BIOMASS AND BIOENERGY 35 (2011) 2893–2902

Available at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

Lifecycle assessment of the economic, environmental and energy performance of *Jatropha curcas* L. biodiesel in China

Zanxin Wang [a,*], *Margaret M. Calderon* [b], *Ying Lu* [a]

[a] *School of Development Studies, Yunnan University, No. 2 Cuihu Northern Road, Kunming, Yunnan 650091, China*
[b] *Institute of Renewable Natural Resources, University of the Philippines Los Banos, Philippines*

ARTICLE INFO

Article history:
Received 1 February 2010
Received in revised form
10 March 2011
Accepted 11 March 2011
Available online 30 April 2011

Keywords:
Jatropha curcas L.
Lifecycle assessment
Second generation biodiesel
Financial feasibility
Carbon value
Energy balance

ABSTRACT

Due to issues relating to the sustainability of biofuel production, second generation biofuel has attracted much attention. As a promising feedstock of second generation biodiesel, *Jatropha curcas* L. (JCL) is being massively planted on marginal land in China, but its viability as a biofuel source has not been systematically assessed. This paper performed a lifecycle assessment of the economic, environmental and energy (3E) performance of the JCL biodiesel, assuming JCL oil is either used for direct blending with diesel or further processed into JCL methyl ester (JME). The results show that, at the current technical levels, the production of JCL biodiesel is financially infeasible, but has positive environmental and energy performance. Despite the additional cost incurred in the transesterification process, the net present value of JME is slightly higher than that of JCL oil when a part of the cost is allocated to the co-product, i.e., glycerin. As compared with that of diesel, the production and consumption of per liter JCL oil and JME can reduce 7.34 kg and 8.04 kg CO_2 equivalent, respectively. The energy balances of both JCL oil and JME are 1.57 and 1.47, respectively, in terms of the ratio of the heat value of biodiesel and that of energy input. The main factors affecting the 3E performance of JCL biodiesel are seed yield, co-product output, and farm energy input.

1. Introduction

Because of its renewable, biodegradable, nontoxic and environmentally beneficial characteristics, biofuel is considered an ideal alternative for fossil fuel. The production and use of biofuel has the potential of reducing dependence on petroleum, improving environmental quality, lowering the emission of greenhouse gas (GHG), promoting rural development, and providing farmers job opportunities [1,2].

Like many other countries such as the United States of America and some European Union countries [3], China is laying much effort in producing biofuel for use in vehicles and easing the great pressures from oil scarcity and environmental degradation, and at the same time promoting rural development. In 2006, the National Development and Reform Commission of China set a target of meeting 15% of transportation energy needs with biofuel by 2020 [4].

The production of first generation biofuels whose feedstock is agricultural crops will have a negative effect on food security if produced in large quantities [5,6]. However, using biomass crop produced from non-agricultural land as feedstock to produce second generation biofuel will not affect food security, and can be more conducive to improve the environment than the first generation biofuel. That is, sustainable biofuel production will be better achieved with a shift from the production of first generation biofuel to that of second generation biofuel [1,7]. Thus, much concern has been attached to woody oil plants, among which *Jatropha curcas* L.

* *Corresponding author*. Tel.: +86 13708473922.
E-mail address: wzxkm@hotmail.com (Z. Wang).
0961-9534/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biombioe.2011.03.031

(JCL) is considered as a priority feedstock species in many countries, including China.

J. curcas L. is widely considered an ideal feedstock for the production of biodiesel. It grows in tropical and subtropical climates across the developing world [8]. Apart from the high fat content of its seeds, it has a high potential for the production of biodiesel because of its strong adaptability to the environment, especially in terms of drought resistance, high survival rate, and high seed yield [9].

JCL oil can be easily converted to liquid biofuel, which meets the American and European standards [10,11]. It can also be used as an alternative to diesel for use in engines and reduce harmful exhaust emission, particularly HC, smoke and CO, as compared to diesel [12,13].

JCL oil cannot be directly used in engines because it is of high viscosity and easily forms carbon deposits in engines, which will result in inadequate combustion and reduced engine life. However, it can be used as fuel after it is blended with fossil diesel, or processed into methyl ester. Diluting JCL oil with fossil diesel greatly reduces its viscosity. The viscosity of mixed oil with 30% (v/v) JCL oil is similar to that of fossil diesel [14]. In particular, mixed oil with 2.6% JCL oil can produce the greatest brake force and brake thermal efficiency, minimize fuel consumption, and be used as an ignition-accelerator additive for diesel fuel [15].

To be a viable alternative for fossil fuel, biofuels should yield a positive energy balance, have environmental benefits, be economically feasible, and can be produced in large quantities without compromising food security [16]. The production and use of biofuel may have positive environmental impacts, but not absolutely. The results will be affected by specific factors, such as feedstock, applied production technology, sites, market and others. For example, Farrell et al. [17] conclude that the production and use of bioethanol has a contribution to energy independence and environmental improvement, while Crutzen et al. [18] reveal that the production of biodiesel resulted in an increase in GHG emission due to the use of nitrogen fertilizers.

Despite biodiesel development initiatives in many countries, a few studies have been carried out to assess the environmental, economic and energy performance of JCL biodiesel. To make JCL biodiesel a more sustainable alternative for fossil fuels, the environmental effects have to be investigated so as to provide policy makers with the necessary data for supporting or opposing the energy crops [19,20], and/or to avoid risks and provide a basis for making policies for the development of the biofuel industry before the biofuel industry is developed on a large scale.

The study aimed to assess and compare the lifecycle economic, environmental and energy performance of both JCL oil and JCL methyl ester (JME) in China.

2. Production system of JCL biodiesel

2.1. Distribution and yield of JCL

JCL was introduced in China 300 years ago. It mainly grows in plains, hills, and river basins between 250 and 1600 m above sea level (masl) in southern China, especially Yunnan, Guizhou and Sichuan provinces [21–24]. It was previously used as a medicinal plant or hedge, a raw material of green manure and soap, and a soil fixing plant [25].

The yield of fruits depends on the site condition and the size of trees. Assuming that the spacing of JCL plantation is 2 m × 3 m (1650 trees ha^{-1}), the seed yield of JCL is 0.6–4.5 t ha^{-1} at the present levels of technology and management in China [23,24,26,27]. The oil percentages are 38–41% in seeds [28] and 49–62% in kernels [29].

2.2. Production process of JCL biodiesel

The production chain of JCL oil is divided into four stages, including the production of JCL seeds, the extraction and conversion of seed oil, the distribution of JCL biodiesel, and the consumption of JCL biodiesel (Fig. 1).

2.2.1. Production of JCL seeds

The production of JCL seeds involves the establishment and maintenance of JCL plantation, the harvest of JCL seeds, and their preliminary treatment. JCL trees can be propagated by seedling, cutting, and micro-propagation. In practice, JCL plantations are generally established using seedlings. This is because the survival rate of cutting plantation is low, while micro-propagation is much costly.

Usually, irrigation and fertilization are required after the plantation is established. In the dry season, the plantation is watered twice a week. For some areas with a high annual rainfall level of more than 2500 mm, irrigation is not necessary. The JCL plantation is fertilized with chemical fertilizers, green manure and JCL seed cakes. Green manure is placed into the holes during site preparation. Chemical fertilizers are applied after seedlings are transplanted during the first three (3) years. In each of the 3 years, about 100 g of urea and 250 g of NPK for each tree are applied in the first part of the year, followed by top dressing with 100 g of urea for each tree. From the fourth year to the 30th year of plantation, JCL seed cake and green manure are used instead of chemical fertilizers. One kilogram of seed cake is equivalent to 0.15 kg of NPK fertilizer (N:P:K = 4:2:1) [8].

Weeding and disease control are important during the early ages of JCL plantation. To remove weeds at the farm, herbicide application and manual cutting are applied once a year. Glyphosate is sprayed at a rate of 2 l ha^{-1} yr^{-1} during the rainy season, and manual cutting is conducted during the dry season. JCL is disease-resistant, and its parts can be used to produce insecticides. The damage from attack of insects is not significant. However, carbendazim should be applied to control diseases. The dose of this fungicide is 2 kg ha^{-1} yr^{-1}. It takes 5 man-hours to apply the fungicide to each hectare of JCL plantation.

JCL trees are pruned once a year during the first 3 years. Starting from the 4th year, only minor pruning is required. Pruning one hectare of plantation requires 5 man-days.

There is no harvest for the first two years after planting because fruit yield is too low. It is assumed that JCL will have a constant yield from the 5th year onwards, while the yields in the 3rd and 4th years are 1/3 and 2/3 of the regular seed yields, respectively. The harvested fruits are dried by sunlight, followed by husk removal. One man-day of labor is capable of picking 100–200 kg fruits and removing 50 kg dried fruits per day. The husks are viewed as a co-product and a substitute for coal.