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Life cycle assessment of biodiesel from soybean, jatropha and microalgae in China conditions

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ABSTRACT

Increasing demand for transport fuels has driven China to attach great importance to biodiesel development. To evaluate the environmental impacts caused by producing and driving with biodiesel made from soybean, jatropha, and microalgae under China conditions, the LCA methodology is used and the assessment results are compared with fossil diesel. The solar energy and CO_2 uptake in biomass agriculture and reduction of dependency on fossil fuels lead to a better performance on abiotic depletion potential (ADP), global warming potential (GWP), and ozone depletion potential (ODP) in the life cycle of biodiesel compared to fossil diesel. Except for ADP, GWP and ODP, producing and driving with biodiesel does not offer benefits in the other environmental impact categories including eutrophication, acidification, photochemical oxidation, and toxicity. Jatropha and microalgae are more competitive biodiesel feedstock compared to soybean in terms of all impacts. By using global normalization references and weighting method based on ecotaxes, the LCA single score for the assessed 10 mid-point impact categories of soybean, jatropha, and microalgae based biodiesel is 54, 37.2 and 3.67 times of that of fossil diesel, respectively. Improvement of biomass agriculture management, development of biodiesel production technologies, bettering energy structure and promoting energy efficiency in China are the key measures to lower environmental impacts in the life cycle of biodiesel in the future. Various sensitivity analyses have also been applied, which show that, choice of allocation method, transport distance, uncertainty in jatropha and microalgae yield and oil content, and recycling rate of harvest water of microalgae have significant influence on the life cycle environmental performance of biodiesel.

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1. Introduction

In China, in 2009, the national crude oil consumption reached 388 million tons and imported crude oil provided 51.29% of consumption [1]. An increasing demand for transport fuels has not only led to an increase in the price of crude oil but also an increased risk for depletion of fossil resources [2]. Besides, conventional crude oil derived fuels have since long been pointed out as contributors to environmental impacts such as global warming [3]. The development of biofuels as transport fuel has the potential to reduce both greenhouse gas (GHG) emissions and the reliance on fossil fuels [4]. Biodiesel as the most potential biofuel to substitute fossil diesel as a transport fuel has received great attention in China. According to the *Medium and Long-term Development Plan for Renewable Energy* issued by the National Development and Reform Commission on August 31, 2007, the amount of biodiesel usage in China will amount to 0.2 million tons in 2010 and 2.0 million tons in 2020 [5].

Typical raw materials of biodiesel are edible oils like soybean oil, rapeseed oil, sunflower oil, and palm oil. In China the biggest biodiesel producers adopt rapeseed and soybean oil as raw material [6]. To avoid conflict in demand between food and energy, wild energy plants and microalgae have been researched recently to yield oils for biodiesel production [7,8]. To identify the sustainability of diesel produced by biomass feedstock to substitute fossil resource derived diesel as a transport fuel, extensive analyses for environmental performances of biodiesel have been emerged [9–14]. The research by Bernesson et al. [10] shows that, for small plants and by physical allocation, the global warming potential is 40.3 g CO_2-equiv./MJ rape methyl ester produced, the acidification potential 236 mg SO_2-equiv./MJ fuel, the eutrophication potential 39.1 mg $PO_3{}^{4-}$-equiv./MJ fuel, the photochemical oxidant creation potential 3.29 mg C_2H_4-equiv./MJ fuel and the energy requirement 295 kJ/MJ fuel. Harding et al. [11] uses the life cycle assessment (LCA) to compare inorganic and biological catalysis for the production of biodiesel from rapeseed oil by transesterification, and the LCA shows that the enzymatic production route is environmentally more favourable, in which improvements are seen in all impact categories. Lardon et al. [12] provides an analysis of the potential environmental impacts of biodiesel production from microalgae, and the outcome confirms the potential of microalgae as an energy source but highlights the imperative necessity of decreasing the energy and fertilizer consumption.

Contrary to that oil is the world's dominant fuel [15], the total proved coal reserve in China is 114,500 million tons [16] and contributes about 70% to the primary energy production and total energy consumed [17]. The energy input and pollutant emission balance for biodiesel production in China would be quite different to the cases of economically developed countries with improved energy structure and higher energy efficiency.

Previous LCA studies of biodiesel in China focus on fossil energy consumption and greenhouse gas emissions [18–23]. However, the environmental impacts generated in the life cycle of biodiesel do not only include fossil energy resource depletion and global warming. Other impact categories should also be taken into account to evaluate the sustainability of biodiesel comprehensively. This study carries out a life cycle assessment on biodiesel made from soybean oil, jatrophal oil, and microalgal oil in China conditions to evaluate the environmental performance of producing and using biodiesel as transport fuel compared with fossil diesel with a more complete set of impacts.

2. Methodology

2.1. Objective of the LCA

The main objective of the LCA in this study is to quantify and compare the environmental impacts by producing and driving with biodiesel derived from soybean oil, jatrophal oil, and microalgal oil in China conditions, with a view to their potential use as alternative transport fuel of fossil diesel. Additional objective is to identify the most important environmental loads and effective parameters in these biodiesel life cycle systems, helping to suggest measures for improvement.

2.2. Functional unit

In LCA, the functional unit (FU) provides a reference to which the inputs and outputs are related. According to that biodiesel has similar combustion characteristics with conventional fossil diesel, the functional unit for the LCA in this study is 1 MJ of energy from bio- and fossil diesel "well-to-wheel". This justifies a direct comparison of fuels based on their calorific value.

2.3. System boundary

Fig. 1 shows the life cycle system of biodiesel including all relevant processes causing resources use and pollutants emission: production of chemicals and process energy, agriculture of biomass feedstock, production of biodiesel, biomass and biodiesel transport sections, and final vehicle operations.

The soybean and jatropha agriculture process is built from the study by Ou [21]. Industrial-scale facilities for biodiesel production from microalgae have not been built yet. The microalgae cultivation process is built from a nearly complete design for a large production system to produce biodiesel from algae by Regan [24] and Benemann [25]. However, to provide a more realistic approach in the management of jatropha agriculture, a modification is made: jatropha contains a variety of bioactive substances which have well insecticidal effect, and in the study of Ou [21], the agrochemical input is not considered. However, from the literature [26], it appears that application of agrochemicals to jatropha is still needed to resist stem rot and insect damage of shootmoth and Chinese Cricket. Annually, fungicides and pesticides are assumed to be applied in jatropha agriculture.

The conversion of soybean, jatrophal and microalgal oil to diesel consists of steps of vegetable oil extraction, feedstock pretreatment, transesterification, methanol recycling, and crude methyl ester purification. Oil is extracted from cleaned rapeseed, jatropha seeds and microalgae. Crude vegetable oil is pretreated with processes of deacidification, degumming and drying to remove residual free fatty acids, phospholipids and water. Biodiesel is produced through transesterification of refined vegetable oil and methanol in the conditions of catalysis, heating and pressurizing. Excessive methanol is recycled. Crude methyl ester is treated by washing, fractionation, and drying to obtain biodiesel end product.