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Emergy evaluation of biofuels production in Thailand from different feedstocks

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ABSTRACT

Energy demand in Thailand has steadily increased over the years. The aim of this study is thus to investigate whether the use of biodiesel, as an alternative transportation fuel, can provide a sustainable solution for future energy supply in Thailand. Seven different production cases have been classified in two main groups, three actual systems and four proposed systems. These were then investigated using emergy analysis. In the actual cases, the emergy indices indicated that case study B (biodiesel production from palm oil in industrial scale) gave the highest sustainability with emergy yield ratio (EYR), environmental loading ratio (ELR) and emergy sustainability index (ESI) recorded at 1.19, 5.18 and 0.23, respectively. Moreover, industrial scale biodiesel production appeared to be more practical in real-world operation when considering production yields. In the simulated cases, Case G (biofuels production process with steam and electricity generation zones), which utilized all waste residues to produce power and heat, was the best case with results for EYR, ELR and ESI of 1.17, 4.89 and 0.24. The best case in this study can slightly improve the emergy sustainability index. The system sustainability is still insufficient since a high portion of imported and non-renewable sources have been consumed. In pursuing sustainable development, current biomass production and biofuels conversion technologies should be improved to minimize energy and raw materials consumption. Then, the biodiesel from biomass can be considered as a suitable sustainable alternative fuel.

1. Introduction

In recent years, Thailand has faced many challenges, and energy security is one of the most serious problems. While the demand of energy has increased steadily, leading to the increase of primary energy supplies, mainly fossil fuels, these fossil fuels are limited nonrenewable resources and produce greenhouse gases when burned. Thus, new energy resources are needed to attenuate these problems. Currently, fuels from biomass have received attention as alternatives for energy sources since they are renewable and abundant for countries located in tropical zones. The fuels from these renewable resources could reduce the demand of fossil fuels in the future.

The potential of economic crops in Thailand such as oil palm, soybeans, coconuts, sesame, groundnuts and castor beans, to produce biodiesel have been studied. Table 1 shows economic crops, harvest areas, and yields in terms of oil production (Agricultural Statistics of Thailand, 2014). From the table, palm oil has the highest potential as a raw material for biodiesel production since it provides the highest yield per harvest area. In addition to the oil, large amounts of biomass residues such as bunch and shell are viable by-products in oil palm cultivation and the production of palm oil. These types of residues, containing high amount of cellulose, hemicellulose, and lignin, can be turned into valuable biofuels such as alcohols or syngas. In order to utilize

Abbreviations: CHP, combined heat and power; DAP, diammonium phosphate; EFB, empty fruit bunch; EMR, emergy money ratio; Em_{total}, total solar emergy; En, energy content; EYR, emergy yield ratio; ESI, emergy sustainability index; F, purchase resources; F_R, renewable part of purchase resources; F_N, non-renewable part of purchase resources; FFB, fresh fruit bunch; I, resources from outside; JCL, jatropha; JCO, jatropha oil; N, local non-renewable resources; PME, palm oil methyl ester; PR, percent renewable; R, local renewable resources; S, labor and services; S_R, renewable part of labor and services; S_N, non-renewable part of labor and services; sej, solar equivalent joule; Tr, transformity; w/, with; w/o, without; Y, emergy yield.

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Table 1
Harvested area, production and yield of major oil crops in Thailand (recorded 2009–2014).

Oil Crops	Harvested area (1000 ha)				Production (1000 ton)				Yield per ha (kg/ha)			
	2009	2012	2013	2014	2009	2012	2013	2014	2009	2012	2013	2014
Oil Palm	510	594	626	655	8,162	11,353	12,812	13,201	15,996	19,100	20,456	20,144
Soybeans	120	138	126	117	190	85	70	67	1,588	614	559	575
Coconuts	238	258	256	246	1,381	1,057	1,010	_	5,804	4,096	3,945	_
Sesame	65.6	_	_	_	44	_	_	_	675	_	_	_
Groundnuts	33	_	_	_	53	_	_	_	1,606	_	_	_
Castor beans	13.1	_	_	_	11	_	_	_	863	_	_	_

these residues, there are two common pathways to convert ligno-cellulosic biomass into bio-alcohol, including: (1) biochemical pathways such as fermentation process and (2) thermochemical pathways such as the gasification with modified Fischer–Tropsch process (Aden et al., 2002; Phillips et al., 2007). Besides the biomasses from food crops and the recycle of spent cooking oil to produce biofuels, jatropha oil (JCO), a nonedible oil, has also received attention as choice of raw materials for biodiesel production. With higher oxidation stability than soybean oil and sunflower oil (Arbain and Salimon, 2011), Jatropha oil has been used as feedstock for biodiesel production in the U.S. and Europe. Although there are several studies on biofuels production techniques, the comprehensive evaluation on the proposed systems about load emitted to environment and related problems of carrying capacity of economic and industrial development are few and limited. Thus, when considering process development, an environmental impact assessment and systems' efficiency evaluation must be conducted.

Since a biofuel production process requires both non-renewable and renewable resources, one with a high non-renewable fraction could create a burden on the environment. Furthermore, each input stream possesses different forms of energy, materials and information. Thus, to take into account all these different forms of input to the process, emergy analysis, proposed by Odum and Nilsson (1996), was selected for the analysis in this study. It provides perspectives on system sustainability and guidelines to attenuate the problem. Recently, a few studies investigated the sustainability of biofuel production systems. Spinelli et al. (2013) evaluated the biodiesel production from sunflower in Siena, Italy, using emergy evaluation and pointed out the limitations of the agricultural phase for large-scale production of biodiesel from sunflower. Moreover, Cruz and Nascimento (2012) presented the environmental assessment of oil production from microalgae. Because of the high energy consumption during harvesting, raw material consumption and high capital and operating costs, the microalgae was seen as a more non-renewable than renewable source for biofuel feedstock.

The objective of this study is to investigate the sustainability of biodiesel productions from different raw materials, palm oil and jatropha oil (JCO), with various production processes to identify which approaches can provide sustainable solutions for Thailand.

2. Emergy analysis

Sustainability leads to the question of how to supply human needs while producing products or services by generating the lowest negative impact on the environment. The decision on sustainability is based on the tradeoff between human benefits and environmental impacts. Thus, to do the assessment, one has to consider all the benefits and impacts by giving values accordingly. There are several ways of assigning values based on the perspective of the methods. Odum and Nilsson (1996) proposed a method named "Emergy analysis" to build the connection between human needs and the loss of environmental systems by evaluating major inputs from human economy and those coming "free" from the environment (solar radiation, rain, wind, etc.) to produce products or services. The method integrates and analyzes inputs and outputs to help understand the evaluated system. It will provide insight of the evaluated system in terms of environmental inputs and benefits from outputs. The values will show whether the evaluated system is intellectually employed.

Emergy is defined as "the available energy of one kind previously used up directly and indirectly to make a service or product" where the roots of "em" come from "energy memory"

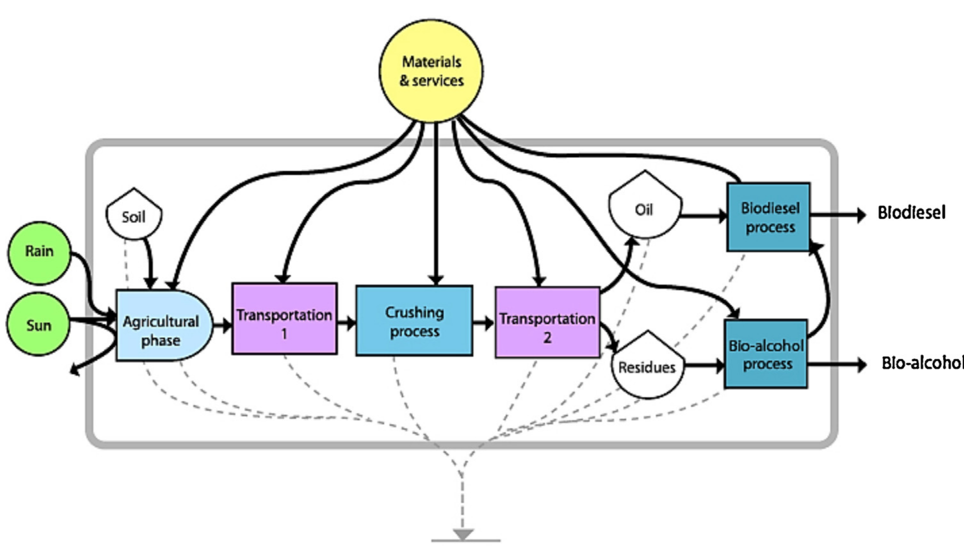

Fig. 1. Energy flow diagram of biofuels production system.