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RESEARCH REPORT

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Producing Biodiesel from *Jatropha curcas* L. in Yunnan, China: Life-cycle Environmental, Economic and Energy Performance

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As in many countries, policy makers in China see biofuel as a potentially important part of the move to a sustainable, post-oil economy. To contribute to this important energy debate, a new EEPSEA study looks at the economic and environmental performance of one potential bio-fuel crop: *Jatropha curcas* L (JCL).

The study is the work of Zanxin Wang, Ying Lu and Siguang Li from China's Yunnan University. It shows that, given current technology levels and management practices, the production of JCL biodiesel is not economically feasible. However, it also shows that JCL biodiesel has excellent performance from both an environmental and energy production point of view. Moreover, it is clear that, if JCL seed yields can be improved, then biodiesel made from the plant would be economically feasible to produce.

With this in mind, the report outlines a number of initiatives that could be pursued to make JCL biodiesel an effective part of China's overall energy policy. These include providing grants and other funding to optimise the JCL biodiesel production process.

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**Producing Biodiesel from *Jatropha curcas* L. in Yunnan, China:
Lifecycle Environmental, Economic and Energy Performance**

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EXECUTIVE SUMMARY

The seeds of *Jatropha curcas* L. (JCL) can be used to extract oil for direct blending with fossil diesel, or be further processed into JCL methyl ester (JME) through transesterification reaction. This study assessed the economic, environmental and energy performance of the production of the two end products using a lifecycle analysis method. It was assumed that: (1) the time horizon for the project is 30 years (the life expectancy of *Jatropha* is 30-50 years), the working days are 330 days per year, and the discount rate is 8%; (2) the spacing of JCL plantation is 2 m × 3 m, or the tree density is 1,650 per hectare; (3) the seed yield is 1,485 kg per hectare (500 fruits per tree); (4) The distance between the JCL plantation and oil refinery or fertilizer plants is 50 km, while the distance between the oil refinery and oil distribution station is 10 km; the carrying capacity of the trucks is 3 t and that of the oil tankers is 5 t.

The primary seed production data was collected from Honghe and Chuxiong Prefectures, Yunnan Province, China, where *Jatropha* plantations have been developed on a massive scale. The technical oil extraction data was collected for Erkang Science and Technology Co. Ltd, a vegetable oil producer.

The results show that, at the current level of technology and management, the production of JCL biodiesel is financially and economically unfeasible, but that JCL biodiesel has excellent environmental and energy performance. However, if the seed yield can be improved to above 2.46 tonnes per hectare, it would be economically feasible to produce any of the two end products and the value of carbon emission reduction and the fruit husks can provide a justification for providing producers with a subsidy.

To promote the development of the JCL diesel industry, incentive policies are vital. When JCL seed and oil is produced by different producers the required annual subsidies are about 881.66 yuan per hectare for seed producers and 2.68 yuan per l for oil producers when the seed yield is 1,485 kg per tonne and the present diesel price is 5.22 yuan per l, assuming a margin of 10% for producers. When JME is the end product and producers purchase JCL seeds to produce JME, a subsidy rate of 4.01 yuan per l should be made to producers so as to promote the production of JCL JME. If the seed yield is higher than 1,485 kg per ton, the subsidy rate for producers at different stages of the production chain tends to decrease. In particular, no subsidy is required if the seed yield is higher than 3,267 kg per tonne and the present seed price (2 yuan per kg) prevails. If the production chain is run by a single producer, subsidy rates for the end products of JCL and JME are 3.97 yuan per l and 4.01 yuan per l, respectively when the seed yield is 1,485 kg per tonne.

The production and use of JCL biodiesel makes a significant contribution to the reduction of carbon emissions with a rate of 7.34 kg CO_{2e} per l for JCL oil and 8.04 kg per l for JME respectively. With an increase in seed yield, the carbon balances of the two end products increase. The main factors affecting carbon balance are seed yields and co-products. The value of carbon emission reduction and co-products may provide a

justification for the subsidization of JCL biodiesel production if a seed yield higher than 2.46 tonnes per hectare can be obtained.

For both end products energy efficiency in terms of E_1 , E_2 and E_3 are all greater than one. That is, the production of both JCL oil and JME are energy-efficient. Without the process of transesterification, the production of JCL oil is more energy-efficient. The energy efficiency becomes higher as the seed yield increases. Other factors affecting energy efficiency include seed yield, co-product output and farm energy inputs.

In Yunnan Province, the types of land suitable for planting JCL have been identified as waste land and hills, “four sides” (the sides of homesteads, villages, roads and ditches) and scattered plots (unused small patches of land, sporadically distributed), and shrub land and open forests. Since waste land and hills are mainly barren, their opportunity costs are negligible. On four sides and scattered plots, JCLs are usually planted for specific purposes, such as fencing and erosion control. The benefit of such kinds of land use can be considered higher than the opportunity cost. When JCLs are planted on shrub land and open forests, the impact on land use depends on how the JCL plantation is established. If shrub land and open forests are cleared to plant JCLs, costs may be high because of a loss of biodiversity, carbon emissions and other ecological damage. However, if JCLs are planted by intercropping, the impact on land use is negligible.

Finally, policy implications were drawn from the study.

1.0 INTRODUCTION

1.1 Background

1.1.1 Rationale of Biodiesel Production

The increases in crude oil prices and the concern for environmental protection have created a spur in the search of renewable alternative sources of oil (Shay 1993; Runge 2007; Hazell and Pachauri 2006). As an alternative fuel for diesel engines, biodiesel is attracting more and more attention throughout the world. As a renewable, biodegradable and nontoxic fuel, biodiesel has low emissions and thus is environmentally beneficial (Krawczyk, 1996). In recent decades, considerable research has been done on vegetable oils as diesel fuel, including palm oil, soybean oil, sunflower oil, coconut oil, rapeseed oil and tung oil (Ma and Hanna, 1999).

Although biodiesel is a promising fuel, the production of biodiesel is challenged by its cost and the limited availability of fat and oil resources (Ma and Hanna, 1999). The present production of biodiesel is only about 4 billion liters per year globally (Rajagopal and Zilberman 2007). Biodiesel has to compete economically with petroleum diesel fuels and the availability and sustainability of sufficient supplies of less expensive feedstock will be a crucial determinant in delivering a competitive biodiesel to commercial filling stations. One way of reducing biodiesel production costs is to use less expensive feedstock containing fatty acids such as inedible oils, animal fats, waste food oil and byproducts of refining vegetable oils (Veljkovic et al., 2006). Fortunately, inedible vegetable oils, mostly produced by seed-bearing trees and shrubs, can provide an alternative. With no competing food uses, this characteristic turns attention to *Jatropha curcas* L. (JCL), which grows in tropical and subtropical climates across the developing world (Openshaw, 2000).

Since 1998, the consumption of energy in China has been increasing at a rate of 5%, which is three times faster than the world average. China is now the second largest importer of oil in the world. In 2005, China imported 168 million tonnes of crude oil, which accounts for 42.9% of the total amount of domestic consumption. The demand for oil in China is projected to be 450 million tonnes in 2020 and more than half of it will come from foreign countries (Ma, 2007). Diesel consumption was 67.15 million tonnes in 2000 and 85.3 million tonnes in 2005. The demand for diesel will be 108.3 million tonnes in 2010 and 133 million tonnes in 2015. Thus, it is a difficult task to meet the demand for diesel in China in the long term (Li, 2001). In the next two decades, China will face a severe energy supply challenge. Moreover, given rich supplies of coal and insufficient oil and gas, China has mainly relied on coal for its energy in past decades. As pollution from the burning of coal becomes severer and severer, searching for environment-friendly alternatives to fossil fuel has become an urgent task. Therefore, the development of renewable sources of energy has become an important component of China's energy development strategy (Ma, 2007).

As in many developed and developing countries, the production of bio-fuel in China

is seen as a vehicle to release the pressures created by oil scarcity and to achieve sustainable development. In 2005, China became the world's third largest biofuel producer with an output of one million tonnes, behind Brazil and the US (USDA, 2006). In 2006, the National Development and Reform Commission (NDRC) of China set a target of meeting 15% of transportation energy needs with biofuels by 2020 (USDA, 2006). The State Forest Administration (SFA) of China set a target of establishing 195 million mu (13 million hectares) of biodiesel plantations by 2010. Under Ministry of Science and Technology (MOST) plans, biodiesel production is set to reach 1.5-2 million tonnes by 2010, and 12 million tonnes by 2020 (GTZ, 2006).

In 2007, concerns over food security led China's central government to ban the use of grain-based feedstock for biofuel production and to reorient the country's bioenergy plans toward perennial crops grown on marginal land. As one such crop, JCL has emerged as a high potential biodiesel feedstock because of its adaptability to diverse growing conditions. Provincial governments in Southwest China have drafted plans to increase the area of JCL planting by over one million hectares in the next decade (Weyerhaeuser et al. 2007). Due to land availability and natural advantages for the growth of JCL, Yunnan Province aims to build the largest biodiesel base in China. It makes sense to develop biodiesel here because there are no oil fields or refineries in this province. The main means of transportation in Yunnan is road, with a total length of 198,000 km, giving Yunnan the highest road ranking in China. Diesel is an important fuel for large trucks and buses, as well as for ships and railway locomotives; in recent years, the yearly demand in Yunnan for diesel has been more than 2 million tonnes (Hu, 2007). According to *The plan for the development of biodiesel feedstock plantation in Yunnan*, the total area of JCL plantation in Yunnan is one million mu (1 ha=15 mu) at present, and will be increased to between 4 and 10 million mu at the end of 2010 and 2015, respectively (Hu, 2007; Bai, 2007).

In Yunnan, 94% of the land area is upland and high mountains. The government strategy for JCL plantation has focused on barren lands. Barren land is a specific term used in Chinese agriculture and forest accounting and it refers to land that is not being used for obvious productive purposes, including some land that is in fact used for grazing livestock. At present, there is more than 4 million hectares of barren land in Yunnan Province, of which one third is suitable for the growth of JCL. This barren land is owned by the government or village collectives, with rights to use the land granted to individual households. A significant portion of the land area planned for JCL plantation is likely to be collectively owned and contracted to individual households. Thus, the number of households involved in the JCL development plan would be hundreds of thousands.

As Yunnan targets the establishment of the largest biodiesel base in China, it is necessary and meaningful to study the impact of biodiesel plantations on the local economy. Although world-wide there is a fast-expanding library of economic and policy literature that analyzes the various effects of biofuels from both micro and macro perspectives, all biofuels are not created equal but exhibit considerable spatial and temporal heterogeneity in production. The economic and environmental impact of biofuels will also be heterogeneous varying with space and time (Rajagopal and

Zilberman, 2007).

This study aims to assess the environmental, economic and energy performance of producing biodiesel from JCL seeds in Yunnan and to suggest policies encouraging biodiesel production.

1.1.2 *Jatropha curcas* L. and its Development in China

Jatropha curcas L. is a small arbor or shrub belonging to the family of Euphorbiaceae. It is widely distributed in tropical and subtropical regions, including Central America, South America, Southeast Asia, India and Africa, and its origin may be Central America and Mexico (Heller, 1996). JCL was introduced into China 300 years ago, with wild growth found in Guangdong, Guangxi, Hainan, Fujian and Taiwan, especially in Yunnan, Guizhou and Sichuan (Wu and Zong, 2007). JCL has great potential for the production of biodiesel due to its easy adaptability to the environment, especially drought resistance, its high survival rate and its high seed yield. In Yunnan Province, JCL can typically grow at an altitudinal range of 600 to 1,400 m above sea level (Zeng, 2006). In Yunnan Province, JCL mainly grows between 600 and 1,400 m above sea level, and can survive in plains, hills and valley slopes between 700 and 1,600 m above sea level (Yuan, 2007). In Guizhou Province, JCL is mainly distributed in the southern and southwest parts, mainly in dry and hot valleys in the basins of Nanpan River, Beipan River and Hongshui River, with an altitude range of 275 to 800 m above sea level (Chen et al. 2006). In Sichuan Province, JCL is mainly distributed in the dry-hot valleys below 1,600 m above sea level (Xu et al. 2008).

Existing JCL resources are mainly found in Yunnan, Guizhou, and Sichuan. According to preliminary statistics, the natural growth of JCL in these provinces is about 33,000 hectares (Wu and Zong, 2007). Over the past two years, the area of *Jatropha* plantation has been gradually increased as more effort has been made in the development of biodiesel. It is reported that the area of *Jatropha* plantation has so far been 680,000 hectares in Yunnan (Anonymous, 2008), more than 17,300 hectares in Sichuan in 2007, and 15,300 hectares in Guangxi by the end of July 2008.

Before it was cultivated for the production of biodiesel, *Jatropha* trees were planted for fencing or hedging along rivers and the sides of roads and its seed oil was mainly used to produce lubricant and lacquer (Zheng et al. 2007). In Nanpan River, Beipan River of Guizhou and Panzhihua of Sichuan, it is a raw material of green manure; in Qiaojia County of Yunnan Province, it was also used to extract oil and make soap; in recent years, it has been used to prevent soil erosion in Binchuan County of Yunnan Province and Panzhihua and Liangshan prefectures of Sichuan Province (Xiang et al. 2008).

Yield of JCL seeds varies greatly as the site conditions change. Achten et al. (2008) conducted a literature survey of JCL seed yields in India, Mali, Nicaragua, Paraguay, Thailand and Cape Verde, and the results showed that the annual yield of JCL seeds was 0.3-5 tonnes per hectare, with a few reports of 6.7 tonnes per hectare in India and 8

tonnes per hectare in Mali. At a conference on the production of biodiesel from JCL held in Wageningen in the Netherlands in March 2007, participating experts agreed that a yield of 4-5 tonnes per hectare was possible. However, the upper limit of seed yield (5 tonnes per hectare) has never been confirmed by JCL growers. One year after planting JCL can bear fruit in small quantities. The yield of fruit can reach 4-5 kg per tree four or five years later when the plantation is well-managed, but it will only be 1-1.25 kg if the plantation is planted on barren hills and fed by rain (Kumar et al. 2003).

In China, He et al. (2007) found that the seed yield is between 300 and 600 fruits per tree with an average of 200 fruits per tree and a maximum of 1,500 fruits per tree after surveying 10 plots of JCL of between five and 20 years of age in Honghe Prefecture of Yunnan (Table 1). Since there are usually three seeds in each capsule, the weight of a single seed is 0.5-0.7 g, and the seed yield is 0.54-1.08 kg per tree with an upper limit of 2.70 kg per tree. Chen et al. (2006), after a survey of JCL in Guizhou, reported that the seed yield was between 2 and 4 kg per tree for trees five years or older. After a study of the population of JCL in Sichuan, Xu et al. (2008) found that the seed yield of wild-growing JCL reached 750-2,250 kg per hectare. Therefore, assuming that the spacing in the JCL plantation is 2 m × 3 m (1,650 per hectare), the seed yield of JCL is 0.6- 4.5 tonnes per hectare at the present levels of technology and management in China.

Table 1. Seed Yields of Well-grown JCL

No. of samples	Coordinates of sample Sites	Elevation (m)	Age (yr)	Height (m)	Crown width	Number of fruits
1	23°05'37"N; 103°10'47.3"E	183	10	5.3	7.5	300
2	23°36'55.5"N; 102°27'22.2"E	1150	10	3.3	4.0	450
3	23°34'21.9"N; 103°52'2.22"E	1476	10	2.8	3.0	300
4	23°0'6.72"N; 103°40'3.84"E	1220	15	4.8	3.5	600
5	22°42'7.3"N; 102°57'6.1"E	774	10	5.1	3.7	500
6	23°18'34"N; 102°39'6"E	258	5	4.4	4.8	600
7	23°21'54.4"N; 102°25'60.8"E	858	8	4.5	3.5	300
8	23°17'46. 5"N; 102°36'43.3"E	482	15	4.2	4.5	500
9	23°0'47"N; 102°13'14.3"E	1116	7	5.1	4.4	600
10	23°47'2218"N; 103°16'3311"	1 092	20	5.0	4.5	1000

Source: He et al. (2007)

There are usually three seeds in each fruit, occasionally only two seeds. The weight of the seeds is about 55-65% of that of the fruit. The JCL seeds are black and toxic. For each kilo of seeds there are about 1,300-1,800 pieces, with each piece weighing 0.55-0.75 g (Zheng et al. 2008). The dry JCL fruit is mainly composed of water (4.4%-4.7%), protein (17.8%-28.9%), fat (52.9%-57.4%), and cellulose (3.7%-4.3%) (Chen et al. 2006).

The characteristics of JCL seeds from different regions of Yunnan are shown in Table 2. According to the nine samples taken from different parts of Yunnan, the weight per 100 seeds is about 48.2-72.3 g, of which the kernel accounts for more than 60%. The oil percentage ranges from 32.2-40.2% in seeds and 50.0-61.3% in kernels. These oil yields were obtained using the mechanical extraction method which is widely used in

Yunnan. However, more oil can be extracted from seeds using chemical extraction.

Table 2. The Characteristics of JCL Seeds from Different Regions of Yunnan

Seed sources	Yuan-mo	Liu-ku	Bin-chuan	Yong-sheng	Mang-shi	Da-luo	Yong-ren	Shuang-bai	Yuan-yang
Weight per 100 seeds (g)	52.5	71.0	67.8	48.2	59.3	72.3	50.9	68.9	68.3
Weight per 100 kernels (g)	33.5	44.2	46.0	33.2	39.3	47.2	31.3	45.3	41.2
Oil percentage in seeds (%)	35.4	32.2	35.7	34.4	37.6	33.5	34.3	40.2	37.0
Oil percentage in kernels (%)	55.5	51.7	52.6	50.0	56.7	51.3	55.7	61.2	61.3

Sources: Zhang et al. (2001) and field surveys

1.1.3 Economic, Environmental and Energy Performance of Biofuels

To be a viable alternative to fossil fuel, biofuels should yield a positive energy balance, have environmental benefits, be economically feasible, and be producible in large quantities without impacting on food security (Srinivasan, 2009). The production and use of biofuels have the potential to reduce dependence on petroleum, improving environmental quality, lowering the emission of greenhouse gas (GHG), promoting rural development, and providing farmers with job opportunities. However, there is no guarantee that the objectives will be met as expected.

Runge (2007) and Huang et al. (2009) showed that the production of the first generation of biofuels had a negative impact on food security because it consumed a lot of foodstuffs. Using non-agricultural crops as feedstock, the production of second-generation biofuels will not affect food security and will improve the environment to a greater extent than first-generation biofuels. In order to produce biofuels in sustainable ways, a shift from the production of first-generation biofuels to that of second-generation biofuels is advocated (FAO 2008; Flavin, 2008).

In the real world, the production and use of biofuels may have positive impacts on environment, but not absolutely – the result depends on specific factors, such as the production technology, sites, market etc. For example, Farrell et al. (2006) concluded that the production and use of bioethanol makes a contribution to energy independence and environmental improvement, while Crutzen et al. (2007) revealed that the production of biodiesel results in an increase in GHG emissions because of the use of nitrogen fertilizers and Pimental and Patzek (2005) found that the energy balance of producing ethanol from corn is negative. Scharlemann and Laurance (2008) state that, compared to fossil fuel, 12 kinds of biofuels have a greater environmental impact than fossil fuel, including corn bioethanol in the US, sugarcane bioethanol and soybean biodiesel in Brazil, and palm biodiesel in Malaysia.

Thus, it is necessary to assess the economic, environmental and energy performance of biodiesel before the biofuel industry is developed on a large scale, so as to avoid risks and provide a basis for policy making in the development of the biofuel industry. Life

cycle assessment (LCA) is a suitable method for this purpose and is widely used in the assessment of the impacts associated with biofuels, for example Delucchi (2003) and Kim and Dale (2005).

1.2 Statement of Problems

The biodiesel production chain can be divided into four stages: 1) Production of JCL seeds through cultivation; 2) Extraction and conversion of biodiesel; 3) Distribution and retailing of finished fuels; and 4) Consumption of biodiesel. At each stage, a variety of economic questions arise. From a private standpoint, the main questions are: How much does biodiesel production cost at each stage?; and what is the difference in cost when JCL is planted on sites with different degrees of fertility? In Yunnan Province, JCL uptake among farmers has been slow because a significant portion of available marginal land is not currently suitable for commercial-scale growing (Weyerhaeuser et al. 2007). So how much marginal land in Yunnan is of sufficient quality to grow JCL on a commercial scale? To answer this question costs need to be accounted for at each stage. From a societal standpoint, the main questions are: How fast and what level of incentives are needed to support the growth of the JCL biodiesel industry?; and What are the aggregate impacts of biodiesel on welfare? These questions require systematic research.

For the present Chinese market, some degree of subsidization is inevitable. Recently, the Chinese government considered preferential policies for biofuel producers. The Ministry of Finance of China recently drew up a policy to encourage the use of non-food feedstock to make biofuels by providing subsidies and other forms of financial support to people involved in the production of biofuels (*China Daily*, 2007). Specifically, farmers will get a subsidy of 3,000 yuan for each hectare of forest products for biofuel, such as ethanol and biodiesel, and 2,700 yuan for every hectare of crops. However, so far, there is still no specific statement on how to subsidize producers at other stages. To improve the efficiency of this policy, some questions should be answered, such as how will the subsidy policy affect the commercial viability of biodiesel production and land use options? How much and on which basis, say, on a per tonne of biodiesel basis and a per mu JCL seed basis, should biodiesel companies at different stages of the life cycle of biodiesel be subsidized in order to promote the growth of the biodiesel industry? How will the development of JCL plantations affect land use by local farmers?

As a perennial plant, JCL can sequester carbon for tens of years and thus there is some potential to offset some of the cost of JCL production. In pursuit of the dual goals of biodiesel production and greenhouse gas emission reduction, a British company, Sunshine Technology Group Ltd., planted 4,000 mu of JCL in Yuanyang in 2008. However, it is still unclear whether JCL plantations can contribute to carbon reduction before the lifecycle carbon balance is accounted for. Accordingly, how will the economic feasibility of the production of biodiesel be affected by the inclusion of the economic value of carbon sequestration? In which ways can the contribution of biodiesel production to carbon reduction be improved?

One more critical problem is the energy efficiency of energy production. An energy

growth project can be sustained only if it is energy-efficient. Since energy input is required at different stages of the production chain, it is necessary to assess the energy efficiency of producing biodiesel from JCL, and to find ways to improve energy efficiency.

1.3 Significance of the Study

Biodiesel is an environment-friendly alternative to fossil fuel and holds immense potential to mitigate the future energy needs of China and also to impart economic prosperity to poor and backward areas of the country. JCL exhibits great advantages for biodiesel production. However, biodiesel production is still an emerging industry. The commercialization of JCL in China is fairly recent, with commercial seedling production beginning in 2005. Although Yunnan has set an ambitious target of establishing the largest biodiesel base in China and achieving energy independence, there is still a lack of information on the environmental, economic and energy performance of biodiesel production. The results of a systematic study might provide important information for policy making for the promotion of JCL biodiesel. Before rapidly scaling up JCL acreage, a systematic study may also avoid unnecessary costs and reduce producers' financial risk.

Although the research on JCL cultivation in China dates back to the 1970s, with JCL germplasm and tissue culture, little attention has been given to the economic and environmental impacts of JCL cultivation. This study may provide the first systematic study on the environmental, economic and energy performance of biodiesel production with JCL and the results may lay a foundation for further studies as the biodiesel industry grows.

Since most rural areas in Yunnan are poverty-stricken, the development of biodiesel is considered a means of raising income in regions where more conventional agricultural markets have been comparatively slow to take shape. Because JCL can be successfully grown on marginal land or intercropped on farms, its seeds could represent a new source of income for farmers. However, how much farming households can earn from JCL planted on marginal land is specific to certain ecological zones and an understanding of the earning potential of JCL in these different zones, rather than at an aggregate level, is critical for designing support programs.

Moreover, the results of the study can serve as a reference for other areas developing JCL, such as Sichuan and Guizhou provinces. The study can also contribute to the scant literature on the economics of biodiesel in developing countries.

1.4 Objectives of the Study

The overall objective of the study was to assess the environmental, economic and energy performance of the production of biodiesel from JCL seeds in Yunnan, China.

These are the specific objectives:

- 1) To assess the financial viability and economic efficiency of the production of JCL biodiesel;
- 2) To assess the energy efficiency of the production of JCL biodiesel;
- 3) To assess the impact of biodiesel production on land use; and
- 4) To identify possible incentives mechanisms and policy support if JCL biodiesel production is found favorable in economical, financial and environmental terms.

1.5 Scope of Study

While many provinces in China are involved in producing biodiesel, Yunnan Province is selected as the study region. It was selected due to its geographical and climatic advantages for the growth of JCL, as well as its land availability. The unique diverse climate in the province provides an excellent environment for the industrialization of JCL plantations. The water system in Yunnan is rich. Besides the six major rivers, namely the Yangtze, Lancang (the upper reach of Mekong River), Pearl, Nu (the upper reach of Salween in Myanmar), Red, and Irowadi, there are more than 20 tributaries, each with a watershed area of more than 1,500 km². The hot and dry areas along the six major rivers are abundant in sunlight, heat and water, with an annual temperature of 20-24 °C, and an annual rainfall of 400-1,000 mm. The total area of hot and dry valley is around 1.33 million hectares, among which 0.67 million hectares are suitable for the growth of JCL (Bai, 2007).

The impacts of producing biodiesel from JCL can be assessed at three levels: the micro level, sector level and regional level. Because the biodiesel industry is still at a formative stage there is a lack of data on the costs of the industry so the study will be at a micro level. The main targets of the study are the environmental lifecycle, and the economic and energy performance of biodiesel production. Though there are other environmental impacts, the study will focus on carbon balance. Moreover, the impact of JCL cultivation on land use will also be studied. However, the demand side of biodiesel, such as consumer behavior when choosing biodiesel, is not the target of the study.

Subsidies to be studied are those affecting production attributes, namely subsidies to producers. More remote subsidies, such as to particular modes of transport used to ship biodiesel or feedstock, and to consumers, were beyond the scope of the study.

Indices used to assess the 3E performance are net present value (NPV), CO₂ equivalent balance (CEB) and net energy ratio (NER). The NPV is the difference between the present value of the flow of revenues and the present value of the flow of costs. The CEB is the difference between the total sequestered CO₂ and reduced CO₂ emissions. The NER is the ratio of total energy outputs to total energy inputs, reflecting the energy efficiency of the process.

Since JCL oil can be used in engines after it is directly blended with fossil diesel or converted into JCL Methyl ester (JME) through transesterification reaction, biodiesel in the study refers to both the mixture of JCL oil and diesel and JME.

The oil from can be extracted using mechanical and chemical methods. Only the mechanical method has been investigated because it is far more widely used than the chemical method.

The lifecycle of JCL biodiesel consists of four stages: JCL cultivation, oil extraction and refining, biodiesel production, and use in engines. The analysis includes the assessments of 3E performance associated with direct inputs and facilities construction, such as manufacturing machines, housing, etc. as well as with manual labor, such as planting, pruning, fruit collection and drying, weeding etc. The calculations are based on 1 hectare of JCL plantation for 30 years. The main result is the estimate of overall 3E performance as seed yields vary.

The allocation of costs to co-products is based on monetary values in the market. The credits for allocating environmental and energy burdens are based on displacement effects. Although parts of the JCL tree can be exploited for a number of uses such as medicines, insecticides, fuel, fertilizer, etc., this study considered seed cake as fertilizer and other parts for fuel stock as a substitute for coal.

2.0 RESEARCH METHODS

2.1 Research Questions

The study sought to answer the following questions:

- 1) What are the costs of biodiesel production?
- 2) What are the financial and economic viabilities of JCL biodiesel production based on current fossil diesel prices?
- 3) What are the incentives required for producers at different stages of production?
- 4) What is the carbon balance and what are its effects on the economic strengths of JCL biodiesel production?
- 5) What is the energy efficiency of biodiesel production?
- 6) What are the major factors affecting the environmental, economic and energy performance of biodiesel production?
- 7) How can the economics of biodiesel, its energy efficiency, and its contribution to carbon reduction be improved?

2.2 Framework of the Study

A lifecycle inventory analysis was first carried out to identify and quantify the input and output of the biodiesel production system, following a “from cradle to grave” sequence. Detailed analysis will be conducted in three areas: financial and economic feasibility, carbon balance and energy efficiency (Figure 1). However, each aspect is not independent – on the contrary, they are linked. The environmental value of carbon

balance will be integrated into the economic analysis and the results will be analyzed along with the results of energy accounting to find out the cost-effectiveness of biodiesel production. Based on financial and economic analysis, the incentives required for the promotion of the production of JCL biodiesel was studied. Finally, suggestions for policy changes or improvements were elicited.

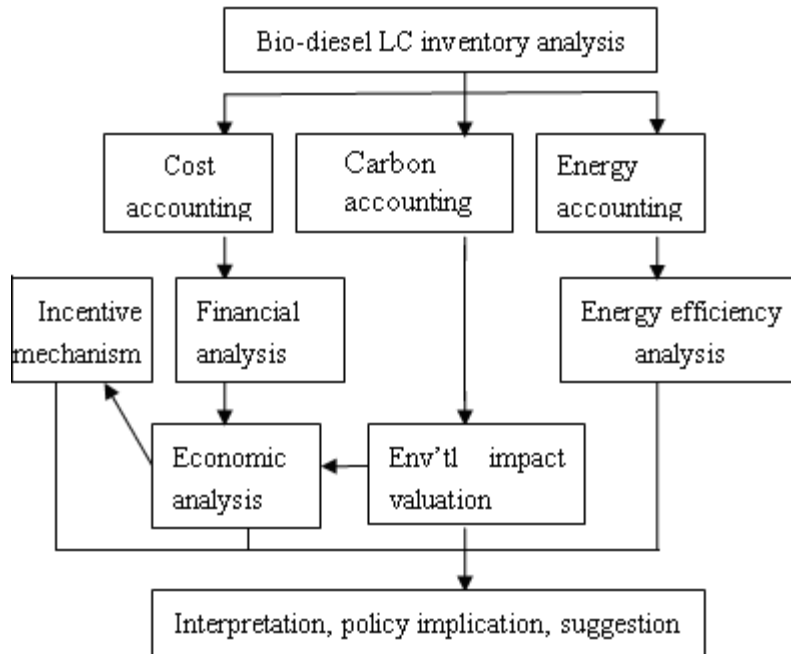


Figure 1. Framework of the Study

2.3 Methods of Data Gathering

Both primary and secondary data was used in the study. Primary data was collected through field surveys and discussions with producers at different stages of biodiesel production. Secondary data came from published journal articles and books.

Data was collected from the areas designated for priority development, including Honghe, Chuxiong, Xishuangbanna and Lincang. The following activities were carried out in order to collect data.

- 1) Visits to various related Government departments, such as Yunnan Forestry Department, Yunnan Agriculture Department, and Yunnan Commission on Development and Planning, to access possible changes in existing policies to promote biodiesel, roles and resources available from various departments.
- 2) Focus group discussions (FDG) were conducted at a community level to assess the roles of communities at each stage of biodiesel production and to obtain related data, such as the existing area of JCL plantations and JCL yields in previous years. Members of FDG included leaders of rural communities and knowledgeable villagers.
- 3) Interviews with producers and entrepreneurs to understand their role in the biodiesel supply chain from extraction, conversion and marketing to price and

cost data at each stage.

- 4) Visits to biofuel plants to become familiar with production processes and to obtain information on the capital and labor inputs and outputs of products and residuals.
- 5) Interviews with experts and visits to research organizations involved in the production of JCL biodiesel.

3.0 LIFECYCLE INVENTORY OF JCL BIODIESEL

The data covers the inputs and costs of biodiesel production at each stage, as well as the yields of products. Field surveys were conducted in Honghe and Chuxiong prefectures of Yunnan Province, China. The production of JCL biodiesel was classified into four stages (Figure 2). Data of inputs and outputs at each stage were collected. The data on seed production was collected from Yuanjiang and Shuangbai counties and the data on oil extraction was from Erkang science and technology Co. Ltd. Secondary data, includes the emissions of fuels and fertilizers from the GREET model, and other technological inputs and outputs from related journal articles.

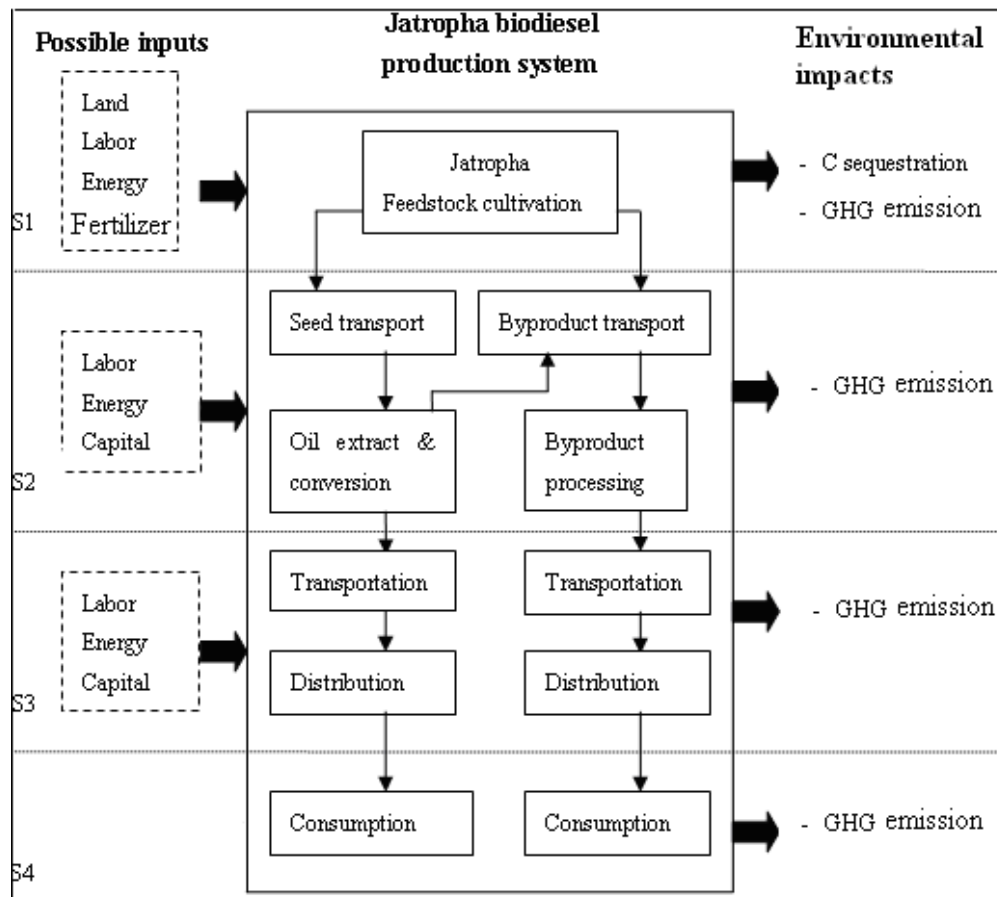


Figure 2. The Lifecycle System of the Production of JCL Biodiesel

3.1 Production of JCL Seeds

This is mainly an agricultural activity in which JCL is grown, harvested and transported to a conversion facility. Data from this stage was collected through field surveys (see Annex I).

The production of JCL seeds involves the establishment and maintenance of JCL plantations, and the harvest of JCL seeds and their preliminary treatment. The establishment of JCL plantations includes site preparation, seed treatment, seedling cultivation, nursery management, and transplanting. The maintenance of JCL plantations involve irrigation, fertilizing, weeding, disease control, and pruning. The harvest of JCL seeds includes fruit flickering, drying and transportation.

Price data for fertilizers, fungicides, and herbicides was collected through field surveys. The seed price was obtained by interviewing investors in JCL plantations. The cost of these expendable inputs was determined by multiplying the price of the input by the quantity.

The cost of transporting *Jatropha* seeds to a biodiesel plant was estimated by using the equation:

$$\text{Transportation cost} = \alpha + \beta d \quad (1)$$

where α is the basic charge of transportation, β is the charge per unit of road distance, and d is the mean round-trip distance between the JCL plantation and the processing plant.

The efficiency of diesel for transportation (the energy requirement per kilometer in transportation) was sought by surveying local drivers. This data provided a basis for an estimation of energy use and carbon emissions due to transportation at different stages of biodiesel production.

The capital cost might start from site preparation to seed collection. In Yunnan, most cultivation is done manually because there are plenty of labors and agricultural machines, such as tractors, are hard to operate in mountainous areas. The capital cost mainly includes expenditure on implements such as hoes, spades and shovels.

The labor cost per hectare of JCL plantation was calculated by multiplying the local wage rate with the total hours or days involved.

The cost of a hectare of land was based on the net returns of other land use that had been surveyed. Since JCL plantations can only be established on marginal land, which has a negligible economic value, the opportunity cost of the land is neglected.

Benefits at this stage may come from JCL seeds and some by-products, including seed husks and shells.

The practices of seed production are as follows:

1) *JCL plantations*. Despite a great deal of literature on the establishment and management of JCL plantations, *Guidelines for JCL plantations*, prepared by Yunnan Department of Forestry, was used as a guide. The process of JCL seed production is shown in Figure 3. There is a lot of literature reporting the different yields of JCL seeds. For a more complete representation, a range of fruit yields from 100 to 1,500 fruits per tree was assessed. Since the JCL trees can live for a period of between 30 and 50 years, it was assumed that the project period is 30 years.

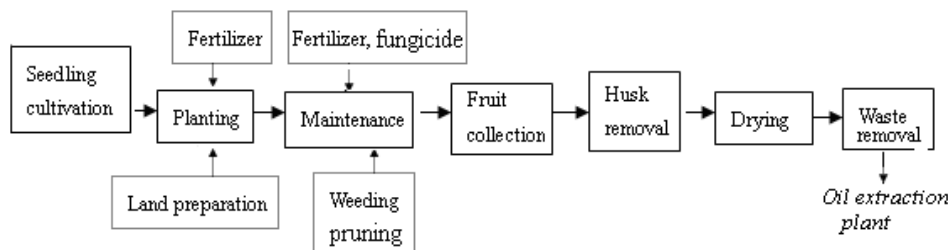


Figure 3. The Process of JCL Seed Production

2) *Spacing of plantations*. Most available literature on the seed yield of JCL per unit area was estimated according to per-tree yields and the possible number of trees per unit area. According to the crown sizes at different ages, it has been assumed that the spacing in JCL plantations is about 2m×3m, or 1,650 JCL trees per hectare.

3) *Propagation*. JCL trees can be propagated by seedling, cutting, and micro-propagation. Since the survival rate of cutting plantations is low and the cost of micro-propagation is much higher than seedlings and cuttings, it has been assumed that JCL plantations are established with seedlings.

4) *Land preparation*. Land preparation mainly comprises of terracing, digging holes (40×40×40 cm), applying green manure and soil erosion control. However, some sites do not perform all of these activities, depending on site conditions.

5) *Irrigation*. Irrigation is mainly applied in the first year after the plantation is established. In the dry season, the plantation will be watered twice a week. Areas with a high annual rainfall level of more than 2,500 mm do not need irrigation.

6) *Fertilization*. The JCL plantation will be fertilized with chemical fertilizers, green manure and JCL seed cakes. In the course of site preparation, green manure is put into the holes. Chemical fertilizers are applied after seedlings are transplanted throughout the first three years. In each of the three years, about 100 grams of urea and 250 grams of NPK will be applied to each tree in the first part the year, followed by top dressing with 100 grams of urea for each tree. From the fourth year to thirtieth year of plantation, JCL seed cake and green manure will be used instead of chemical fertilizers. According to Openshaw (2000), one kg of seed cake is equivalent to 0.15 kg of NPK fertilizer (N: P: K=4:2:1).

The distance between the fertilizer shops and the plantation sites is

assumed to be 50 kilometers. Fertilizers are transported by trucks with a carrying capacity of 5 tonnes. The consumption of diesel for a loaded and an unloaded truck is 30 liters and 15 liters per 100 km, respectively. Since it is difficult to estimate the nutrient content of green manure and since there is no price for it, the economic value or cost of green manure has been excluded.

7) *Weeding*. Cutting and herbicides are used to remove weeds. The calculations assume that each of the two methods are used once within a year. In detail, about 2 liters per year per hectare of glyphosate is used during the rainy season, and labor is used in the dry season. Herbicide is applied using simple sprayers. It takes a laborer 60 hours to remove weeds from one hectare of land by cutting, and five hours by applying herbicides.

8) *Application of fungicide*. JCL is disease-resistant and its parts can be used to produce insecticides. Damage from insect attack is not significant. Many kinds of insects pollinate JCL flowers to produce fruit, and the application of insecticide may kill pollinators and thus negatively affect productivity. Therefore this study assumes that no insecticides are used. However, carbendazim should be applied to control disease. The dose of this fungicide is 2 kg per hectare per year. It takes a laborer five hours to apply the fungicide to each hectare of JCL plantation.

9) *Pruning*. JCL trees are pruned once a year for the first three years of their life. From the fourth year onwards only minor pruning is required. Each laborer can prune one hectare of plantation in five days.

10) *Harvesting*. There is no harvest for the first two years after planting because the fruit yield is too low. In calculations, it is assumed that JCL will have a constant yield from the fifth year onwards, while the yields in the third and fourth years are one-third and two-thirds of the full seed yields, respectively. The harvested fruits will be dried by sunlight, followed by husk removal. Each laborer 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.

The distance between the fertilizer shops and the plantation sites is assumed to be 50 kilometers. Fertilizers are transported by trucks with a carrying capacity of 5 tonnes. The consumption of diesel for a loaded and an unloaded truck is 30 liters and 15 liters per 100 km, respectively.

3.2 Processing of JCL Seed Oil

This is an industrial activity in which the JCL seed is converted into biodiesel. Costs and inputs at this stage occur at every step of processing and residual treatment. Data for this stage was collected through questionnaires used on visits to vegetable oil plants (Annex II).

The capital cost was allocated for the whole lifetime of the machines and tools. The costs per liter of seed oil or biodiesel were calculated. The processing of JCL oil includes the following steps.

3.2.1 Preparation of JCL Seeds

The ripe fruits are plucked from the JCL trees and then are sun-dried and de-husked. To prepare the seeds for mechanical extraction, they should be solar heated for several hours or roasted for 10 minutes. If chemical extraction is chosen, the shelling of seeds can increase the yield of oil.

3.2.2 Extraction and Refinement of JCL Oil

The oil from JCL seeds can be extracted by mechanical extraction using a screw press, or solvent extraction. Since mechanical extraction is more widely used in China, it is assumed that the JCL oil is extracted using mechanical expellers.

The process of oil extraction with mechanical expellers and refining is shown in Figure 4.

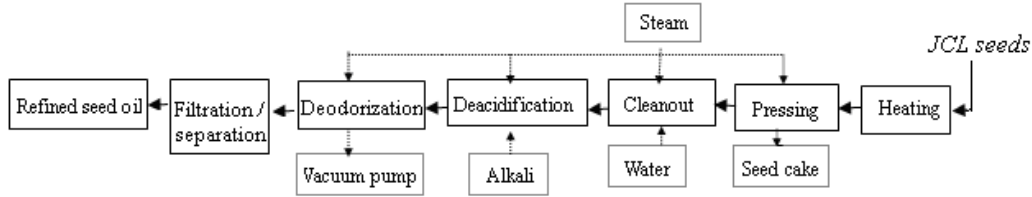


Figure 4. The Process of Oil Extraction with a Mechanical Expeller

The selected engine specifications for calculation are from a private vegetable oil company. The mechanical expeller is Model YHN-95, made by Yunnan Huanian Machinery Plant. Its processing capacity is 3-5 tonnes of seed per day (in an eight-hour period) with a power of 7.5 kilowatt-hours. The equipment for the oil refinery was Model YZYSX-1,000A, produced by Wuxi Daling Vegetable Machinery and Equipment, Co. Ltd. Its processing capacity was 1 tonne of oil per day (in an eight-hour period) with a power of 7.41 kilowatt-hours.

To reduce the acid content in the crude oil, NaOH should be added for the purpose of de-acidification. The relationship between the amount of NaOH needed (W_{NaOH}) and the amount of crude JCL oil is shown in the following equation:

$$\begin{aligned}
 W_{\text{NaOH}} &= W_{\text{crude oil}} * \text{Acid value} * 40/56 * 1 * 1/1,000 \\
 &= 7.13 \times 10^{-4} * W_{\text{crude oil}} * \text{Acid value}
 \end{aligned} \tag{2}$$

3.2.3 Transesterification of JCL Oil

The JCL oil can be directed blended with diesel, or can be made into biodiesel through transesterification reaction with methanol.

Because of its viscosity, JCL oil is not suitable for direct use in engines (Table 3). The high viscosity of JCL oil may contribute to the formation of carbon deposits in engines and incomplete fuel combustion, resulting in a reduction in the life of an engine. However, a significant reduction in viscosity can be achieved by the dilution of vegetable oil with diesel in varying proportions (Pramanik 2003). Among various blends, the blends containing up to 30% (v/v) JCL oil have viscosity values close to that of diesel fuel, and up to 50% JCL oil can be substituted for diesel for use in a C.I. engine without any major operational difficulties. Forson et al. (2004) showed that a 97.4% diesel/2.6% JCL fuel blend produces maximum values for brake power and brake-thermal efficiency as well as minimum values for specific fuel consumption, and thus can be used as an ignition-accelerator additive for diesel fuel.

Table 3. Characteristics of JCL Oil

Calorific value (MJ/kg)	Flash point (°C)	Cetane value	Cloud point (°C)	Specific gravity (g/cm ³)	Water content %	Acid number (mgKOH/g)	Iodine number (mg iodine /g)	Saponification number (mg/g1)
39.6 ~ 41.8	110 ~ 240	51.0	2	0.91 ~ 0.92	0.24	7.62-16.82	100.85	213.14

Source: Chen et al. (2006); She et al. (2005); Liu et al. (2007) and Zhang et al. (2001)

Moreover, Prasad et al. (2000) found that the use of pure JCL oil results in a higher brake-specific energy consumption, lower brake thermal efficiency, higher exhaust gas temperature and lower NO_x emissions in comparison with fossil diesel. Kumar et al. (2003) compared the use of JCL oil and fossil diesel in a single cylinder four-stroke water-cooled diesel engine and concluded that the CO, smoke and soot (hydrocarbon) emissions are higher with JCL oil than with fossil diesel, and that there was an increase in ignition delay and combustion duration with JCL oil compared to fossil diesel.

In this study, biodiesel refers to the blend of JCL oil and diesel, JME or its blends with diesel (Figure 5). That is, refined JCL oil can be directly used in engines after it is blended with diesel. Nevertheless, the oil's quality will be better and there will be fewer long-term problems if it is first converted into biodiesel. This study assessed the economic, environmental and economic performance for the two end uses. JCL oil can be produced in small-scale plants in remote areas. Small-scale biodiesel plants in remote areas are expected to increase in number to a greater extent than large-scale centralized plants because they can be easily operated by local proprietors without the need for complicated control and with lower distribution costs. On the contrary, to control the pollution caused by small-scale chemical plants, the Chinese government requires newly established chemical plants, including JME biodiesel plants, to have a minimum production capacity of 50,000 tonnes per year for final products.

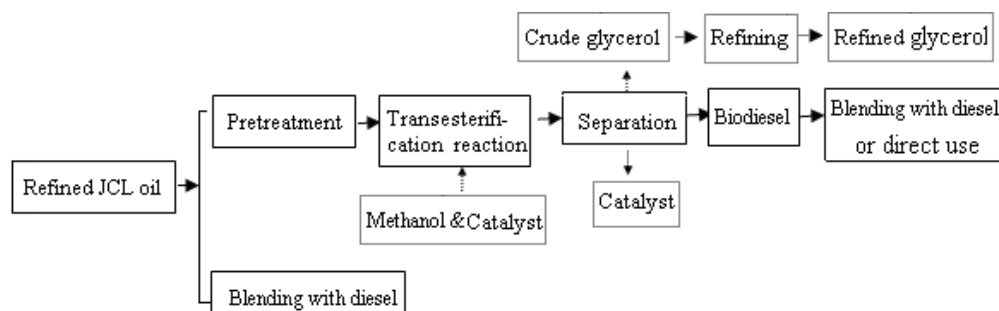


Figure 5. The Process of JCL Biodiesel Production

When JCL oil is directly used, the 3E performance is represented by the production activities and facilities shown in Figure 4. If the end product is JME biodiesel, the selected production specifications for calculation refer to a biodiesel plant which yearly produces 50,000 tonnes of JME from JCL by transesterification (Figure 6). It was assumed that the distance between the oil extraction plant or workshop and the transesterification plant or workshop was negligibly short, and thus no transportation cost is included in calculation.

The chemical principle is shown by Figure 6. Obviously, besides JME, glycerol is an important by-product. It can be burned for heat or used as feedstock in the cosmetics industry. It is also the raw material of some high value-added products, such as bichlorid glycerol.

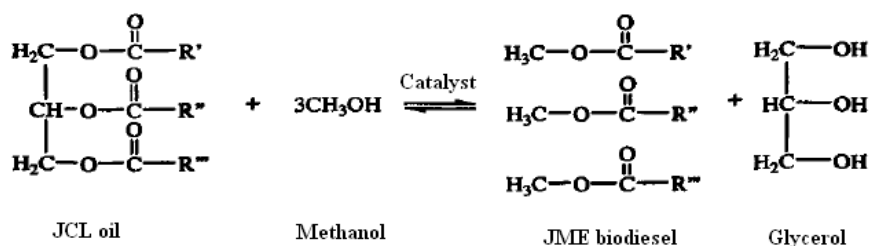


Figure 6. Transesterification Reaction

Although the transesterification process is quite straightforward, the genetic and environmental background of reagents might require the modification of the input ratios of the alcohol reagent and reaction catalyst and alterations to reaction temperature and time, in order to achieve optimal biodiesel production results. Zhou et al. (2006) studied the production of biodiesel using JCL oil and found that the optimal conditions for transesterification reaction were that the molar ratio of JCL oil: methanol=1:6, the amount of catalyst is 1.3% of the weight of the JCL oil, at which the yield of JME was higher than 98% after a 20-minute reaction time at 64°C. For industrial production, the yields of JME and glycerol were about 96% and 87% of JCL oil, respectively (Li et al. 2004). The characteristics of JME biodiesel are shown in Table 4.

Table 4 shows that JCL biodiesel satisfies the international standards of diesel. It has

a higher cetane No. and flashpoint, a similar calorific value and lower sulfur content compared to diesel. Therefore, JCL biodiesel has an overall performance close to that of diesel and thus can be used a substitute for diesel (Chen et al. 2006).

Table 4. Physical and Chemical Properties of JCL Biodiesel and Diesel

Characteristics	Jatropha biodiesel	Standard method	German DIN51606 standards	Diesel
Gravity(20 °C,g/cm3)	0.8784	SH/T0604	0.875 ~ 0.900 (15°C)	0.84 ~ 0.85
Kinematic viscosity (mm ² /S)	7.320 (20 °C)	GB/T265	315 ~ 510 (40°C)	112 ~ 315 (40°C)
Calorific value,(MJ/kg)	40	GB/T384	≥32	42.6 ~ 45.0
Flashpoint (°C)	>170	GB/T261	≥110	80
Cloud point (°C)	+1	GB/T3535		-14
Carbon residual (%)	<0.05	GB/T17 144	≤0.05	
H ₂ SO ₄ residual (%)	<0.005	GB/T2433		
Sulfur content (mg/L)	32 (0.0036%)	SH/T253 -92	≤0101	1.0 ~ 1.2
Cetane No.	56.1		≥49	47.8

Source: Chen et al. (2006)

3.3 Distribution of JCL Biodiesel

This involves the distribution of refined seed oil or JME for blending with fossil fuels. It was assumed the distance between the biofuel plant and the diesel distribution point was 10 km. The biofuel is to be transported by oil tankers with a carrying capacity of 5 tonnes per trip. The consumption of diesel is 3 liters per 10 km when the truck is loaded, and 1 liter per 10 km when unloaded. Because the shared capital cost and labor cost is negligible, they were not included in the calculation.

3.4 Consumption of JCL Biodiesel

This refers to the ultimate end use where the biodiesel enters the fuel tank of a vehicle or other engines.

The data of the unit emissions of CO₂, N₂O and CH₄ was taken from the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model developed at Argonne National Laboratory (Wang 1999a; Wang 1999b) and other sources, including Agarwal and Agarwal (2007) and Dai et al. (2006). However, since the emissions of N₂O and CH₄ are low, the emissions of CO₂ from the combustion of biodiesel is considered neutral because the emitted CO₂ is originally from the atmosphere.

4.0 DATA ANALYSIS

It was assumed that: (1) the time horizon for the project is 30 years (the life expectancy of JCL is 30-50 years), the number of working days is 330 days per year, and the discount rate is 8%; (2) the spacing in the JCL plantation is 2 m × 3 m, or the tree density is 1,650 per hectare; (3) the seed yield is 1,485 kg per hectare (500 fruits per tree); (4) one liter of JCL oil is equivalent to one liter of diesel because one liter of diesel has a calorific value equivalent to 0.994 liters of JCL oil as calculated according to the average calorific values and specific gravities of diesel and JCL oil; (5) The distance between the JCL plantation and oil refinery or fertilizer plants is 50 km, while the distance between the oil refinery and the oil distribution station is 10 km; the carrying capacity of trucks is 3 tonnes and that of oil tankers is 5 tonnes.

The data analysis consists of five parts. First, an explicit cost accounting model, a spread-sheet budgeting model, was first used to estimate the profitability of an activity for a single price-taking agent, such as an individual farmer or processor; and an analysis was then conducted to estimate the financial viability of the whole process of biodiesel production from the perspective of producers. Second, the carbon balance was accounted and valued. Third, an economic analysis was preliminarily conducted by integrating the value of carbon sequestration and the value of fruit husks as a fuel substitute for coal. Four, the energy efficiency of JCL biodiesel production was assessed. Finally, sensitivity analysis was carried out to identify significant variables affecting the environmental, economic and energy performance of JCL biodiesel production.

4.1 Financial Analysis

4.1.1 Explicit Cost Accounting

At each stage of production, the unit cost of production in the n th year is given by

$$C_{in} = \sum_{j=1}^J Q_{ijn} P_{jn} + A_{in} + D_{in} + E_{in} \quad (3)$$

where C_{in} is the unit function of production at the i^{th} stage in the n^{th} year; Q_{ij} is the amount of the j^{th} input used at the i^{th} production stage; P_j is the price of the j^{th} input, such as labor and materials; J is the total number of input used at the i^{th} stage; A_{in} is the abatement cost at the i^{th} stage in the n^{th} year, if applicable; D_i is the charge for the depreciation of fixed assets at the i^{th} production stage in the n^{th} year; and E_i is the distributive cost at the i^{th} production stage in the n^{th} year. The fixed assets were depreciated using the straight-line average service life method, assuming a salvage value of 5% of the total.

For producers at each stage, the financial feasibility was assessed using the following equation:

$$FNPV_i = \sum_{n=0}^N \frac{NCF_{in}}{(1+r)^n} \quad (4)$$

$$NCF_{in} = q_{in} (P_i) + \sum_{m=0}^M q_{inm} p_{im} - q_{in} (C_{in}) \quad (5)$$

where NPV_i is the net present value of biodiesel production at the i^{th} stage, NCF_{in} is the net cash flow at the i^{th} stage of production in the n^{th} year; N is the project horizon; n is the n^{th} year of the project; and r is the discount rate; q_i is annual quantity of products, say, seeds at the first stage and extracted oil at the second stage; P_i is the local price of products produced at the i^{th} stage; q_{inm} is the quantity of the m^{th} by-product produced at the i^{th} stage in the n^{th} year; p_{im} is the price of the m^{th} by-product; and M is the total number of by-products produced at the i^{th} stage.

In particular, the influence of taxes or subsidies on the net financial return at the i^{th} stage can be assessed when tax and subsidy are included in equation 4.

The profitability of biodiesel production at different stages can also be assessed by comparing the market price of products produced at each stage with their respective breakeven prices (BP). The breakeven price represents the price per hectare or per liter that the producer would need to receive to cover all operating, overhead and establishment costs of production, and was obtained by dividing the cost per hectare or per liter by the expected yield per hectare or per liter, as given below:

$$BP = \frac{Cost / hectare}{Yield / hectare} \quad \text{or} \quad BP = \frac{Cost / litre}{Yield / litre} \quad (6)$$

It is obvious that producer at the i^{th} stage of production should be subsidized, if it can be justified, when the breakeven price is higher than the market price. The minimum subsidy should be the amount making the cost and benefit breakeven. That is, the price of product plus subsidy should be at least equal to the breakeven price.

4.1.2 Financial Analysis of Biodiesel Production

A financial analysis was conducted to estimate the financial feasibility of the whole process of biodiesel production. The financial feasibility was assessed by the net present value of production, which is given by:

$$FNPV = \sum_{n=0}^N \frac{P_n Q_n + \sum_{i=1}^4 \sum_{m=0}^M q_{inm} p_{im} - \sum_{i=1}^4 C_{in} - \sum_{i=1}^4 T_{in} + \sum_{i=1}^4 S_{in}}{(1+r)^n} \quad (7)$$

where $FNPV$ is the financial net present value of biodiesel production; P_n is the price of biodiesel in the n^{th} year; Q_n is the quantity of biodiesel produced in the n^{th} year; T_{in} and S_{in} are the tax levied and subsidy given at the i^{th} stage in the n^{th} year, if applicable. Note that T and S emerge in the above equation, but they may occur at a different stage of

production. That is, it is possible that a producer at a certain stage is subsidized, while a producer at another stage is taxed.

It is obvious that the production of biodiesel is financially feasible if the FNPV is positive, otherwise it is not feasible.

4.2 Carbon Accounting and Valuation

At each stage of the biodiesel supply chain there are potential environmental impacts such as habitat destruction, carbon sequestration, emissions of liquid and/or solid hazardous gases. Owing to limited time and financial resources, this study only considers the carbon balance in the production chain of JCL biodiesel. Moreover, carbon balance is the environmental effect that it is most related to current worldwide environmental policy. The carbon balance will be accounted for from the cultivation of JCL trees to the combustion of biodiesel (Figure 2). Although they are considered a solution to environmental problems, especially climate change, biofuels can have a positive environmental impact relative to gasoline, or a negative one, depending on how the fuel is produced or grown, processed, and then used (Farrell, et al. 2006).

The carbon balance is the sum of the reduced carbon stock minus the added carbon stock in the whole lifecycle of JCL oil. The inventory covered all inputs and processes involving net emissions, or sink, of the major GHGs (CO_2 , CH_4 and N_2O). All emissions, from the cultivation of JCL trees, seed transportation and processing, biodiesel transportation and combustion were accounted for. In the first stage, carbon emissions come from fuel consumption and fertilizer application, and carbon sequestration by JCL plantations. In the second and the third stages, carbon is released as fuel is burned. In the fourth stage, carbon is emitted as biodiesel is combusted. Inventory mass emissions were summed and converted into a final global warming potential measured in CO_2 equivalent considered over a 100-year timescale: $\text{CO}_2 = 1$, $\text{CH}_4 = 23$ and $\text{N}_2\text{O} = 296$ (Styles and Jones, 2007).

According to *Revised 1996 IPCC Guidelines* (IPCC, 1996), CO_2 emissions from biomass combustion are regarded as recycling atmospheric CO_2 if biomass is extracted from a sustainable (i.e. replenished) source. These CO_2 emissions are therefore excluded from net emission calculations.

The combustion of biodiesel in locomotives is assigned a zero emission factor to account for the carbon sequestered during the cultivation of *Jatropha* trees.

When the end product is JME, glycerin is a co-product. The carbon emission from synthetic glycerin, which is 9.6 kg CO_2 -eq per kg glycerin (Wicke et al. 2008), was considered a credit to the carbon balance of JME production.

The $\text{CO}_{2\text{eq}}$ balance is mathematically expressed as:

$$W_{c_{eq}} = \sum_{i=1}^4 CR_i - \sum_{i=1}^4 CE_i \quad (8)$$

where $W_{CO_{2eq}}$ is the CO_{2eq} balance of the lifecycle of JCL biodiesel, i is the i th stage of production, CR_i is the amount of CO_{2eq} emission reduced at the i th stage, and CE_i is the amount of CO_{2eq} emitted at the i th stage.

The monetary value of carbon was estimated using an implicit price for tradable emission permits in the international carbon market, and was then integrated into economic analysis.

4.2.1 Carbon Sequestered by JCL Plantations

There is no information on the total biomass production of JCL so far. For an irrigated JCL plantation in Egypt, Henning supposes the future total biomass production to be 80 tonnes of dry mass per hectare (or $11 \text{ t drymha}^{-1} \text{ yr}^{-1}$ including seeds) (spacing $2.5 \times 2.5 \text{ m}$) representing $5.5 \text{ tCO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$ (Benge, 2006). For Indian wastelands, the average annual CO_2 sequestration rate in standing biomass is estimated to be $72.25 \text{ tCO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$ (excluding the $2\text{--}2.5 \text{ t dry seed yield ha}^{-1} \text{ yr}^{-1}$ (Francis et al. 2005)). The wood density of this tree species is reported to range from 0.33 to 0.37 gcm^{-3} (Benge, 2006).

The annual net primary production (NPP) of JCL is about $1.0\text{--}10.0$ tonne oven-dry biomass per hectare (Openshaw, 2000). JCL trees tend to become mature five years after they are planted and the biomass stock is about $6\text{--}60$ tonnes per hectare, or $0.4\text{--}4 \text{ t/mu}$. Because the ratio of carbon in biomass is about 0.5 (Johnson and Sharpe, 1983; Zhao and Zhou, 2004), carbon sequestered from JCL plantations is around $3\text{--}30 \text{ t/ha}$, or $0.2\text{--}2 \text{ t/mu}$. Based on the molecular theory and structure of CO_2 , the ration of CO_2 to C is $44/12$, or 3.67 . The CO_2 sequestered by JCL plantations is about $11.01\text{--}110.1 \text{ t/ha}$.

As surveyed, the yield of JCL seed is proportional to the biomass of the trees. The biomass stock is about 45 times that of the annual seed yield. This relationship is used to estimate the amount of carbon that a JCL plantation can sequester.

4.2.2 Carbon Reduced by Substituting Coal with JCL Fruit Husks and Seed Shells

The fruit husks and seed shells can be used as a substitute for coal and thus reduce carbon stock which would otherwise be released from the combustion of coal. The husks and seeds account for 40% and 60% of the weight of fruits, respectively. Since the carbon embodied in fruit husks and seed shells is from the atmosphere and is then released into the atmosphere when they are burned, the carbon balance of fruit husks and seed shells can be considered neutral. Thus, GHGs can be reduced when fruit husks and seed shells are used as a substitute fuel for coal.

The weight of the fruit husks accounts for about 40% of the fruit and the weight of

the seed shells accounts for about 40% of the seeds. As the yield of JCL seed increases, a higher fruit yield and number of seed shells will be produced. Although fruit husks and seed shells can be used as fuel or raw material of activated carbon, only the former has been considered so far. When the mechanical extraction method is used, JCL seeds are usually processed without shelling.

According to Wang (1999), the calorific values of coal and forest residuals are 19.546 and 13.243 mmBtu/tonne, the equivalent amount of coal equivalent to fruit husks are calculated. Further, according to the CH₄, N₂O and CO₂ emission factors of coal, which are 1.095, 0.014 and 878 g/mmBtu (Table 5), respectively, the equivalent CO₂ emission of coal is calculated to be 17.778g/kg.

Table 5. The Emissions of Fertilizers and Fuels

Fertilizers/Fuels	Emissions		
	CH ₄	N ₂ O	CO ₂
N (g/g)	0.0029	0.0016	2.4382
P ₂ O ₅ (g/g)	0.0018	0.0000	0.9905
K ₂ O (g/g)	0.0010	0.0000	0.6648
Diesel (g/MJ)	0.011134	0.002875	81.4674
Coal (g/mmBtu)	1.095	0.014	878

Source: Wang (1999)

4.2.3 Carbon Reduced by Substituting Fertilizers with JCL Seed Cake

The seed cake contains about 6% Nitrogen, 3% P and 1% K as well as traces of Ca and Mg (Lieth 1975). One tonne of seedcake applied to the soil is equivalent to applying 0.15 t of NPK [40:20:10] mineral fertilizer (Openshaw 2000). Thus, seed cake can be used to replace chemical fertilizers.

As a fertilizer, JCL seed cake can add a credit to the carbon balance of JCL biodiesel because of its displacement effects. In other words, more GHG will be emitted if chemical fertilizers rather than seed cake are used to fertilize JCL plantations. The displacement effect is calculated according to the NPK contents in seed cake and the emission factor of chemical fertilizers (Table 5).

4.2.4 Carbon Reduced by Substituting Diesel with JCL Oil or JME

Since the carbon embodied in JCL oil or JME comes from the atmosphere, the substitution of diesel with JCL oil or JME can reduce GHG which would otherwise be emitted when diesel is used. According to Wang (1999), the equivalent CO₂ emission of diesel (including CO₂, CH₄ and N₂O) is calculated as 82.6025 g/MJ⁻¹. Based on the specific gravities and unit calorific values, it is calculated that one liter of diesel has an equivalent calorific value to that of one liter of JCL oil and 0.918 one liter of JME. As the seed yields of JCL plantations change, the potential for carbon stock reduction by substituting fossil diesel with JCL oil or JME were estimated.

4.2.5 Carbon Emissions at the Seed Production Stage

In the course of seedling cultivation, phosphorus salts (Ca^{2+} and Mg^{2+}) were applied to the seed bed. The dose is 1,500-2,250 kg per hectare. At the present technological level, the output of seedlings is about 210,000 seedlings per hectare and the emergence percentage is about 80%, or the output of transplanted seedlings is 168,000 seedlings per hectare. Assuming that the survival rate of transplanted seedlings is 85%, the carbon emission was thus attributed to each unit of JCL plantation (1,650 trees per hectare).

At the stage of seed production, JCL plantations are fertilized with chemical fertilizers for the first three years. From the fourth year onwards the seed cake will be used as fertilizer and no more chemical fertilizers will be applied.

In the first three years, the annual application of compound fertilizers (N:P:K=40:20:10) and urea are 27.5 kg and 22 kg, respectively. The global warming effect of CH_4 and N_2O are 25 and 298 times of that of CO_2 for a time span of 100 years (Wang, 1999). Thus, the combustion of one kg of coal produces 2.1 kg of $\text{CO}_2\text{-eq}$. Based on the amount of fertilizers used in each unit of land, the emissions of fertilizers from JCL plantations was estimated.

4.2.6 Carbon Emissions from the Oil Extraction Stage

The source of carbon at this stage is the combustion of coal to generate steam in the process of refining crude JCL oil. For the production of one tonne of JCL seed, the amounts of coal are about 100 kg for mechanical extraction and crude oil refining, and 600 kg for chemical extraction and crude oil refining. Based on the different yields of JCL plantations, the corresponding carbon emissions at the oil extraction stage were calculated. Limited by data availability, carbon emission results from the construction of offices, workshops, and other buildings was not included, and the indirect carbon emissions from the manufacturing of machinery is only the portion from the production of cast steel, structural steel and stainless steel.

Although JCL can bear fruit in the year following transplantation, the carbon emission at this stage are considered to start from the third year because the yields in the previous two years are low and neglected.

4.2.7 Carbon Emissions from Transporting Seeds and Fertilizer

In mountainous areas of Yunnan, the main cargo vehicles a medium heavy-duty trucks (tonnage: 5 tonnes). It is assumed that the total distance from the JCL plantation to and from the oil extraction plant and fertilizer shop is 50 km and that the combustion efficiency of diesel for a medium heavy-duty truck is 10 km per liter. Based on the emission factor of diesel (Table 6), the equivalent carbon emissions a calculated to be

30.72 kg.

As stated in 3.3, carbon emissions from the transportation of JCL oil and/or JME were also accounted for.

4.3 Economic Analysis

Economic feasibility of biodiesel production was assessed using this equation:

$$ENPV = \sum_{n=0}^N \frac{P_n Q_n + \sum_{i=1}^4 \sum_{m=0}^M q_{inm} p_{im} + V_E - \sum_{i=1}^4 C_{in} - C_E}{(1+r)^n} \quad (9)$$

where ENPV is the economic net present value of biodiesel production; V_E is the total environmental benefit; C_E is the total environmental cost.

The production of biodiesel is economically feasible if the ENPV is positive, otherwise, it is not feasible. In particular, if the ENPV is greater than the FNPV, the provision of a subsidy can be justified.

4.4 Energy Efficiency Analysis

Energy efficiency is an important indicator to evaluate the eco-performance of renewable energy. Energy efficiencies were assessed with the following indicators:

$$EE_1 = \frac{HV_{biodiesel}}{HV_{energy\ input}} \quad (10)$$

$$EE_2 = \frac{HV_{biodiesel} + HV_{by-products}}{HV_{energy\ input}} \quad (11)$$

$$EE_3 = \frac{HV_{biodiesel}}{HV_{direct\ energy\ input}} \quad (12)$$

where EE_1 is the ratio of the heat value of per unit of biodiesel and that of the energy used to produce that unit of biodiesel; $HV_{biodiesel}$ is heat value of biodiesel; $HV_{energy-input}$ is the heat value of input energy; EE_2 is the ratio of the heat value of biodiesel and co-products and that of the input energy; EE_3 is the ratio of the heat value of biodiesel and that of direct energy inputs.

All direct material and energy inputs were calculated at the primary energy level. The GREET model (Wang, 1999a) was used to provide the input efficiencies to convert from primary energy to process energy, such as diesel fuel and gasoline. For example,

residual oil, diesel fuel, natural gas and electricity are process fuels in manufacturing N, P and K fertilizers and herbicide. The total energy inputs include the energy used to mine, extract and manufacture raw materials into those energy products. Multiplication by the input efficiencies converts the uses of the N, P and K fertilizers and herbicide, as well as the direct diesel fuel, electricity and coal uses, into primary energy inputs. Labor inputs were regarded as calorie-equivalent energy. Agricultural workers work eight hours per day, and one man-hour input is 2.3 MJ/h (Hopkinson, 1980; Ozkan et al. 2004). The energy consumption of buildings, offices and workshops as well as the machinery for oil extraction and further processing were estimated according to the energy coefficients in Yáñez Angarita et al. (2009). Limited by data, the energy consumption of machinery is only composed of the portions used in the production of cast steel, structural steel and stainless steel used in the machinery sets, while those in the processes of fabrication were not included.

The energy content of JCL seed oil and JME are 37.83 ~ 39.20 MJ/kg (Augustus et al. 2002; Sahoo et al. 2009; Baitiang et al. 2008) and 40 MJ/kg (Chen et al. 2006), respectively.

4.5 Sensitivity Analysis

Sensitivity analysis assesses risks by identifying the variables that most influence a project's 3E performance and quantifying the extent of their influence. The analysis was conducted by varying a certain percentage in the value of variables considered.

The variables affecting financial feasibility include biodiesel price, yields of JCL seeds, discount rate, and total cost, etc. Variables for the sensitivity analysis of carbon balance and energy efficiency are seed yield, co-product yield, farm energy inputs, farm chemical inputs, energy consumption in oil extraction, and energy consumption in JME production.

5.0 RESULTS

5.1 Financial Analysis of the Production of JCL Oil

The financial analysis is composed of two parts: firstly, the financial feasibility of the different stages of JCL oil production when the seed producer and oil producer are independent; secondly, the financial analysis of JCL oil production when the entire production is run by a single producer.

5.1.1 Seed Production

The production of JCL seeds starts from seedling cultivation to seeds delivered to oil extraction plants, and involves activities that include transplanting, site preparation,

tending, seed collection and drying, husk removal and transportation.

Assuming a base yield of 1,485 kg per hectare (500 fruits per tree), the total cost at the seed production stage is 73,609 yuan per hectare and its components, shown in Table 6. The main costs are associated with fruit drying and husk removal, fruit collection, fertilization, fungicide spraying, and weeding.

Table 6. The Cost Components of Seed Production

Cost component	Description	Percentage
1. Seedling cultivation	Including land rent, seeds, seed treatment, nursery treatment, fertilization and tending. The cost of each seedling is 0.11 yuan. At an assumed survival rate of 85%, 130 seedlings are needed for each mu of land.	0.59%
2. Land rent	50 yuan per mu for a period of 30 years.	2.06%
3. Site preparation & transplanting	Contracted to reforestation company at the cost of 120 yuan per mu.	4.95%
4. Fertilization	Including fertilizer and the associated labor cost for the first three years. Fermented seed cake will be used as fertilizer instead of chemicals from the fourth year onwards.	18.74%
5. Weeding	Manual weeding followed by a spray of herbicide each year for the first five years.	6.87%
6. Spraying fungicide	Annual application. Labor and fungicide/pesticide costs.	11.05%
7. Pruning	Twice in one year. Cost of labor and instruments.	1.84%
8. Fruit collection	By hand. Labor cost only.	20.48%
9. Drying and husk removal	By hand. Labor cost only.	30.72%
10. Transportation cost	Including seeds and fertilizer transportation costs. C=200 yuan+1.5 yuan/km*mileage for a 5 tonnage truck.	2.69%
Total	Including costs incurred from seedling cultivation, to seed transportation, to oil plant.	100%

To estimate the revenue of seeds, the present price of JCL seed, 2 yuan per kg, was used. According to equations 4 and 6, the financial net present value at seed production stage (FNPV_s) and the breakeven price of JCL seed at the seed production stage was calculated to be -8,425.46 yuan per hectare and 2.6 yuan per kg, respectively.

Obviously, the production of JCL seed is financially unfeasible. However, when some variables are changed, the results might be different.

The Relationship between Seed Yields, the FNPV_s and the Break-even Price

Assuming that the JCL tree has annual fruit yields of 100, 300, 500, 700, 900, 1,100, 1,300 and 1,500 pieces per tree, corresponding to an annual seed yield of 297, 891, 1,485, 2,079, 2,673, 3,267, 3,861 and 4,455 kg per hectare, respectively, the relationship between the FNPV_s and the yields is shown in Figure 7. It reveals that the FNPV_s tends to increase as the seed yield is improved. When the price of seeds is 2 yuan per kg, the FNPV_s will be positive only if the seed yield is higher than 3 tonnes per hectare.

Obviously, the seed yield is one of the important determinants of the financial feasibility of biodiesel production.

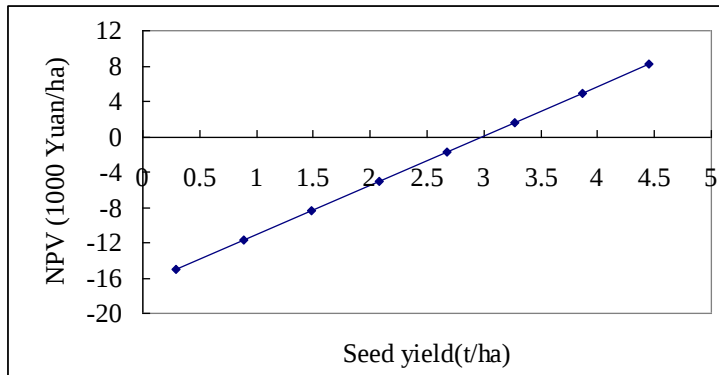


Figure 7. The Relationship Between $FNPV_s$ and Seed Yield

The relationship between seed yields and the breakeven price is shown in Figure 8. As expected, the breakeven price tends to decrease as the seed yield increases. When the seed yield is low, the breakeven price can be sharply decreased by increasing seed yield. However, the increase of seed yield has a decreasing effect on the breakeven price because the cost of seed production is mainly composed of payment for labor, which increases as seed yield is enhanced. Therefore, to cut the cost of seed production, less labor should be used.

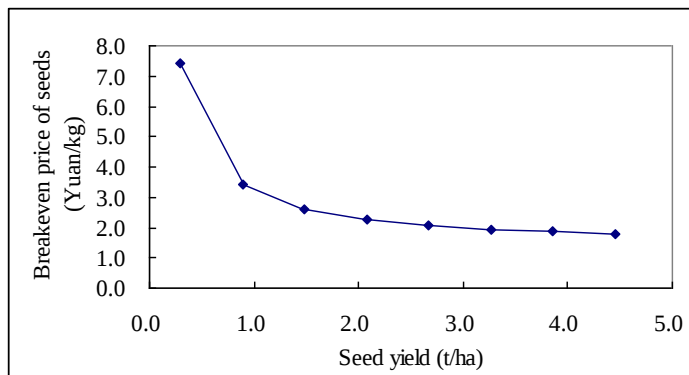


Figure 8. The Relationship between the Breakeven Price and Seed Yield

The Relationship between the Market Price of JCL Seeds and the $FNPV_s$

As shown in Figure 9, the $FNPV_s$ is highly sensitive to any change in seed price. When the seed yield is 1,485 kg per hectare, the breakeven price of seed is 2.6 yuan per kg. However, the price is unrealistic as the oil content and the present price of diesel are concerned. At the present seed price of 2 yuan per kg, the $FNPV_s$ is negative and it is impossible to make $FNPV_s$ positive. Obviously, if a target for using biodiesel is set up, the gap should be bridged by government subsidy as long as there is an economic justification.

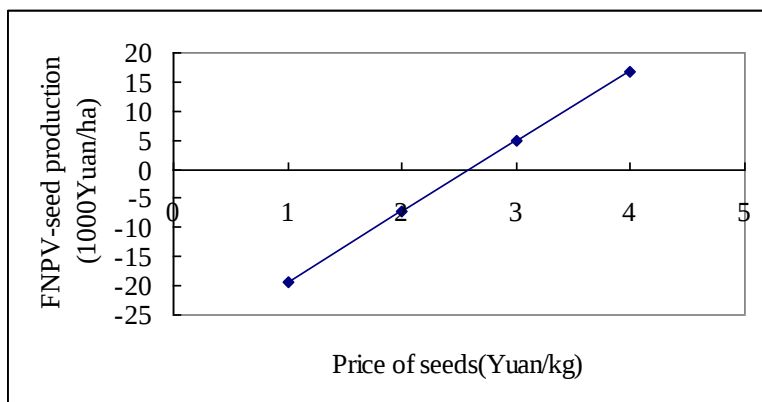


Figure 9. The Relationship between Seed Price and the FNPV_s

5.1.2 JCL Oil Extraction

When mechanical extraction is used, the oil extraction stage begins with heating seeds into refined JCL oil. When the seed yield is 1,485 kg/ha, the total cost of the processing of JCL seeds is 2,321.91yuan per tonne and its components are shown in Table 7. The major cost comes from the purchase of the seeds which accounts for 86.13% of the total cost, while the sum of all the other costs accounts for only 14.87%.

Table 7. The Cost Components of Mechanical Extraction and Refinement per Tonne of Jatropha seeds

Cost Components	Description	Percentage %
1. Shared cost of machinery by each tonne of Jatropha seed	Calculated with the straight-line average service life method with a salvage value of 5%. The machinery includes a mechanical expeller and the equipment for oil refining.	2.06%
2. Coal	0.1 tonne × 450 yuan per tonne	1.94%
3. Electricity	17.5 kilowatt × 1 yuan per kilowatt	0.70%
4. Labor	Three workers, 50 yuan/(worker × day)	6.01%
5. Workshop rent	20,000 yuan per year, 240 working days a year	2.43%
6. Seed cost	Seed price is 2 yuan per kg	86.13%
7. NaOH for deacidification of crude oil	The present local price of NaOH is 3,700 yuan per tonne. The acidic value of crude oil is about 12.35 mgKOH/g.	0.47%
8. Transportation of oil	The distance between the plant and the oil distribution point is assumed to be 10 km. The cost is 100 yuan for a distance of 10-30 km.	0.26%
Total		100%

As shown in Table 2, the oil percentage ranges from 32.2-40.2% in seeds when oil is extracted using an engine driven-expeller. However, it is the yield of crude oil. According to researchers' recent survey at an oil extraction plant of Erkang Science and

Technology Co. Ltd.. The yield of refined oil is about 30.4%. Based on the specific gravity of JCL oil and the total cost in the above table, the cost of producing one liter JCL oil is calculated to be 6.99 yuan per liter when the seed price is 2 yuan per kg.

5.1.3 Subsidies Required for JCL Oil Production

Subsidies will be required for both JCL seed producers and processors if a biodiesel output target is set.

At the seed production stage, subsidies can be provided based on the weight of seeds or the area of JCL plantation. Assuming that both the seed producers and processors will receive a margin of 10%, the two kinds of subsidies are shown in Table 8. Subsidies are required when the seed yield is lower than 3 tonnes per hectare. The required subsidy tends to decrease as the seed yield increases.

Table 8. Subsidies Required for the Production of JCL Seeds

Annual seed yield (kg/ha)	297	891	1485	2079	2673	3267	3861	4455
Break-even price of seed (yuan/kg)	7.4	3.4	2.6	2.3	2.1	2.0	1.9	1.8
Subsidies based on seed weight (yuan/kg)	5.4	1.4	0.6	0.3	0.1	0	0	0
Annual subsidies based on Plantation area (yuan/ha)	1603.8	1247.4	891	623.7	267.3	0	0	0

At the oil extraction stage subsidies can be based on the volume of JCL oil. According to the average calorific values and specific gravities of diesel and JCL oil, it was calculated that one liter of diesel has a calorific value equivalent to 0.994 liters of JCL oil, so one liter of JCL oil is equivalent to one liter of diesel. As previously calculated, the breakeven price of JCL oil is 6.99 yuan per liter when the seed yield is 1,485 kg per hectare. Based on the present local price of diesel, 5.89 yuan per liter, the subsidy is 1.88 yuan per liter when a margin of 10% is assumed. An increase in the price of diesel may provide an incentive for investors in JCL oil.

5.1.4 Full-chain Financial Analysis of the Production of JCL Biodiesel

Both JCL oil and JME can be end products. When production chains of both JCL oil and JME are operated by single producers, financial feasibility is shown in Table 9. The results reveal that the FNPVs of the production of the two end products are negative. That is, the production of JCL oil or JME is not financially feasible.

The major cost of the production of JCL oil or JME is incurred at the seed production stage. As an extension of JCL oil, the transesterification reaction incurs additional costs. However, as a co-product of JME, glycerin shares 8.1% of the total cost according to credits for allocation which are determined in terms of the market values of JME and glycerin. As a result, the FNPV of JME is slightly higher than that of JCL oil.

When the production chain, beginning with seedling cultivation to end products of JCL oil or JME, is operated by single producers, subsidies can be provided according to the amount of JCL oil the producers produce. The subsidy rate can be determined according to the breakeven price of the end product. Assuming a margin of 10%, the required subsidy rates are as shown in Table 9. The difference between the breakeven prices or required subsidy rates of JCL oil and JME is insignificant. Thus, from an economic perspective, it does not matter if JCL oil or JME is produced.

Table 9. Full-chain Financial Analysis of JCL Biodiesel

Item	Quantity	
	JCL oil	JME
Cost of seed production (%)	88.38	82.83
Cost of oil extraction and refining (%)	11.40	10.89
Transesterification cost (%)		6.10
Cost of biodiesel distribution (%)	0.22	0.19
Total cost (10^4 yuan/ha)	4.11	4.39
Cost of JME		4.03
Cost of glycerin		0.36
JCL oil or JME output (10^4 l/ha)	1.33	1.30
Glycerin output (t/ha)		1.06
Total revenue (10^4 yuan/ha)	2.73	2.89
FNPV (10^4 yuan/ha)	-1.38	-1.37
Breakeven price (yuan/l)	8.87	8.91
Required subsidy rate (yuan/l)	3.97	4.01

The production process of JME is as shown in Figure 5. It begins with the pretreatment of JCL oil and continues with the transesterification of the oil, and the refinement of JME and glycerol. Based on a production line with an annual capacity of 50,000 tonnes of JME, the inputs are as shown in Table 10 (Li et al. 2007). Excluding the cost of seed oil, the cost of production of JME is 674.68 yuan per tonne, among which the major expenditures are methanol, catalyst, electricity, NaOH and coal. Since glycerol is a co-product of JME, the costs shared by JME and glycerin are found to be 615.31 yuan per tonne of JME and 59.37 yuan per tonne of JME, respectively, by allocating credits between JME and glycerol according to their market values.

Table 10. Inputs of the Transesterification of JCL Oil

Input	Quantity	Cost (YUAN/t biodiesel)	Percentage %
Phosphorous acid (85%)	≤ 2.8 kg/t oil	12.02	1.78
Sodium hydroxide (50%)	≤ 3.0 kg/t oil	5.95	0.88
Sodium hydroxide (30%)	20 m ³ /t biodiesel	22.20	3.29
Water	2.11t/t biodiesel	8.93	1.32
Electricity	51.8 kWh/t oil	52.66	7.81
Hydrochloric acid (HCl)	10 kg/t biodiesel	4.00	0.59
Activated carbon	0.4 kg/t biodiesel	1.60	0.24
Citric acid (50%)	1 kg/t biodiesel	2.00	0.30
Sodium Methoxide (30%/70%)	17 kg/t biodiesel	85.00	12.60
Methanol	≤ 120.0 kg/t biodiesel	420.00	62.25
Shared machinery cost	A salvage value of 5% calculated with the straight-line average service life method	22.02	3.26
Labor	Payment for employers	6.20	0.92
Coal	50kg/t biodiesel	22.50	3.33
Office expenditure	10,000 yuan/year	1.67	0.25
Maintenance costs	476,000 yuan/year	7.93	1.18
Total		674.68	100
Cost shared by glycerol		59.37	8.8
Cost shared by JME		615.31	91.2

As a co-product of JME, glycerol contributes around 8.1% of total revenue. Based on the market values of JME and glycerol, the total cost is allocated by assigning 91.9% to JME and 8.1% to glycerol. According to the outputs and shared costs, the breakeven prices of JME are calculated to be 8.91yuan per liter. If they purchase JCL seeds to produce JME, producers should be provided with a subsidy rate of 4.01yuan per liter, assuming a margin of 10% of the breakeven price.

5.2 The Carbon Balance of JCL Biodiesel

When different technology options are chosen, the carbon balance of the end product will differ. Analysis of the carbon balances for end products of JCL oil and JME follow.

5.2.1 The Lifecycle Carbon Balance of JCL Oil

When JCL oil is directly used by blending it with fossil diesel, its lifecycle carbon balance is as shown in Table 11. The production and use of JCL oil has a positive carbon balance. JCL plantations and JCL oil are major contributors to carbon balance. As co-products of JCL oil, the combustion of fruit husks can also reduce carbon emissions when they are used as a substitute for coal.

Table 11. The Lifecycle Carbon Accounting of JCL Biodiesel

Sources of CO ₂ reduction	Quantity of CO ₂ equivalent	
	JCL oil	JME
Application of fertilizers (for the first three years) (kg/ha)	-6719.65	-6719.65
Transportation of seeds and fertilizers (kg/ha)	-972.25	-972.25
JCL plantation (t/ha)	61.93	61.93
Substituting coal with Jatropha fruit husks (kg/ha)	321.97	321.97
JCL oil extraction and refining (kg/ha)	-172.27	-172.27
Substituting fertilizers with seed cake (t/ha)	6.16	6.16
Transesterification of JCL oil (t/ha)		-2.37
Substituting synthetic glycerin with bio-glycerin (t/ha)		10.18
Distribution of end products (kg/ha)	-14.3	-13.32
Substituting fossil diesel with JCL biodiesel (t/ha)	37.11	36.21
Lifecycle carbon balance per ha plantation (t/ha)	97.64	104.54
Lifecycle carbon balance per liter biodiesel (kg/l)	7.34	8.04

The major GHG emitters are the application of fertilizers and the transportation of seeds and fertilizers. Although a lot of direct energy is used in the oil extraction stage, the GHG emissions are relatively small.

5.2.2 The Carbon Balance of the Lifecycle of JME

The production process of JME is an extension of that of JCL oil. The carbon sources of the former differ from that of the latter starting with the transesterification reaction. The lifecycle carbon balance of JME is positive (Table 11), similar to that of JCL oil.

Intuitively, more GHG will be emitted for the production of JME because more inputs are used. However, as a co-product of JME, glycerin adds a credit to the lifecycle carbon balance of JME because it can be considered a substitute for synthetic glycerin. Consequently, the lifecycle carbon balance of JME is higher than that of JCL oil.

5.3 Economic Feasibility of the Production and use of JCL Biodiesel

Despite other economic values and costs, the economic feasibility study included the carbon value and the value of fruit husks and seed shells, where fruit husks and seed shells are considered to be substitutes for coal. According to Xing and Wang (2009), the recent price of CER in China's CDM market was around € 10 /t or 91.8 yuan per tonne (Xing & Wang 2009). This is the most recent price since the global financial crisis although it was previously much higher. The fruit husks were first converted to the coal equivalent based on their calorific value and then on the coal price, 450 yuan per tonne, was used as the proxy price of fruit husks since fruit husks are not traded in the market.

Table 12 shows that, when no other external values are included, both the ENPVs of JCL oil and JME are negative, with the former slightly higher than the latter. The total value of carbon emission reduction and fruit husks is 7,800 yuan per hectare, which is an important external benefit of the production of JCL biodiesel. However, the ENPVs are

slightly lower than zero and there is good potential for providing an economic justification for the production of JCL biodiesel if the production technology is improved.

Table 12. The Economic Feasibility of the Production of JCL Biodiesel

Item	Quantity	
	JCL oil	JME
Total cost (10^4 yuan/ha)	4.11	4.39
Value of carbon emission reduction (10^4 yuan/ha)	0.50	0.52
Value of fruit husks (10^4 yuan/ha)	0.28	0.28
Value of JCL biodiesel (10^4 yuan/ha)	2.73	2.66
Value of glycerin (10^4 yuan/ha)		0.24
Total revenue (10^4 yuan/ha)	3.51	3.70
ENPV (10^4 yuan/ha)	-0.60	-0.69

5.4 The Energy Efficiency of the Production and Use of JCL Biodiesel

The major energy use for the production of JCL biodiesel is from the application of herbicides, insecticides, and chemical fertilizers, and the extraction and refining of oil, which are the same for the end products of JCL oil and JME.

The energy attributed to chemicals is mainly indirect energy input, i.e., the energy inputs for the production of these chemicals. For example, the energy used for the production of glyphosate and carbendazim are 454MJ/kg and 397MJ/kg (Tzilivakis et al. 2005; Green 1987), respectively. Because of the low level of mechanization, the energy inputs in fruit collection and drying, husk removal, planting and tending are mainly labor energy, which is 2.28MJ/h (Kallivroussis, 2002). The direct energy input is mainly used in the extraction and refinement of JCL oil, as well as for the transportation of seeds, fertilizers and end products.

Where JCL oil is the end product, the energy inputs were accounted for from site preparation to the distribution of refined JCL oil. When the seed yield is $1,485 \text{ kg/hm}^2$, the composition of energy inputs are as shown in Figure 10. The major energy inputs are for oil extraction and refining, fungicide or pesticide application, and fertilization. The energy output includes the chemical energy in JCL oil, which is $37.83 \sim 39.20 \text{ MJ/kg}$ (Augustus 2002; Sahoo 2009; Baitiang et al. 2008) or 35.3 MJ/l on average, and the biomass energy in twigs, woods and leaves, which is around 15.5 MJ/kg (Wang 1999a).

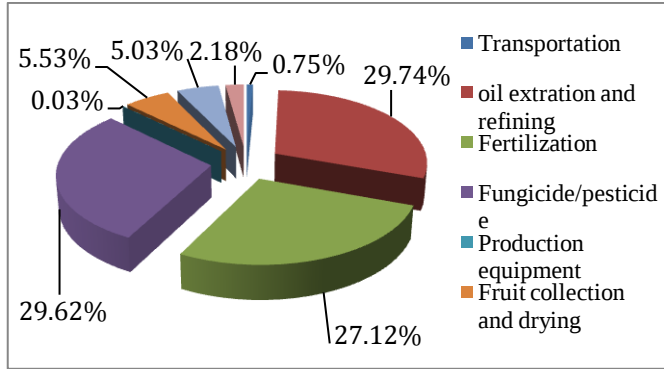


Figure 10. The Composition of the Lifecycle Energy Inputs of JCL Oil

However, when JME is the end product, additional energy inputs are required for the transesterification of JCL oil. Thus, the energy input for each liter of JME is higher than that of JCL oil.

According to equations 10, 11 and 12, the energy efficiencies of JCL oil and JME are shown in Table 13. The results showed that for both end products, the E_1 , E_2 and E_3 are greater than one. That is, the production of both JCL oil and JME are energy-efficient. Without the process of transesterification, the production of JCL oil is more energy-efficient.

Table 13 The Energy Efficiency of the Production of JCL Biodiesel

Item	Quantity [*]	
	JCL oil	JME
Total energy input (MJ/l)	22.53	25.87
JCL oil output (10^4 l/ha)	1.33	
JME output (10^4 l/ha)		1.30
Glycerin output (tonne/ha)		1.06
Biomass energy except seed oil (10^4 kg/ha)	6.75	6.75
EE_1	1.57	1.47
EE_2	6.68	5.54
EE_3	11.22	7.68

^{*} Note: the calorific values of JME and glycerin are 34.96 MJ/l and 18.05 MJ/kg, respectively.

5.5 Sensitivity Analysis

5.5.1 Financial Feasibility

The financial feasibility of biodiesel production is affected by seed yield, biodiesel price, discount rate and the outputs of co-products.

As a determinant of biodiesel output, seed yield has a significant effect on the FNPV. As shown in Figure 4, the FNPVs tend to increase as the seed yield is enhanced. Because the marginal cost is higher than the marginal revenue, the FNPVs are still negative when the seed yield is as high as $3,861 \text{ kg ha}^{-1}$.

Table 14. The Financial Feasibility of Producing JCL Biodiesel

Annual seed yield (kg ha ⁻¹)	297	891	1485	2079	2673	3267	3861	
JCL oil	NPV (10 ⁴ yuan ha ⁻¹)	-1.62	-1.50	-1.38	-1.26	-1.14	-1.03	-0.91
	Breakeven price (yuan l ⁻¹)	23.32	11.28	8.87	7.83	7.26	6.90	6.64
JME	NPV (10 ⁴ yuan ha ⁻¹)	-1.50	-1.44	-1.37	-1.30	-1.23	-1.16	-1.09
	Breakeven price (yuan l ⁻¹)	22.53	11.18	8.91	7.94	7.40	7.06	6.82

Since the unit cost of JME is higher than that of JCL oil, changes in seed yield have a higher effect on the FNPV of JCL oil than that of JME. As Figure 11 depicts, the gaps between the FNPVs of two end products increase as the seed yield is improved. The two curves intersect at coordinate (-1.35, 1.66). On the left side of the intersecting point, or when the seed yield is lower than 1.66 t ha⁻¹, the NPV of JME is higher than that of JCL oil. On the right side of the intersecting point, the relationship reverses. The contribution of glycerin to the NPV is higher when the seed yield is lower and tends to decrease as the seed yield increases.

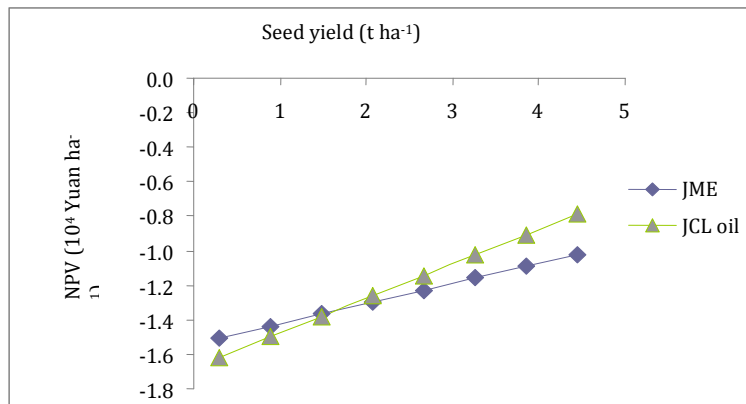


Figure 11. Relationship between FNPV and Seed Yield

The FNPV is also affected by the discount rate, which represents the opportunity cost of investment. As shown in Figure 12, the FNPVs tend to increase as the seed yield is improved. However, the NPV of JME is more sensitive to a change in discount rate than that of JCL oil. When the discount rate is 6.8%, the production of JME and JCL oil will yield the same of level of NPV. The NPV of JME is lower than that of JCL oil when the discount rate is lower than 6.8%, and the relationship reverses when the discount rate is higher than 6.8%.

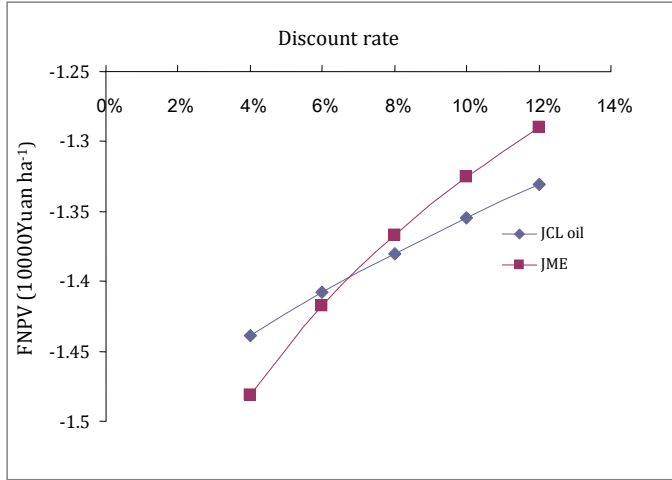


Figure 12. Relationship between FNPV and Discount Rate

Being a determinant of the end product's value, price plays an important role in determining the financial feasibility of the production of JCL biodiesel. As shown in Figure 13, the FNPVs are very sensitive to changes in biodiesel price. However, before the biodiesel price increases to the breakeven prices of JME and JCL oil, respectively, the FNPVs of the two end products are negative. Figure 13 also reveals that the effects of changing biodiesel price on the NPVs of JME and JCL oil do not differ much.

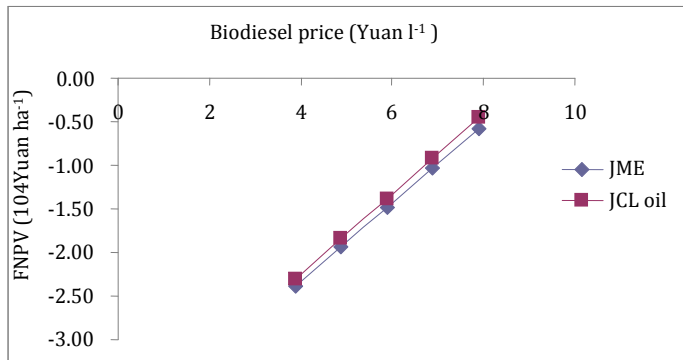


Figure 13. Relationship between FNPV and Biodiesel Price

As shown in Figure 14, the FNPVs of JCL oil and JME are also very sensitive to changes in the production cost. That is, a slight change in production cost will result in a sharp decrease in the FNPVs of both end products. Thus, more effort should be made to reduce the total cost to enhance the financial feasibility of the production of JCL biodiesel. In particular, major efforts should be focused on the seed production stage because, as shown in Table 9, more than 80% of the total cost is incurred at the seed production stage.

Due to lower base of total cost, the FNPV of JCL oil is slightly more significant than that of JME.

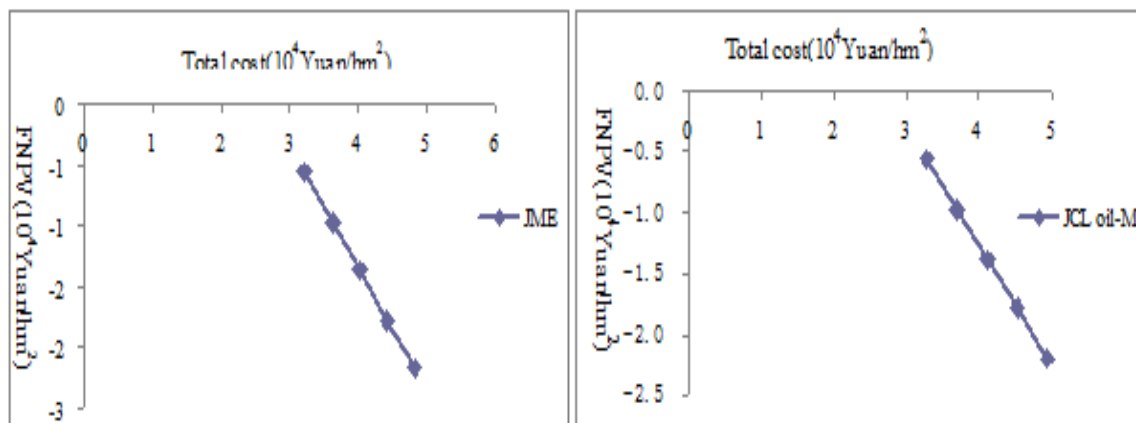


Figure 14. Relationship between FNPV and Total Cost

5.5.2 Carbon Balance

The major contributors to carbon stock are the substitution of fossil diesel with JCL biodiesel and the carbon sequestration of JCL plantations. Since the seed yield is usually proportional to the biomass stock of JCL plantations, seed yield can be considered a major factor affecting carbon balance.

The relationship between carbon balance and seed yield is shown in Table 15. Obviously, the carbon balance will be significantly improved as the seed yield is enhanced. The reason for this is that the effects of carbon emission reduction by substituting diesel with JCL oil and through carbon sequestration by JCL plantations tends to become more significant when the seed yield is improved. In other words, the carbon balance can be significantly increased by enhancing the seed yield or biomass growth of JCL plantations.

Compared with the carbon balance of JCL oil, the carbon balance of JME is more sensitive to the change in seed yield. This is because as a co-product, glycerin adds a credit to the carbon stock of JME and the output of glycerin increases with an increase in seed yield.

Table 15. The Carbon Balance of the Production of JCL Biodiesel

Annual seed yield(kg ha ⁻¹)	297	891	1485	2079	2673	3267	3861
CO _{2eq} of JCL oil (tonne ha ⁻¹)	14.11	55.88	97.64	139.41	181.17	222.94	264.70
CO _{2eq} of JME (tonne ha ⁻¹)	15.49	60.01	104.54	149.06	193.59	238.11	282.64

A sensitivity analysis was also done to determine the effects of the following factors on carbon balance: co-product yield, farm chemical inputs, coal consumption in oil

extraction and transesterification reaction. As Figure 15 shows, carbon balance is very sensitive to a change in co-product yield. A 10% change in co-products results in a 7% change in carbon stock. The intuitive reason is because co-products are one of the major contributors to carbon stock. The effect of changes in all other factors on carbon stock is less significant. Thus, the results of this study are robust.

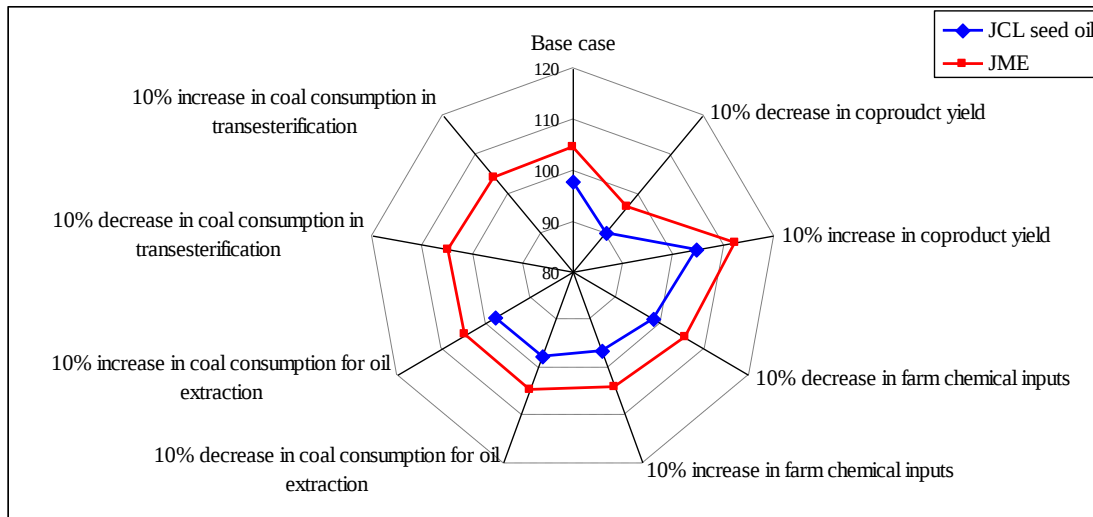


Figure 15. Sensitivity Analysis of Factors Related to Carbon Balance

5.5.3 Economic Analysis

Despite many other external benefits that the production of JCL biodiesel may bring, only the values of carbon emission reduction and fuel co-products have been considered. The value of carbon emission reduction is valued according to the price of CER in the CDM (Clean Development Mechanism) market. Fuel co-products refer to the fruit husks, which are valued according to the price of coal based on the amount of calorific value. Because the carbon balance and co-product output is affected by the seed yield, the economic value will thus be affected by seed yield.

The relationship between the ENPV and seed yield is shown in Figure 16. It reveals that the ENPV increases as the seed yield increases. In particular, when the seed yield reaches a certain level, the ENPV becomes positive. That is, the ENPV becomes positive if the seed yield is higher than 2.27 t/ha for the production of JCL oil and 2.46 t/ha for the production of JME. Since they tend to increase as the seed yield is improved, the values of carbon emission reduction and fruit husks play an important role in making the ENPV positive. Positive ENPV may provide an economic justification for providing subsidies to producers.

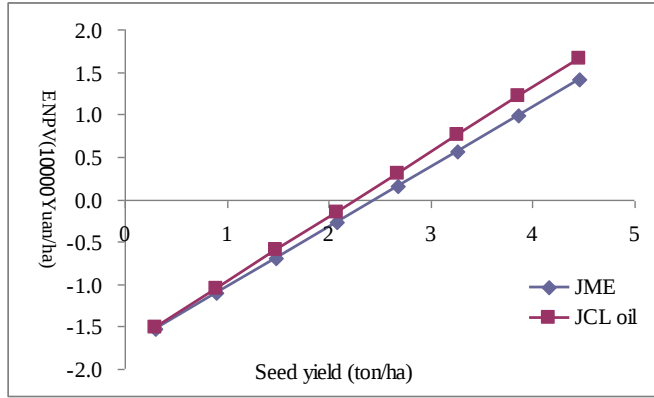


Figure 16. Relationship between ENPV and Seed Yield

Figure 16 shows that the gap in ENPVs between the end products of JCL oil and JME is small. However, the gap between the ENPV of the two end products tends to become larger as the seed yield increases. Obviously, from an economic perspective, it is more desirable to produce JCL oil as a final product when the seed yield is high. However, the long-term effects of JCL oil on engines are unknown.

Other factors may also affect the ENPV but their effects are the same as their affects on the FNPV and carbon balance. Thus, only the effect of changes in seed yield have been analyzed here.

5.5.4 Energy Efficiency

The output of energy is mainly determined by the seed yield. When JCL plantations are established in mountain areas, the seed yield varies a lot as site conditions change. Figure 17 depicts the relationship between energy efficiency and seed yield. It shows that both E_2 and E_3 are greater than one, or energy-efficient at different levels of seed yield, while E_1 is highly dependent on seed yield. However, when the seed yield is higher than 891 kg/t, all indicators of energy efficiency are greater than one. In other words, if a seed yield of 891 kg/t can be obtained, the production of JCL oil and JME are energy efficient no matter how the energy efficiency is assessed.

Without the process of transesterification reaction, the energy efficiency of JCL oil is obviously higher than that of JME at all levels of seed yield in terms of any of the three indicators.

As shown in Figure 17, EE_2 is more sensitive to changes in seed yield while EE_3 is least sensitive. The reason is that the output of energy in wood, twigs and trunks has a positive relationship with seed yield.

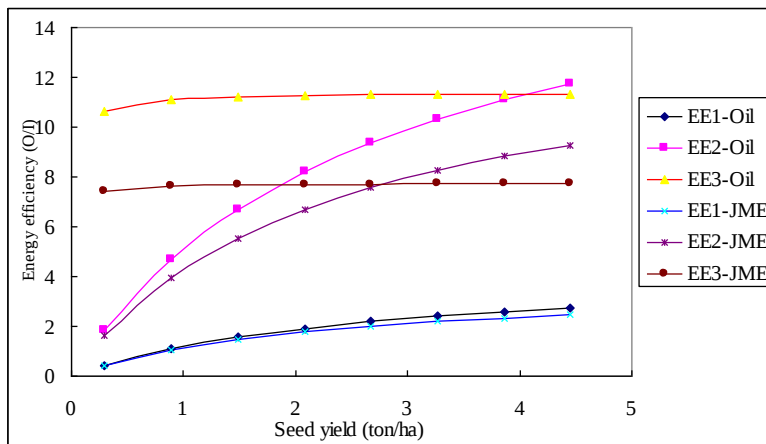


Figure 17. Relationship between Energy Efficiency and Seed Yield

Energy efficiency can also be affected by other factors. Because EE_3 is very high, a sensitivity analysis was done to assess the effects of other factors on EE_2 and EE_3 . As shown in Table 16, changes in co-product yield have no effect on EE_1 because EE_1 includes the energy of co-products. Unlike EE_1 , EE_2 is sensitive to changes in co-product yield. Both EE_1 and EE_2 are sensitive to changes in farm energy inputs for both the end products of JCL oil and JME. However, they are not sensitive to changes in energy consumption in oil extraction and/or transesterification.

Table 16. Sensitivity Analysis of Factors Related to Energy Efficiency

Variation	JCL seed oil	JME			
	EE1	EE2	EE1	EE2	
Base case	1.57	6.68	1.47	5.54	
Co-products yield	-10%	1.57	5.12	1.47	5.12
	+10%	1.57	8.23	1.47	5.96
Farm energy inputs	-10%	1.75	7.46	1.63	6.15
	+10%	1.41	6.00	1.33	5.01
Energy consumption in oil extraction	-10%	1.61	6.86	1.51	5.68
	+10%	1.53	6.50	1.43	5.41
Energy consumption in transesterification	-10%			1.48	5.58
	+10%			1.46	5.51

Thus, to increase the energy efficiency of the production of JCL biodiesel, more effort should be made to increase the seed yield, co-product output and to reduce farm energy inputs.

6.0 IMPACTS OF LAND USE CHANGE

In conducting LCA of biofuels, much of the literature has recognized the necessity for assessment of land use change and there is consensus that land use change and land use occupation impacts on soil and local biodiversity. There is currently no literature available on the impacts on land use of JCL plantations, but it is expected that JCL

plantations will have a positive impact on the soil. JCL has been observed to improve soil structure, and is strongly believed to control and prevent soil erosion.

6.1 Ecological Impacts

In practice, JCL is increasingly used for erosion control in southwest China. No information is available on nutrient cycles and the impact on soil biological life. However, the land use impact will heavily depend on the cultivation system and its intensity. The use of heavy machinery and the intensive application of fertilizers are most likely to be the main drivers towards negative impacts. However, in China, JCL is mainly planted in mountain areas by hand with little use of machinery. Thus, the negative impacts of heavy machinery can be ignored.

Being an exotic species in most growing areas, the impact on biodiversity of land use change towards JCL is expected to be negative, although this will largely depend on the land use which is replaced by JCL and on how the JCL is cultivated. Impact on biodiversity will be especially negative where natural systems such as dryland forests are cleared. However, the development of JCL plantations is presently focusing on four types of land, namely, wasteland and hills, four sides, scattered usable plots, and shrub land and open forests. The impact on biodiversity for the previous three types of land is negligible because of low levels of vegetation or because the land itself is highly marginalized. An assessment of JCL's impact on biodiversity should be performed when JCL plantations are established by clearing shrub land and open forests. However, planting JCL on barren wasteland has the potential to help restore local biodiversity and using JCL as a live fence or in intercropping and agroforestry systems might not have a significant impact.

With a strong ability to regenerate, JCL can grow in tropical and subtropical zones as well as in hot and dry valleys where the rainfall is low and the land is infertile. JCL can be used for soil and water control, anti-desertification, humus enrichment, and forest protection, as well as for the alleviation of soil compaction. Thus, it can be planted in infertile land, barren hills, slopes and rocky hills, without competing with crops for land. JCL is usually used as pioneer tree species for reforestation in areas where soil and water loss is severe. For example, in Yuanmo county of Yunnan Province, the forest cover is only 6% and the restoration of vegetation is an urgent task for local government. The loss of water and soil in the Jiangsha river basin has a direct relationship with the frequent floods in the middle and lower reaches of the Yangtze River. In Binchuan County of Yunnan Province, and in Panzhihua, Jinyang, Ningnan, Butuo and Leibo counties of Sichuan Province, JCL is increasingly used for erosion control. Thus, it is possible for JCL plantations to generate both economic and ecological benefits if ecological restoration and the development of the biodiesel industry can be combined.

JCL is good for stabilizing soil when it is planted on the backs of ditches or tunnels, and for bio-fireproofing on slopes. Moreover, since parts of JCL can be used as pesticides and fertilizers, JCL can be planted on the banks of reservoirs to prevent pest damage to the banks and can be used to improve the edaphic condition and bioactivities of the soil.

In Guizhou and Sichuan, JCL twigs and leaves are buried by the local people as a way of adding nutrients to the soil.

6.2 Land Use for JCL in Yunnan

The JCL resource is rich in Yunnan, where JCL is mainly distributed in valleys and can be found in every one of the 15 prefectures of the province – JCL trees cover an area of more than 1,000 hectares in Chuxiong, Honghe, Lijiang and Kunming, respectively. The land area covered by existing JCL trees is around 18,000 hectares (Table 17). Despite its strong ability to adapt to ecological conditions, existing JCLs are mainly distributed on the sides of villages and homesteads, banks of ditches and channels, alluvial rivers, valleys and the lower end of slopes.

Table 17. The Distribution of Existing JCL Resources

Forms of JCL existence	Forests	Clusters on four sides	Scattered trees	Total
Area (ha)	7,162.01	8,066.76	2,823.87	18,052.65
Percentage %	39.67	44.69	15.64	100

According to its survival characteristics and ecological adaptation, JCL can grow in most dry and semi-dry areas, especially in dry and hot valleys. Yunnan Province is suitable for the growth of JCL, especially in the hot and dry valleys of the Jiangshajiang, Yuanjiang, Lancangjiang, Nanpanjiang and Nujiang rivers. There are more than 4 million hectares of barren hills or wasteland in the valleys of the six river basins. According to surveys by Yunnan Academy of Forest Planning and Design, more than 675,000 hectares of land are suitable for JCL plantations (Table 18).

Table 18. Land Suitable for Planting JCL in Yunnan (ha)

Prefecture	Wasteland and hills	Four sides and scattered plots	Shrub land and open forests	Total	Percentage %
Dali	4782.73	1691.13	0.00	6473.87	0.96
Dehong	706.73	8405.35	5333.33	14445.41	2.14
Qujing	10864.97	3874.73	0.00	14739.70	2.18
Nujiang	2046.97	5452.36	7644.21	15142.72	2.24
Kunming	16182.70	2648.08	0.00	18830.78	2.79
Lijiang	16059.70	4586.63	0.00	20646.33	3.06
Yuxi	10060.33	444.27	16162.07	26666.67	3.95
Baoshan	15040.87	11643.63	1187.03	27871.53	4.13
Zhaotong	10537.00	12696.81	10666.67	33900.48	5.02
Xishuangbanna	0.00	0.00	40000.00	40000.00	5.92
Puer	30856.62	22226.80	10000.00	63083.42	9.34
Wenshan	36336.90	19622.74	22626.31	78585.95	11.64
Lincang	55598.87	1336.27	23283.30	80218.43	11.88
Chuxiong	69926.07	6250.27	6666.67	82843.01	12.27
Honghe	112456.98	16165.81	23279.73	151902.52	22.49
Subtotal	391456.62	117044.88	166849.31	675350.81	100.00

Source: Liu et al. (2008)

6.3 Economic Impacts

It was explicitly indicated in China's *Eleventh Five-Year Plan for the Development of Renewable Energy* that the scale of production of the first-generation biofuels should be controlled, while greater effort would be made to promote the production of second-generation biofuels. The principle behind the production of feedstock for second-generation biofuel was "no competition with people for food, no competition with crops for land." That is, the production of second-generation feedstock should focus on marginal land or wasteland and those small scattered pieces of land that are not used for food production.

In Yunnan, JCL seeds will be produced on wasteland and hills, four sides land and scattered plots, and shrub land and open forests (Table 20). Since these lands are not used for any commercial purpose, their financial value can be ignored.

However, apart from the economic value of carbon sequestration, JCL plantations may bring other economic benefits. As surveyed in Honghe and Chuxiong prefectures, wasteland and hills in the hot and dry basins are clothed with little vegetation. Plantations of JCL may yield economic value by facilitating the ecological restoration of barren land, and JCL can also provide protection when it is planted on four sides as a living fence or hedge, or as a soil stabilizer on the banks of bodies of water. When they are established on shrub land and open forests, JCL plantations may bring economic benefits or costs, depending on how they are planted. If JCL plantations are established by clearing shrub land and open forest, economic costs may occur from a loss of biodiversity and the combustion of existing vegetation. When JCL plantations are established by intercropping, these costs may be avoided or minimized. Since they are usually site-specific and hard to measure within a limited time period, these economic benefits and costs are not included in the economic analysis in this study.

7.0 CONCLUSION AND POLICY IMPLICATIONS

7.1 Conclusion

JCL seeds can be used to extract oil for direct blending with fossil diesel, or be further processed into JME through transesterification reaction. This study assessed the economic, environmental and energy performance of the production of these two end products using a lifecycle analysis method.

The results show that, at the current level of technology and management, the production of JCL biodiesel is financially and economically unfeasible, but it has excellent environmental and energy performance. If seed yield can be improved to above 2.46 t/ha, it will be economically feasible to produce either of the two end products.

To promote the development of the JCL biodiesel industry, government support is

indispensable. When JCL seed and oil is produced by different producers, the required annual subsidies are about 881.66 yuan per hectare for seed producers and 2.68 yuan per liter for oil producers when the seed yield is 1,485 kg/t and the present diesel price is 5.22 yuan per liter, assuming a margin of 10% for producers. When JME is the end product and producers purchase JCL seeds to produce JME, about 4.01 yuan per liter should be made available to producers to make enough revenue and to breakeven on costs. If the seed yield is higher than 1,485 kg/t, the compensation rate for producers at different stages of the production chain tends to decrease. In particular, no compensation is required if the seed yield is higher than 3,267 kg/t and the present seed price (i.e., 2 yuan per kg) prevails. If the production chain is run by a single producer, then compensation rates for the end products of JCL and JME are 3.97 yuan per liter and 4.01 yuan per liter, respectively.

For both end products of JCL oil and JME, the major costs incur at the seed production stage, which accounts for more than 80% of total costs. In detail, these costs are from the purchase of fertilizer, fruit collection and drying, husk removal, and weeding.

The production and use of JCL biodiesel makes a significant contribution to the reduction of carbon emissions with a rate of 7.34 kgCO_{2e}/l for JCL oil and 8.04 kg/l for JME, respectively. The carbon balances of the two end products increase as seed yield increases. The main factors affecting carbon balance are seed yields and co-products.

For both end products, energy efficiency in terms of E_1 , E_2 and E_3 are greater than one. That is, the production of both JCL oil and JME are energy-efficient. Without the process of transesterification, the production of JCL oil is more energy-efficient. Energy efficiency becomes higher as the seed yield increases. Other factors affecting energy efficiency include seed yield, co-product output and farm energy inputs.

Since China is targeting marginal land for the development of second-generation biofuel, the impact on land use will be minor if the governments' rule is adhered to. Three types of land suitable for planting JCL are identified to be wasteland and hills, four sides and scattered plots, and shrub land and open forests. Since wasteland and hills are mainly barren land, their opportunity costs are negligible. On four sides and scattered plots, JCLs are usually planted for specific purposes, such as fencing and erosion control. The benefit of such kinds of land use can be considered higher than the opportunity cost. When JCLs are planted on shrub land and open forests, the impact of land use depends on how the JCL plantation is established. If shrub land and open forests are cleared for planting JCLs, costs may be high resulting from a loss of biodiversity, emissions of carbon and other ecological damage. However, if JCLs are planted by intercropping, the impact on land use can be possibly neglected.

Based on the above-mentioned results, the lifecycle of the economic, environmental and energy performance of JCL oil can be improved in the following areas: (1) at the current level of oil extraction technology, since much oil is still in the seed cake after pressing, oil yield could be improved by optimizing the production process; (2) the

lifecycle of the economic, environmental and energy performance of JCL oil is sensitive to seed yield and thus can be improved through the selection of high-yield seed varieties and genetic improvement; (3) the creation of machines for de-husking and fruit collection would reduce the cost of seed production; (4) the labor cost of fruit collection can be reduced by cultivating high-yield and dwarf varieties; (5) financial and economic feasibility can be improved by developing high-value added products from co-products – for example, the seed cake can be used to produce foodstuff and pesticides, and glycerin is an important raw material for some high-value pharmaceuticals, such as anti-virus medicines; (6) Since energy consumption is primarily due to the use of pesticides, herbicides, fertilizers, and the extraction and refinement of oil, improvement of ecosystem management and the application of green manure can reduce the indirect energy inputs of pesticides, herbicides and fertilizers. Moreover, fruit husks can be used as a fuel to reduce the consumption of coal. In particular, because too much energy is used for the production of glyphosate, energy efficiency can be improved by applying low energy input herbicides, such as atrazine and cyanazine, or by manual weeding.

7.2 Policy Implications

The promotion of second-generation biofuels is politically attractive for governments as a response to global warming, energy independence, environmental pollution, and rural development, but there are concerns about the production of first-generation biofuels, such as food security. Government policies play an important role in the financial attractiveness of biofuel production and trade. Brazil has achieved relatively successful results producing bio-ethanol but is no exception to these incentives.

China's Renewable Energy Law, which was passed by the Congress on 28 February 2005, and took effect on 1 January 2006, laid a solid foundation for the production of JCL biodiesel. This law shaped an integrated renewable energy policy framework by providing a set of directives encouraging renewable energies, including national renewable energy targets, a special fiscal fund, tax relief or exemption, and public research and development support as well as education and training.

Although it provides a framework, China's Renewable Energy Law requires relevant governmental authorities to formulate specific measures for the production and use of biofuels, especially JCL biodiesel, which is targeted for promotion by many provinces.

Despite its lack of financial feasibility, the production and use of JCL biodiesel as a labor-intensive economic activity could generate many job opportunities and increase farmers' income. The positive carbon balance and significant energy efficiency of JCL provide a way for governments to respond to climate change and energy security. These outcomes are consistent with governments' expectations and thus have important policy implications for policy makers.

Firstly, in 2006, the State Administration of Taxation announced that biodiesel would be exempt from consumption tax. In 2008, the Ministry of Finance, State Administration

of Taxation, and National Development and Reform Committee jointly announced that 90% of the income tax on biodiesel would be reduced. In the same year, the Ministry of Finance and the State Administration of Taxation enacted a policy that if more than 70% of the raw material of biodiesel is from plant oil and waste animal fat, the value-added tax would be refunded to producers. Within this policy context, no tax is assumed for the production and consumption of JCL biodiesel. The results show that to promote the industrialization of JCL biodiesel, tax exemption is not enough.

Although China has set up a directive to subsidize woody feedstock producers of 3,000 yuan per hectare (*China Daily* 2007), it is obviously insufficient make up the loss in JCL seed production. Moreover, the government has set up the subsidy rate for bioethanol plants, but no policy is yet available for the subsidization of biodiesel plants. The experience of other countries shows that government support plays a critical role in the promotion of biofuels. For example, to improve the competitiveness of biofuels, many countries, such as Germany and France (Manuel and Peters 2007), levy a consumption tax on gasoline and diesel, and reduce or exempt tax on biofuels. Mandatory blending obligations can also be adopted to promote biofuel production.

However, before any policy instruments are adopted, their economic impacts should be assessed. For instance, mandatory blending would increase fuel prices at the filling station and the extra cost would be transferred to the consumer rather than billed to the taxpayer. The subsidy or tax exemption is usually set higher or lower than the cost disadvantage of biofuel.

Secondly, considering that most of the provinces that are putting a great deal of effort into promoting JCL biodiesel are poverty-stricken, there is an opportunity to integrate rural development with the production of JCL biodiesel. In particular, as the cost accounting shows, the production of JCL biodiesel is labor-intensive, and can be integrated with government strategies for rural development, such as job creation and poverty alleviation.

Thirdly, the production and use of JCL biodiesel can greatly reduce GHG emissions. This sound environment performance has significant implications for China's commitment to carbon emission reduction, that is, for the carbon emission per unit of GDP in 2020 to be 40-45% lower than that of 2005 (set before the Copenhagen Climate Change Summit). To substitute fossil fuel with biofuel could be an effective measure in the implementation of China's energy saving and emission reduction program.

The effect of reducing GHG emissions is a positive externality which can provide partial justification for government to subsidize JCL biodiesel producers. A carbon tax is viewed by economists as an effective instrument to address this externality (Tol, 2005). However, since it will possibly result in higher energy prices, the distributional effects should be further analyzed before such a policy is adopted. Taking Denmark as an example, a carbon tax proved to be an effective measure to reduce GHG emissions but resulted in a distribution effect (Wier et al. 2005). In addition, the economic performance of JCL biodiesel can be greatly improved if it is possible to integrate the development of

the biodiesel industry with CDM projects. However, such integration requires new mechanisms and institutional arrangements.

Fourthly, the results of the 3E performance obtained in this study are based on the existing traditional technology of JCL cultivation, oil extraction and conversion. There is still great potential to improve 3E performance through technical innovation. More grants and funding should be made available for research and development purposes by government or private companies in the near future. China's renewable energy law has endorsed a special fiscal fund for renewable energy development. This special fiscal fund is a very important financial facility for the promotion of JCL biodiesel but it needs the relevant governments to make it available.

Fifthly, the results obtained in the study are based on the assumption that JCL seeds are produced on marginal land. The results cannot be guaranteed if other types of land are used to grow JCL. To ensure positive environmental performance – sustainability standards and certification systems to regulate the production and trade of JCL biodiesel, for example – a system for guarantees of origin, are needed. Although some sustainability criteria and biomass certification systems are being developed in some countries, such as the Netherlands, the UK and Germany (van Dam, 2008), they are just guidelines and are not yet operational. In China, despite the rapid development of biofuels, the issue of their sustainability is seldom addressed. To meet China's target for biofuels in the long run, a sustainability and certification system is essential.

From the mix of policy tools available to support the development of the JCL biodiesel industry, it is necessary to identify the most effective ones, but also the least trade distorting. Alternatively, new tools should be created if those currently available are insufficient.

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