 2002, 2009; Lehmann et al., 2006; Ogawa et al., 2006; Woolf et al., 2010). A number of studies have highlighted the potential benefits of utilizing biochar as a soil amendment. These have covered issues such as mitigation of global warming through application of stable C into soil, waste management, production of bioenergy, soil health, and productivity benefits (Atkinson et al., 2010; Laird, 2008; Lehmann, 2007a,b; Lehmann et al., 2006; Mathews, 2008; Ogawa et al., 2006; Sohi et al., 2010; Woolf et al., 2010). Specifically, the energy products and the biochar as a soil additive have GHG implications including displacing both fossil fuel use and nitrogen fertilizer with their associated emissions, plus sequestering carbon. Consequently, biochar applied as a soil amendment is also attracting the attention of policy makers in the United States, Australia, Europe, Japan, and some developing countries (Bracmort, 2009). Fig. 1 indicates the full GHG effects under pyrolysis and biochar applications. However, it is worth to mention that the hazards, risks, and other implications associated with biochar technology are yet to be fully understood (Downie et al., 2011; Kookana, 2010).

In addition to environmental benefits, biochar brings economic benefits. Soil fertility increases have been observed following some biochar soil additions (Adams, 1991; Agblevor et al., 2010; Jeffery et al., 2011; Vaccari et al., 2011), and may studies show that when biochar is applied in soil, it increases crop yield, reduce irrigation needs and enhance fertilizer efficiency (Steiner et al., 2007; Lehmann et al., 2003), all of which have values by increasing income and reducing production costs. However, the exact mechanisms behind these yield improvements still require study (Atkinson et al., 2010; Lehmann et al., 2011). Table 1 summaries the pyrolysis outputs from various biofeedstocks, all of which are available in large quantity in Poyang Lake Eco-economic Zone. With these estimates, the study can quantify the potential economic and environmental benefits from pyrolysis and biochar applications.

3. Economic components of pyrolysis and biochar

Pyrolysis can be feasible only when it is economically profitable. This section introduces the economic components associated with

Table 1
Pyrolysis outputs of various biofeedstocks.

Raw materials	Pyrolysis type					
	Fast			Slow		
	Biochar % Of feedstock (dry ton)	Bio-oil	Syngas	Biochar	Bio-oil	Syngas
Poplar	14	66	13	31	56	7
Corn stover	17	62	21	30	20	50
Rice straw	27	47	26	48	15	37
Orchards wastes	25	41	26	NA	NA	NA
Animal wastes	60	33	7	NA	NA	NA
Open pasture wastes	23	43	25	NA	NA	NA

Source: Tewfik et al. (2011), Mullen et al. (2010), Kern et al. (2012), Graber and Hadas (2009) and Kung et al. (2013).