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Reducing carbon emissions from soybean cultivation to oil production in Thailand

Withida Patthanaissaranukool [a, c, *], Chongchin Polprasert [b, c]

[a] Department of Environmental Health Sciences, Faculty of Public Health, Mahidol University, Rajvithee Road, Bangkok, 10400, Thailand
[b] Department of Sanitary Engineering, Faculty of Public Health, Mahidol University, Rajvithee Road, Bangkok, 10400, Thailand
[c] Center of Excellence on Environmental Health and Toxicology, Bangkok, 10400, Thailand

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ABSTRACT

The purpose of this study was to evaluate the carbon equivalences (CE) of whole-chain soybean oil production, starting from plantation until production of soybean oil. Appropriate approaches for the reduction of carbon emissions were also evaluated. Following a carbon-balanced model, total carbon emissions from soybean oil production were found to be +711 ± 14 kg CE/ton soybean oil. Cultivation, threshing, and industrial phases were responsible for 63%, 3%, and 34% of overall emissions, respectively. The highest equivalent carbon emissions in the cultivation process come from use of diesel fuel for watering and spraying chemical fertilizers. Meanwhile, the most significant emission from soybean oil production was found to be due to fuel oil used for steam production, contributing to 52% of total emissions in industrial phase. In addition, emissions from soybean meal, a co-product from soybean oil industry is equal to 169 kg CE/ton soybean meal. It involves fixed carbon as valuable protein sources sent to feed mills. From the complete carbon cycle scenarios of soybean oil production, the carbon fixation efficiency is computed to be equal to 74.7%. This indicates that soybean oil production still continues to emit carbon into the atmosphere. However, nutrients fixed in plant residues remaining in cultivation areas help reduce carbon emissions of about 175 ± 23.8 kg CE/ha from decreasing amount chemical fertilizers to be applied. From the selected scenarios, potential reductions of carbon emissions from soybean oil production were found to be 87% as compared to existing conditions. Moreover, cost saving from selected approaches to reduction of carbon emissions were estimated to be 7.4 Baht/kg soybean oil (0.21 USD/kg soybean oil). Based on emitted CE, the unit cost of soybean oil production was found to be 49.6 Baht/kg CE (1.41 USD/kg CE).

1. Introduction

Nowadays, climate change is a common concern of mankind. It represents an urgent and potentially irreversible threat to human societies and the planet. Additionally, World Health Organization emphasized that the scale of environmental health problems has expanded from household (e.g. indoor air pollution), to neighborhood (e.g., domestic wastes) to community (e.g. urban air pollution) to region (e.g. transboundary contamination), and now to global level (e.g. climate change) (WHO, 2003). Therefore, the major challenge facing the world community is to achieve sufficient reduction in greenhouse gas emissions so as to avoid dangerous interference in the climate system. In the 2015 United Nations Climate Change Conference, the member of participants including Thailand agreed to reduce carbon output "as soon as possible" to keep global warming to well below 2 °C compared to pre-industrial level. In the 21st Conference of the Parties (COP21), also known as the 2015 Paris Climate Conference, Thailand commits to reducing greenhouse gases emission to 20–25% by 2030 (UNFCCC, 2016). In 2013, Thailand emitted 262.23 million tons of CO_2 (European Commission, 2016). Therefore, many activities to produce products required in the country including agriculture, industry, and transportation sectors should be considered to help reduce carbon emission to the atmosphere.

Cooking oil plays an important role for household and industrial use. The global demand for vegetable oil has increased rapidly in the past decade from many important factors including increasing demand for edible oil and development of biofuel industries. The

* Corresponding author. Department of Environmental Health Sciences, Faculty of Public Health, Mahidol University, Rajvithee Road, Bangkok, 10400, Thailand. Tel./fax: +66 23548525.
E-mail address: withida.pat@mahidol.ac.th (W. Patthanaissaranukool).

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shares of palm oil and soybean oil in the total cooking oil market in Thailand are estimated at 56 and 18%, respectively (DOA, 2006). However, more than 90% of soybean consumption in Thailand are imported from abroad, especially from Brazil, USA, and China. In 2014, the production of soybean in Thailand was reported to be 0.052 million tons with a planted area of 34,015 ha (OAE, 2015a). Nevertheless, domestic demand for soybean has risen to 1.86 million tons (NFI, 2015). These come from the need for soybean as cooking oil and other end-user products (i.e. tofu, soy milk, flour, and meal), contributing 69.4 and 29.7% of total consumption, respectively (DOAE, 2015). This indicates that production of end-user products from soybean rely on imports. Moreover, numerous research works on carbon emissions from edible oil in Thailand are focused on palm oil, but, none on soybean oil. Therefore, carbon emissions from whole-chain soybean oil production should be conducted for inventory data of cooking oil in Thailand. In addition, some researchers believe the expansion of soybean areas and production of soybean-based products would affect land use change and add more CO_2 to the atmosphere (Alvarenga et al., 2012; Mourad and Walter, 2011). While, others are keen on studying greenhouse gas emission from soybean production, using LCA (Life Cycle Assessment) method (Castanheira and Freire, 2013). Notably, carbon is a major substance in the biosphere, playing a very important role for all living organism as one of primarily essential component of cells (Wayne, 2010). However, its excessive quantity in the atmosphere, mainly from the burning of fossil matter by humans, has already aggravated the global problem of climate change (VijayaVenkataRaman et al., 2012). Moreover, carbon dioxide contributes more than 82% of total GHG emissions (US.EPA, 2016).

Therefore, this work was carried out with the objectives to: (1) identify the main path of carbon transfer and quantify the amount of carbon equivalences (CE) produced in soybean plantations and soybean oil production, following a carbon movement categorization and (2) to suggest alternative methods to help reduce carbon emissions along the full chain of soybean oil production. As soybean is a major raw material fed to a number of downstream productions, the outcomes of this study would serve as reference of carbon emissions for a consequent study of related end-user products.

2. Method

2.1. Goal and scope of research

The goal of this study is to evaluate CE produced associated with the soybean plantation and the production of soybean oil in Thailand. The scope of this work begins with plantation activities to grow soybean of which the harvested product will be used as raw material to produce olein in soybean oil industries. Energy and resources required in the plantation and soybean oil production processes were evaluated. Carbon emissions, fixation, and reduction were also assessed. A schematic flow diagram of mass and carbon transfer is presented in Fig. 1.

Throughout this study, the functional unit used for carbon equivalence evaluation is either kg CE/ton soybean oil or kg CE/ha. This is used to signify the quantities of carbon equivalence occurring per unit mass of products produced from the soybean oil production or per unit area of plantation where carbon flux is fixed, emitted, or reduced. CE estimations were made using carbon equivalence conversion factors following the carbon-balanced model (CBM) concept (Patthanaissaranukool and Polprasert, 2011). In the cultivation process, it is common to call soybean productivity in the unit of kg/ha-crop as to emphasize the important of photosynthesis in which the sun radiates the energy of 168 W/m^2 to the plantation to produce crop. Each soybean crop takes 3 months to grow and ready for harvesting. In milling phase, the unit of kg CE/ton soybean oil is used. Hence, the conversion factor for changing kg CE/ha-crop to kg CE/ton soybean oil is 0.345 ton soybean oil/ha-crop.

At the time of this study, costs were estimated using current local market prices of energy and materials sold in Thailand, which were sought from the literature and reliable webpages.

2.2. Concept of carbon categorization

This study follows the CBM concept which has already been applied to the works of Patthanaissaranukool et al. (2013) and Polprasert et al. (2015). With its concept, not all C emitted to the atmosphere is considered to cause harmful effects of global warming. It is because a certain amount of C needs to be circulated between earth's atmosphere and lithosphere so as to sustain lives living in the biosphere. Therefore, C in the CBM is classified based on movement pathway and usefulness into three groups-emission, fixation, and reduction.

- Carbon fixation is the product of photosynthetic reaction in which atmospheric CO_2 is combined with H_2O to form organic carbon and oxygen with energy absorption of 39 MJ/kg C calculated from the enthalpy change of photosynthetic reaction using the thermodynamic data (Stumm W, Morgan, 1996; Schroeder, 2000). It then mobilizes horizontally to satisfy human needs in the form of food, fiber, and fuel. Finally, after human consumption, it degrades either aerobically or anaerobically and returns to the atmosphere, resulting in no emissions through this pathway. However, to fulfil the human need to consume organic products for life, adequate land areas with suitable environmental factors are required for the photosynthetic reactions to take place.
- Carbon emission comes from the anthropogenic use of fossil energy and other fossil-derived materials. Once fixed and accumulated two billion years ago (Tissot and Welte, 1984), fossil matter underneath the earth's surface is mined today to facilitate human activities. It then remains in the atmosphere as incremental CO_2, resulting in disastrous global warming.
- Carbon reduction is the amount of carbon involved with any recovery, recycling, and reuse of waste. It is considered a carbon reduction because it helps conserve the use of natural raw materials and fossil energy (Pimentel et al., 2010).

2.3. Data collection

The majority (75%) of soybean plantations are located in northern Thailand (OAE, 2015a). Therefore a field survey was conducted in Chiang Mai, Mae Hong Son, and Phrae Provinces, which are the largest soybean producing provinces in Thailand (NFI, 2015). From total number of soybean plantation land plots, a simplified formula was used to determine the sample size needed to answer the questionnaires for 85% confident level. Totally, there are four commercial soybean oil factories in Thailand. Only three in Samut Prakan, Sukhothai, and Nonthaburi Provinces were selected to visit and inquire for pertinent data. Data collection was carried out with questionnaires and interviews to obtain all necessary information for 60 plantation land plots and 3 soybean oil refineries. Data information on quantities of energy, fertilizers and herbicides used in soybean plantation, energy and chemical consumption, main product and co-products produced in soybean oil refineries were gathered from the operational records over a one or more year.