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Environmental Impact and Bioenergy Potential: Evaluation of Agricultural Commodity and Animal Waste Based Biochar Application on Taiwanese Set-Aside Land

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Abstract

Taiwan imports more than 99% of her energy and suffers from the climate change such as rising ocean level. Therefore, energy insecurity and GHG emissions offset are two serious problems facing Taiwan. This paper examines the possibilities for domestic bioenergy production in Taiwan utilizing set-aside land and analyzes the comparative economics and choice among these alternatives under current Taiwanese agricultural system policies and also under altered energy and greenhouse gas/carbon prices. Biochar, produced from pyrolysis, is also investigated by different uses: whether it is best used as an energy source and/or a soil amendment. Agricultural residuals and animal wastes possible alternatives for pyrolysis systems and therefore, land competition for agricultural feedstocks and supply of agricultural and animal wastes will be incorporated into the study. The study employs modified Taiwanese Agricultural Sector Model (TASM) to simulate the effects of the alternatives in the face of energy and greenhouse gases prices.

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Keywords: pyrolysis, animal manure; agricultural residuals; biochar.

1. Introduction

Renewable energy produced from agricultural feedstocks (hereafter called bioenergy) in Taiwan has been studied widely because Taiwan is heavily reliant on imported fossil fuels and could be directly affected by climate change consequences such as rising sea level and increases in incidence of tropical cyclones [1]. Collectively these forces have raised interest in examining low emission, domestic energy sources in Taiwan and bioenergy is one such possibility

Although bioenergy has the potentially to enhance Taiwan's energy security and reduce its GHG emissions[2], one important factor that may affect the net benefits is the GHG emissions involved with feedstock production and land use change. When agricultural land is converted into other uses, NO_x emissions will change and offset CO_2 emission reductions from bioenergy production. If the change is

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small, this can be neglected. Unfortunately, this change can be large [3-4]. In addition, since the idled land in Taiwan is far from enough to satisfy the domestic demand, new materials that can be used for bioenergy generation must be explored.

This study examines the economic and environmental performance of a set of bioenergy production strategies including production of ethanol, direct firing of electricity production and pyrolysis-based electricity by incorporating sweet potato, poplar, rice straw, corn stover, orchard waste and animal manure as biofeedstock, all of which will be evaluated under a range of energy and GHG prices. The study makes a contribution by analyzing pyrolysis potential and environmental impacts from not only the agricultural commodities but also the various agricultural related residuals and wastes, which provides the insights of Taiwanese renewable energy development and associated social effects. The results will be useful for energy, environmental and agricultural related policies investigation.

2. Literature Review

Unlike bioethanol and direct firing of electricity production, pyrolysis has been considered in many scientific studies because of its carbon negative property. Pyrolysis involves heating biomass in the absence of oxygen and results in the decomposition of the biomass into biooil, biogas and biochar. Biochar can be used as an energy source or as a soil amendment [2,5-8]. As a soil amendment biochar increases soil water and nutrient holding capacity plus seed germination rates and crop yields. In terms of water holding capacity, Glaser et al. [9] find that soil water retention increased by 18% after biochar application. In terms of nutrient savings, the application of biochar has been found to increase the efficiency of nutrients as discussed in [10]. Lehmann et al. [11] also indicates that biochar application would lead to a reduction of N leaching by 60 percent with an accompanying 20% savings in fertilizer need. On seed germination several studies find that biochar improves seed germination rate [12]. In terms of crop yield enhancement, Lehmann [5] finds that biochar increases the plants available nutrients and in turn crop yields. Biochar is also stable in the soil [11] and offers a chance to sequester carbon [5]. Based on these data we assume that rice yields will increase by 5% when biochar is applied and use that the seed and nutrient savings are based on Lehmann *et al.*'s study (20 and 10 percent respectively) while water savings are assumed to be 10% [13].

Electricity and biochar production vary depending on the pyrolysis systems. We examine fast pyrolysis techniques and alternatives uses of biochar along with lifecycle analysis of GHG emissions. Lifecycle analysis [14] has been used to examine GHG emissions from agriculture and bioenergy production in a number of settings. Schaufler *et al.* showed that changes in land-use strongly affected GHG fluxes from cropland, grassland, forests and wetland [15]. Grover *et al.* [4] pointed out that soil-based GHG emissions increase from 53 to 70 t CO_2-equivalents after land use change. They found that N_2O and CO_2 emissions were highest from grassland soils. Baldos found that the direct lifecycle GHG emissions of corn ethanol fuel can exceed the 20% GHG reduction requirement in the US renewable fuel standard [16]. Another study found that zero tillage resulted in higher N_2O emissions than conventional tillage and N_2O emissions were generally correlated with CO_2 emissions [17].

3. Methodology

The study will be done using an agricultural sector model. The model used herein is based on price endogenous mathematical programming. In particular we will use Chen and Chang's Taiwan Agricultural Sector Model (TASM) [18] and extend TASM to cover bioenergy crop production. The total value of these primary commodities accounts for more than 85 percent of Taiwan's total agricultural product value. Availability of cropland, pasture land, set aside and forest land plus crop and livestock mix constraints are specified at the sub-regional level. Input markets for farm labor are specified at the regional level with supply curves. For this analysis we extend the model by adding features related to farm support, bioenergy and GHG emissions.

The algebraic form of the modified TASM is as follows:

$$Max \ \sum_i \int \psi(Q_i)\, dQ_i - \sum_i \sum_k C_{ik} X_{ik} - \sum_k \int \alpha_k(L_k) dL_k - \sum_k \int \beta_k(R_k) dR_k + \sum_i P_i^G * Q_i^G + \sum_k P^L * AL_k + \sum_j \sum_k SUB_j * EC_{jk} + \sum_i \int ED(Q_i^M) dQ_i^M - \sum_i \int ES(Q_i^X) dQ_i^X + \sum_i \int EXED(TRQ_i) dTRQ_i + \sum_i [tax_i * Q_i^M + outtax_i * TRQ_i] - P_{GHG} * \sum_g GWP_g * GHG_g. \quad (1)$$

Subject to:

$$Q_i + Q_i^X + Q_i^G - \sum_k Y_{ik} X_{ik} - \sum_j EC_{jk} X_{jk} - (Q_i^M + TRQ_i) \le 0 \quad \text{for all } i, \quad (2)$$

$$\sum_i X_{ik} + AL_k + \sum_j EC_{jk} - L_k \le 0 \quad \text{for all } k, \quad (3)$$

$$\sum_i f_{ik} X_{ik} - \sum_j f_{jk} X_{jk} - R_k \le 0 \quad \text{for all } k, \quad (4)$$

$$\sum_{i,k} E_{gik} X_{ik} - Baseline_g = GHG_g \quad \text{for all } g. \quad (5)$$

4. Results

The study examines when sweet potato, rice straw and animal manure are used as biofeedstock for bioenergy production. We need to obtain the basic economic value and energy conversion information for rice straw and animal manure, which are abundant agricultural associated wastes in Taiwan.

Table 1. Revenue from Pyrolysis-based Electricity

	Units	Rice straw	Animal manure
Feedstock cost	US$ ton^{-1}	$1000	$1000
Pyrolysis cost (Modules I and II)	US$ ton^{-1}	$46.82	$46.82
Generating cost (Module III)	US$ ton^{-1}	$30.47	$19.13
Electricity value	US$ ton^{-1}	$272.81	$171.22
Net margin (electricity only)	US$ ton^{-1}	$195.51	$105.28

Table 1 summaries the basic economic value from pyrolysis based economics and can be used for pyrolysis plant construction and operation. Compared to the market electricity price, pyrolysis based electricity does not have competitive advantages to the conventional electricity production. However, environmental benefits must be included to reflect the increase on net social welfare.

5. Conclusions

The study examines how Taiwan can benefit from the bioenergy production in terms of economic and environmental benefits. The results indicate that pyrolysis based electricity dominates the conventional bioelectricity when sweet potato, rice straw and animal manures are selected as biofeedstocks. Climate change mitigation could be effective if large scale pyrolysis based bioenergy could be adopted.

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