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Evaluating energy benefit of *Pistacia chinensis* based biodiesel in China

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ABSTRACT

To be an alternative to fossil fuel, biodiesel should provide a positive energy benefit and a sustainable energy income. Based on the principles of Life Cycle Analysis and using the energy benefits of exploiting *Pistacia chinensis* in China as a case study, this paper presents a quantitative evaluation of the energy consumed throughout the six-phase life cycle process, which includes planting, fruit transport, oil production, biodiesel production, biodiesel transport and biodiesel combustion. The results show that during the life cycle process, the total energy consumption of the biodiesel production and transformation phase is the greatest and that energy consumption during the plantation phase second greatest. The results indicated that the potential maximum gross annual production is approximately 162.19 billion MJ per year for suitable land and 117.20 billion MJ per year for lands classified as fairly suitable, which could produce 6.35 million t of biodiesel. Considering the net energy production and output potential for *P. chinensis* based biodiesel at the provincial level, Yunnan Province has the most amount of production potential, while Beijing City has the least amount of production potential. The annual output value created by *P. chinensis* based bio-fuel is 3007.83 million Yuan in China.

Contents

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1. Introduction

Fossil fuel shortages and environmental pollution problems are worsening, while globally, countries are actively seeking alternative energy sources. Over the past few decades, to guarantee energy security and protecting ecological environment, China has promoted development of bio-liquid fuel such as bio-ethanol and biodiesel. Biodiesel, which has good combustion performance, is environmentally friendly and has an ability to regenerate, has become a viable renewable energy [1]. The Chinese government is developing bio-liquid as one of its transportation fuels for energy security and environmental improvement purposes [2]. The proportion of renewable energy in the total energy is 8% and the percentage of alternative fuel for vehicle will be up to 20% as planned in 2020. The production of biodiesel should be up to 2 million tons in 2020 according to the plan of National Development and Reform Commission (NDRC).

As feedstock for biodiesel, *Pistacia chinensis* is one of the notable plants for renewable energy in China. It is resistant to drought and salinity and can grow in various types of soil where other crops, such as soybean, flax, *Jatropha curcas. L* and *Ricinus communis* cannot grow well. *P. chinensis* fruit oil content ranges from 35% to 42.46%, and oil extraction rate is 22–30% [3]. The carbon chain length of *P. chinensis* biodiesel is very close to that of the ordinary diesel, thus its oil is very suitable for biodiesel production. An accurate assessment of its resource potential, however, is necessary to develop *P. chinensis* in China. To be a suitable substitute for fossil fuels, bio-liquid fuel should be able to provide a net energy income, positive energy income and economic benefits, and not reduce the food supply and increase greenhouse gas (GHG) emission during mass production [4,5]. Life Cycle Analysis (LCA) is a method used to evaluate the energy consumption of a product or system throughout its lifespan, that is, from raw material acquisition, production, and product use through to post-processing [6]. In recent years, LCA has been widely used in domestic and international bio-energy assessment studies [7,8]. Relevant research has been calculated and evaluated on the land use, water and energy consumption of three feedstock, namely, rapeseed oil, *J. curcas L.* oil and waste oil using LCA, including planting, harvesting and transportation, pretreatment, biodiesel production, distribution and consumption [1,9]. The costs, energy consumption and environmental impacts of the bio-ethanol life cycle, which used wheat, corn and sweet potato as raw materials, have been analyzed [10,11]. Other researchers [12–14] compared the life cycle and energy consumption of bio-liquid fuel with fossil fuels and found that bio-fuel consumed less primary energy and reduced CO_2 emissions when taking into account that the bio-liquid fuel replaced some fossil fuels. Literatures on *P. chinensis* are relatively less than those of above mentioned energy plants and usually focused on certain phase of the *P. chinensis* based bio-fuel production. Yu et al. investigated the use of CaO–CeO_2 mixed oxides as solid base catalysts for the transesterification of *P. chinensis* oil with methanol to produce biodiesel [15]; Qin et al. compared three extraction methods to obtain seed oil of *P. chinensis*, and suggested that the Soxhlet extraction was the most effective method [16]. Luo et al. tested the effect of injection timing on combustion characteristics of a direct engine fueled with different *P. chinensis* seed biodiesel [17]. Ma et al. analyzed the emissions of a diesel engine fueled with *P. chinensis* seed biodiesel–diesel blends, and found that CO, HC and exhaust smoke emissions decrease with the increase of the proportions of biodiesel in the blends [18]. However, there are no similar reports regarding the life cycle energy consumption and environmental emissions for *P. chinensis* at present.

Based on the results of previous studies, the main objective of this paper is to (1) estimate the net energy production potential of *P. chinensis* biodiesel in China, (2) present a nationwide quantitative evaluation of its energy efficiency as a source of biomass energy and (3) calculate available direct economic benefits.

2. Methodology

2.1. Sources of research data

In this study, the data sources include the life cycle stages and land resources that are suitable for planting *P. chinensis*. Currently, there are no production plants producing biodiesel from *P. chinensis*. Pilot studies on producing biodiesel with *P. chinensis* have been performed by [19,20]. In this paper, biodiesel production technology and biodiesel conversion process data referred to *J. curcas L.* production data and the pilot study data on *P. chinensis*.

In our previous studies, we established a comprehensive evaluation model for identifying land suitability for *P. chinensis* in China [21]. The model is based on space-gridded data and evaluates the potential for large-scale planting on marginal land through a spatial distribution analysis using a combination of a multi-parameter assessment method and limited policy factors. Previous studies classified marginal land into three categories: suitable for growing, fairly suitable for growing and unsuitable for growing *P. chinensis* [21,22]. The area classified as suitable for growing *P. chinensis* is approximately 7.10 million ha, and the suitable land area totals 12.79 million ha [21].

2.2. Energy analysis of Pistacia chinensis biodiesel life cycle processes

LCA for *P. chinensis* based biodiesel consists of six phases: *P. chinensis* planting and treatment, transporting harvested fruit, oil production, biodiesel conversion, biodiesel transport and distribution; biodiesel combustion. In each phase, the raw material and energy consumed will be calculated based on the energy conservation principle and the law of material invariance [9,13]. The life cycle energy flow of *P. chinensis* biodiesel was shown in Fig. 1.

(1) *P. chinensis* planting and treatment
As shown in Fig. 1, *E*1 represents the energy consumed during the feedstock's growth, including soil preparation, cultivation, fertilizer applications, pesticide spraying, fruit harvesting and drying, husk removal and so forth, which primarily consists of inputs including land, labor, seedlings, fertilizers, machines and energy.

(2) Transport of harvested fruit
E2 represents the energy consumed during the fruit transportation stage. We assumed that fossil energy was consumed during the transportation stage and only diesel vehicles were used.

(3) Oil production and biodiesel conversion
Raw oil production consists of extracting oil from *P. chinensis* fruits through leaching. E3 represents the energy consumed through the use of material inputs, electricity and water. E4 represents the energy used during the bio-liquid fuel production process, which involves producing a synthetic *P. chinensis* biodiesel blend from the transesterification of oil with methanol.

(4) Biodiesel transportation and distribution
E5 represents the energy consumed during the biodiesel transportation and distribution process, which means transport from plant to gas station. It mainly consumes diesel and electricity.

(5) Biodiesel combustion
Biodiesel combustion means the life cycles for biodiesel fuel at the end-use stage in a truck, bus, and car, etc. In this study, the