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Environmental life cycle assessment and social impacts of bioethanol production in Thailand

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ABSTRACT

Bioethanol is an important renewable energy for transportation fuels in Thailand due to energy security it provides and the reduced greenhouse gas emissions. Cassava and sugarcane are considered to be the most important feedstocks that produce bioethanol in Thailand due to an abundant, renewable resource in the country. This study aims to evaluate the potential environmental performance and social impacts associated with the bioethanol supply chain. The environmental impacts of bioethanol in this study were assessed by using life cycle assessment method. The impact categories consisted of the greenhouse gas (GHG) emissions, eutrophication potential (EP), direct land use change (dLUC), and water impact potential (WIP). The social impacts, including the total employment, wages and fatal occupational injury are carried out based on the process-based and input-output analysis approaches. The results showed that the GHG emissions of the bioethanol systems are 26–39 kg CO_2eq/GJ, which is less than conventional gasoline. In addition, the results showed that the dLUC effect on the bioethanol production increased the GHG impact by 10–73%. However, it's found that the EP and water impact caused by bioethanol production is higher than for gasoline. In regards to the social aspects, the bioethanol production has advantages in term of total employment and income generation, the job creation is 15–18 times better than gasoline and the direct income distribution in the agricultural stage accounts for 30–45% of the total income in the bioethanol supply chain. However, the fatal occupational impacts of bioethanol system are higher than for gasoline. This aspect is also discussed in the study.

1. Introduction

Since the energy crisis, energy demand has continued to rise and even the fossil energy sources and new energy generation from other sources is not enough to meet demand. These causes lead to impacts on the volatility of energy prices on the world market. Thailand relies on energy imports from abroad leading to a loss of foreign currency and the government being required to subsidize the domestic oil price to maintain the oil price is too high. Presently, Thai government subsidize E10, E20, and E85 gasohol retail prices are 20, 30, and 40 percent cheaper than regular gasoline due to the excise tax, plus a price subsidy for E10, E20, and E85 gasohol derived from the State Oil Fund and encourage the extension of E20 and E85 service stations (Preechajarn and Prasertsri, 2016). There are also support the manufacture of eco-cars (E20 vehicles) and flex-fuel vehicles (FFV), which are compatible with E85 gasohol, by reducing the excise tax for automobile manufacturers approximately US$ 1600/vehicle for FFV and US$ 950/vehicle for eco-cars (Kumar et al., 2013). In addition, the use of fossil fuels has an impact on the environment, especially greenhouse gas emitted into the atmosphere, which leads to the greenhouse effect. As a result, the temperature rise is a major problem that is affecting all regions of the world. Most countries, with a focus on research and development of renewable and alternative fuels to reduce fossil fuel consumption are gone. Result from renewable energy interests, particularly biofuels drive the increasing biofuels demand of the world. Currently, the rapid growth of industrial production, biofuels from food crops are starting to cause concerns regarding adverse

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effects on both the environmental and social happenings, such as food and energy competition. In addition, the occurrence of increasing greenhouse gas emissions from carbon stock loss due to changes in the land use, loss of biodiversity, impact of holding the land by small farmers, impact on employment and child labour are beginning to develop into the international standard on sustainable biofuels. The Global Bioenergy Partnership Sustainability Indicators for Bioenergy (GBEP, 2011), the Roundtable on Sustainable Biomaterials (RSB, 2009), Renewable Energy Directive of the European Union (EU, 2009), and the Renewable Fuel Standard (RFS) of the United States (EPA, 2007), etc., had been set up for promoting the sustainable biofuels production and consumption.

At present, the Thai government has promoted the production and use of renewable energy, this is designated as part of a national agenda to reduce imports of crude oil from overseas and to mitigate global warming problems. An obvious example is the alternative energy development plan in 2015 (AEDP2015) targets a proportional increase in renewable energy to 30% of final energy consumption of the country, by 2036 (DEDE, 2015). Bioethanol from cassava and sugarcane are the industry targets that play a critical role in the country's production of renewable energy in the present. Its current production of ethanol from cassava and sugarcane molasses are approximately 0.87 and 2.65 million liters per day, respectively (DEDE, 2015). At the end of January 2016, Thailand had twenty-one factories operating to produce bioethanol with a total capacity of 4.44 million liters (ML)/day or 1332 ML per year based on 300 working days. Sugarcane molasses and cassava are two feedstocks for this industrial purpose. There are seventeen factories using only a single feedstock; nine factories using molasses with a total production capacity of 1.93 ML/day, seven factories using cassava with a total production capacity of 1.430 ML/day and only one factory using sugarcane juice with the production capacity of 0.23 ML/day. A multi-feedstock process using both molasses and cassava is present in four factories with a total production capacity of 0.85 ML/day) to avoid feedstock shortages and high-priced feedstock. In addition, there are two factories currently under plant construction (DEDE, 2016).

An Environmental Life Cycle Assessment (E-LCA) is a helpful tool for evaluating and quantifying the environmental consequences relevant to a product, process, or service from the cradle to the grave, using a systematic approach (ISO, 2006). In addition, the social dimensions can be included in the LCA method to evaluate the social impact of the product, the so-called social LCA (S-LCA). The result of the E-LCA and S-LCA is communicating information to stakeholders on the environmental and social performance. When considering environmental sustainability as a principle, there are several studies that evaluated greenhouse gas (GHG) and other environmental aspects of bioethanol in Thailand, using the LCA method (Silalertruksa and Gheewala, 2009; Papong and Malakul, 2010; Moriizumi et al., 2012; Numjuncharoen et al., 2015; Kawasaki et al., 2015; Silalertruksa et al., 2015, 2017). There are also LCA studies of bioethanol in China (Leng et al., 2008; Zhang et al., 2012; Liu et al., 2013), Brazil (Pereira and Ortega, 2010; Cavalett et al., 2012; Khatiwada et al., 2012; Duarte et al., 2013; Gnansounou et al., 2015) and Vietnam (Le et al., 2013). There are some case studies focused on the effect of land use change on GHG emissions of bioethanol production (Silalertruksa et al., 2009; Walter et al., 2011; Egeskog et al., 2014). In addition, the socio-economic impacts in term of employment generation, income, and value added of bioethanol production were addressed in some previous studies (Silalertruksa et al., 2011; Martínez et al., 2013; Walter et al., 2011).

Although previous studies in Thailand have evaluated the environmental (Silalertruksa and Gheewala, 2009; Silalertruksa et al., 2009) and socio-economic impacts (Silalertruksa et al., 2011, 2012, 2015, 2017) of bioethanol from cassava and molasses; the studies were mainly based on the site-specific data of one factory, which has not yet covered a wide variety of current production systems. In addition, the socio-economic sustainability issues still lack clear information. Therefore, this study is intended to assess the environmental and social performance indicators of bioethanol from cassava and molasses in Thailand, based on the life cycle approach. The study sites are covered 67% and 45% of total production capacity for cassava-based and molasses-based ethanol, respectively. The environmental impact categories focused on four major issues: greenhouse gas (GHG) emissions, eutrophication, GHG from the direct Land Use Change (dLUC), and water footprint and water impact. The social indicator was assessed in term of employment generation, wages, and fatal occupational injury.

2. Methodology

2.1. Goal and scope of the study

This study aims to evaluate the environmental and social impacts of bioethanol production from cassava and molasses in Thailand via the life cycle perspective. The analysis focused on (1) the identification of key environmental and social issues of bioethanol production from both feedstocks in comparison with conventional gasoline, and (2) suggestions to improve the environmental and social performance of ethanol production in Thailand.

The scope of the study is from cradle to gate including the feedstock cultivation and harvesting, feedstock processing, ethanol production, and related transport. The system boundary is presented in Fig. 1. The functional unit of the study is 1 GJ of ethanol produced.

The life cycle impact assessment method in this study was selected the ReCiPe method by using the SimaPro 8.0 software. The environmental impact categories selected in the analysis are climate change or greenhouse gas (GHG) emissions and eutrophication potential (EP). In addition, the GHG emissions from the direct land use change (dLUC) was considered in this study. The water impact potential was selected, along with the water stress index of Thailand, to assess this aspect. These environmental impact categories considered in this analysis are interrelated in the Thailand perspective. The social impacts were considered in this study, including the total employment, wages, and fatal occupational injuries.

2.2. Data sources

The input-output data in this study mostly were gathered from the primary sources at the actual sites in Thailand. The data included the consumption of raw materials, energy, water, chemicals, and waste generation in the whole supply chain. The data for the cassava-based ethanol production were gathered from five factories covered 67% of total production capacity in the country in 2013–2015. The molasses-based ethanol production were collected data from four factories covered 45% of total production capacity in the country in 2012–2014. The secondary data were obtained from the literature, the Ecoinvent database (Ecoinvent, 2012), and calculation based on the IPCC guidelines (IPCC, 2006) and the EEA guidebook (EEA, 2013). However, this study excluded the CO_2 uptake during the crop growing stage, and did not include the environmental impacts from infrastructure facilities such as construction of the factory,