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Does palm biodiesel driven land use change worsen greenhouse gas emissions? An environmental and socio-economic assessment

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ABSTRACT

Biodiesel is widely promoted to replace conventional diesel based on considerations of energy security, resource depletion, and global warming mitigation. The extent of greenhouse gas emissions may vary depending upon the type of land area converted for biodiesel crop cultivation. In addition, the economy and society are also affected both positively and negatively. The objectives of the study are to 1) evaluate the effect of biodiesel demand in Thailand on types of crops, 2) estimate the magnitude of change in both land area and prices of the converted crops, and 3) assess sustainability by integrating environmental and socio-economic impacts associated with land use change. Correlation analysis, multiple regression, econometric modeling, and eco-efficiency are used in evaluating crops affected as well as percentage changes in the converted crop area and crop prices, and the sustainability of biodiesel, respectively, as the Royal Thai Government targeted in the Renewable and Alternative Energy Development Plan (AEDP). The study revealed that coffee, rambutan and rice are significantly affected by oil palm expansion. Consequently, the greenhouse gas emissions due to land use change arising from the AEDP are projected to be lower than without land use change. The socio-economic impacts cover positive impacts, i.e., currency savings and increases in farmers' income due to higher prices of oil palm, and negative impacts, i.e., increases in prices of foods, such as bottled palm oil, and biodiesel for energy use. Compared to conventional diesel (B0), the net socio-economic impact of 2% biodiesel (B2) is better, but 5% (B5) and 10% (B10) are worse. When land use change is integrated, the net socio-economic impacts of B5 and B10 become better than those of B0. The eco-efficiency analysis shows that biodiesel blends at 9% would be the optimum.

Introduction

According to the new 10-Year Renewable and Alternative Energy Development (AEDP: 2012–2021) Plan, the Royal Thai Government targeted a biodiesel requirement for the energy sector of approximately 6 ML/day by 2021, and planned to increase the blending ratio up to 10%, or B10 (Department of Alternative Energy Development and Efficiency, 2012). An increased demand for bioenergy affects agricultural systems and food prices. The effects on the value chain of palm oil associated products and on different groups of people can be both positive and negative. Furthermore, when profit from biomass plantations exceed profit from food production, farmers will react by substituting energy crop cultivation for food crop cultivation unless prices for agricultural commodities increase (Johansson and Azar, 2007; Schnepf, 2005). Because agricultural land area is limited, comparative benefits of land use will change, resulting in changes in the structure of agricultural crop production. The rise in price of the energy crops encourages farmers to grow more energy crops (Johansson and Azar, 2007; Schnepf, 2005; Kløverpris et al., 2008a; Fritsche et al., 2010; Ubolsook, 2010). This altering of the structure of agricultural crop production demonstrates that Thai farmers made their choices based on economic factors; they substituted cultivation of higher value, more profitable crops for cultivation of less profitable crops such as rice. The high price of oil palm fresh fruit bunch (FFB) can motivate farmers to invest in oil palm production because they expect that it would be profitable as a long-term investment due to an economic life cycle of more than twenty-five years. Factors that significantly influence oil palm plantation areas are domestic demand for crude palm oil, farm prices of oil palm FFB, prices of diesel oil, and farm prices of unsmoked rubber sheet grade 3 (Phitthayaphinant et al., 2012). This change, in addition to the trend of increasing prices for fossil fuels, garnered support in Thailand and many other nations (Kongrithi and Isvilanonda, 2009). Furthermore, as an effect of the expansion of biofuel production, there is a danger of causing environmental damage to developing regions with delicate, peripheral land or high-value forests. Thus, the directions of crop conversion both in crop types and their magnitudes are very important for the sustainability assessment of biofuels because the types

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and the area of the converted crop would affect the environmental and socio-economic impacts.

To reduce disputes over land use, the stipulation of economically sound and environmentally feasible choices is necessary for optimal land utilization, also in regards to socio-economic effects, and to promote sustainable bioenergy sources (Fritsche et al., 2006). There are several indicators for assessing each category of environmental, social and economic performance. For sustainability assessment, all three categories need to be assessed in tandem to avoid unintended tradeoffs among them. The goals of the study are 1) to evaluate the effects of biodiesel demand on land use change (LUC) for feedstock cultivation, 2) to estimate the magnitude of change both in area and price of the converted crops caused from the biodiesel targeted in the new 10-Year Renewable and Alternative Energy Development (AEDP: 2012–2021) Plan, and 3) to assess sustainability by integrating environmental and socio-economic impacts from the entire life cycle of biodiesel combined with those impacts caused by LUC.

Methods

Essentially, three main methods exist for increasing the production of a given crop: reduced production of other crops, increases in land use for the crop, and improvements in existing crop yields (Kløverpris et al., 2008b). A study conducted by Salvatore and Damen (2010) indicates that the increase in oil palm production in Thailand will result mostly from increased land use. The size of these effects fundamentally depends on the quantity of biomass produced by ecosystems each year. Increases in demand for bioenergy have two major effects on land use change: a direct effect on bioenergy itself, and an indirect effect on other crops. The effects of land-use changes result in both socio-economic and environmental concerns (Miyake et al., 2012; Ubolsook, 2010). Susanto et al. (2008) analyzed the effect of ethanol production on land area of corn planted using regression analysis, where the area planted is a function of the relative price ratio of competing commodities. The study demonstrated that a proportionally large increase in corn prices resulted in significant increases in land use for corn. Their findings are support the findings of a study conducted by Ubolsook (2010) that developed a partial equilibrium econometric model to forecast the effects of a rise in the production of ethanol on the agriculture sector of Thailand over the next decade. The model is applied to three different scenarios were modeled to analyze the impacts of government targets for ethanol production. The predictions of the model and analysis of different production targets were that an increase in the production of ethanol results in a rise in the price of cassava. An increase in cassava prices encourages farmers to increase production of cassava while decreasing their production of other crops. The study also indicated that maize and sugarcane, which are competing crops with similar land use requirements, are displaced by cassava crops. With a reduction in quantity produced, the price of maize tends to rise in the future.

Converting competing crops from food crops to energy crops causes less supply of such crops. Economically, those converted crop prices may be higher and consequently, may positively affect those producing the remaining supply of those crops, while negatively affecting consumers. There have been numerous full life cycle studies taking into account emissions from direct land use changes but none of them reports the magnitude of area and price changes (Siangjaeo et al., 2011; Silalertruksa and Gheewala, 2012).

Scope and functional unit

The scope is the entire life cycle of biodiesel blends covering the stages of feedstock production, transportation, production process, product use, and LUC, as shown in Fig. 1.

Functional unit: the amount of 21,000 million L of biodiesel blends per year which is derived from the biodiesel (B100) demand of 6 ML/day for the highest biodiesel blending ratio at 10% targeted in the AEDP serves as the functional unit. The blending ratios are 2%, 5% and 10%, represented as B2, B5 and B10, respectively.

The socio-economic impacts cover positive impacts, i.e., currency savings and increases in farmers' income due to higher prices of oil palm, and negative impacts, i.e., increases in prices of foods, such as bottled palm oil, and biodiesel for energy use.

Since deforestation is illegal in Thailand (Siangjaeo et al., 2011; Silalertruksa and Gheewala, 2012), forest area is excluded from the converted land.

Biodiesel production in Thailand

Crude palm oil (CPO) from fresh fruit bunch (FFB) of oil palm is the main feedstock for biodiesel (B100) production in Thailand. Typically, the biodiesel production process is trans-esterification of CPO with methanol (MeOH) and sodium hydroxide (NaOH) as catalyst which produces palm oil methyl ester (B100) and glycerol.

The biodiesel industry is comprised of 9 manufacturing plants with the capacity of 1.55 ML/day. Oil palm is cultivated mainly in the southern parts of Thailand — Krabi, Suratthani, Chumporn and Trang provinces.

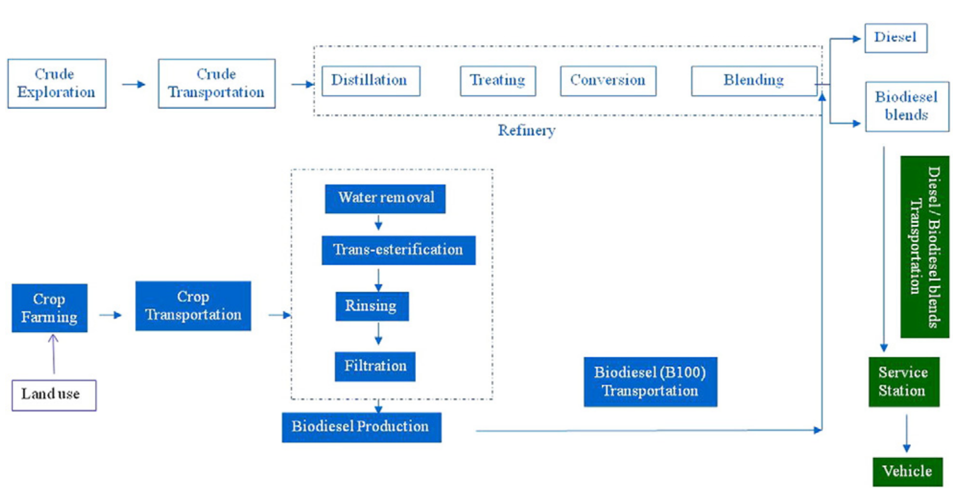

Fig. 1. System boundaries for diesel and biodiesel.

The biodiesel pricing formula is:

$$B100 = 0.97\,CPO + 0.15\,MeOH + 3.32$$

B100 is a selling price of biodiesel (B100) in Bangkok in the unit of baht/L
CPO is a selling price of crude palm oil in Bangkok in the unit of baht/kg
MeOH is a selling price of methanol in Bangkok in the unit of baht/kg.

Biodiesel induced changes in area and price

Area and price estimation

In order to evaluate the impacts of LUC either on the environment or socio-economics, changes in areas and prices have to be estimated (Kim and Dale, 2011). Firstly, a correlation analysis between oil palm area and major crops, and abandoned area by region, is conducted to evaluate crop types significantly competing in terms of land with oil palm for further study. The crops influenced by oil palm expansion are shown with a negative sign. Based on the Office of Agricultural Economics (OAE), the geographical areas in Thailand are divided into 4 regions, i.e., the north, the northeast, the central plain, and south. Secondly, ordinary least square (OLS) multiple regression analysis and time series econometrics are used to estimate the magnitude of change in area of the converted crops. Thirdly, partial equilibrium models are used to estimate the change in the prices of the converted crops arising from the land use change. The equation systems of oil palm and the converted crops are solved simultaneously.

Planted area equation system. The relationship between sectors and regions is determined by so-called elasticity referring the degree to which individuals (consumers/producers) change their demand/amount supplied in response to price or income changes. An economic equilibrium (supply equals demand) adapts to the new conditions by establishing a new economic equilibrium when the relevant variable e.g., increased crop demand changes. This adaptation is driven by price signals resulting in production changes in the different sectors. Kløverpris et al., 2008a stated that "if agricultural sectors are affected, changes in the use of land are also likely to occur. The economic approach is based on price signals caused by the demand for biofuels. The increasing prices lead to increasing production of biomass". Economic theory states that farmers base their planting decisions on the expected price of their output (Pikuntod, 1994; Isaviranon, 1996; Fuengkrasae, 1999). The farmers' expectations about prices are assumed to be based on their observations of previous prices (Ubolsook, 2010; Imai et al., 2011). The planted area equation can be expressed in terms of the previous year's return of oil palm, competitive crop prices, and their planted areas (Eq. (1)) (Leaver, 2004; Eaur-amnuay, 2005; Ubolsook, 2010; Imai et al., 2011). The expected sign of the crop area response to palm return is negative.

$$\begin{aligned} PA_{i,r,t} &= f\left(R_{i,r,\,t-1}, R_{palm,r,t-1}, PA_{i,r,t-1}, T\right) \\ &= h_0 + h_1 R_{i,r,\,t-1} + h_2 R_{palm,r,t-1} + h_3 PA_{i,r,t-1} + h_4 T + \varepsilon_h \end{aligned} \tag{1}$$

where

$PA_{i,r,t}$ is the planted area of crop i in region r at year t (Mha)
$R_{i,r,t-1}$ is the return of crop i in region r at year $t-1$ (MTHB/ha)
$R_{palm,\,r,\,t-1}$
is the return of palm in region r at year $t-1$ (MTHB/ha)
$PA_{i,r,t-1}$ is the planted area of crop i in region r at year $t-1$ (Mha)
h_{0-4} are coefficients
i is the displaced crop
r is the region
T is the trend representing seasonal output
ε is the error term.

Production equation system. Price determination is simple as it will be determined by demand and supply. The expected sign follows the economic theory: the demand side will shift the price up (+) and the supply side will force the price down (−). Crop production equals harvested area times crop yield (Eq. (2)). The harvested area is derived from the estimated planted area times the conversion ratio of the harvested area and the planted area shown in Eq. (3).

$$\Pr_{i,r,t} = Y_{i,r,t} * HA_{i,r,t} \tag{2}$$

$$HA_{i,r,t} = a_{i,r,t} * PA_{i,r,t} \tag{3}$$

where

$Pr_{i,r,t}$ is the production of crop i, region r, year t (Mt)
$Y_{i,r,t}$ is the yield of crop i, region r, year t (Mt/ha)
$HA_{i,r,t}$ is the harvested area of crop i, region r, year t (Mha)
$a_{i,r,t}$ is the ratio of harvested to planted area of crop i, region r, year t; $0 \le a_{i,r,t} \le 1$
$PA_{i,t}$ is the planted area of crop i, year t (Mha).

Price equation. The equilibrium condition for crops means that supply equals demand. In this study, the demand of palm oil is mainly for food and energy. In order to evaluate the effect of biodiesel on energy demand, the biodiesel demand for food is assumed to be constant while the demand for energy is based on the AEDP Plan. The supply is determined by the production as stated in Eq. (2). The equilibrium price is a function of demand and supply as presented in Eqs. (4)–(6).

$$Q_i^D = f\left(Price_{i,t}\right) \tag{4}$$

$$Q_i^S = f\left(Price_{i,t}\right) \tag{5}$$

$$Q_i^D = Q_i^S \tag{6}$$

where

$Price_{i,t}$ is the price of crop i in year t (THB/t)
Q_i^S is the supply of crop i in year t (Mt)
Q_i^D is the demand of crop i in year t (Mt).

Environmental impact assessment

The main reasons for biofuel promotion include, but are not limited to, energy security and climate change mitigation (DEDE, 2012; Awudu and Zhang, 2012). Energy security can be assessed in terms of abiotic

Table 1
Data sources.

Data	Source of data
Crude extraction	Ecoinvent, crude oil production Middle East onshore
Crude oil price	http://www.indexmundi.com/ (Dubai Fateh — monthly price)
Crude transportation	The Bangchak Petroleum Plc., 2010
Diesel/biodiesel blends transportation	
Diesel, biodiesel end use	PTT Plc., 2008
Agricultural area and price	Office of Agricultural Economics, Ministry of Agriculture and Cooperatives http://www.oae.go.th/
GHGs emissions from LUC	IPCC, 2006; Silalertruksa and Gheewala, 2012
GHGs of diesel	Kochaphum et al., 2012
Socio-economic impacts of oil palm market	Kochaphum et al., 2013

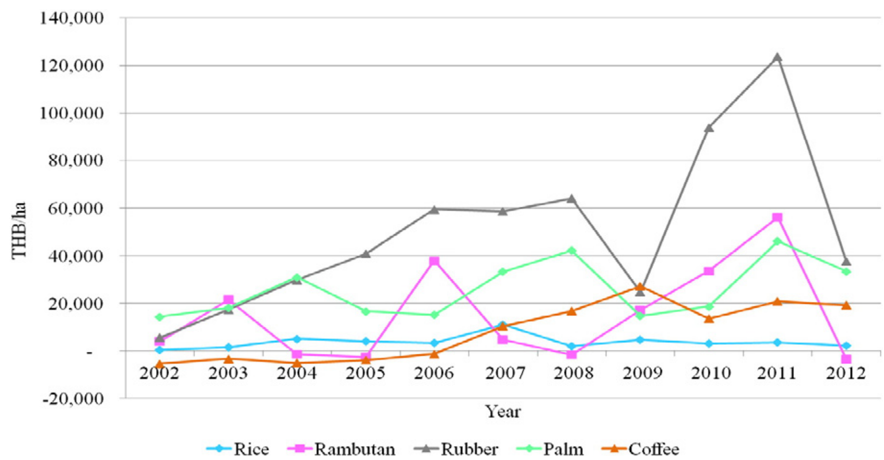

Fig. 2. Return by 2 crop (OAE, 2012).

resource depletion potential while climate change mitigation can be assessed in terms of global warming potential. The life cycle impact assessment method, ReCiPe (2008) is used in the study to characterize the environmental impacts.

Climate change is calculated as Global Warming Potential (GWP), which equals the sum of emissions of greenhouse gases (CO_2, CH_4, N_2O, CFCs) multiplied by their respective GWP factors, GWP_j:

$$GWP = \sum_{j=1}^{J} GWP_j B_j \quad (\mathrm{kg\,CO_2\,eq.})$$

where B_j represents the emission of greenhouse gas j. GWP factors for different greenhouse gases are expressed relative to the global warming potential of CO_2, the GWP for the three relevant GHGs, CO_2, CH_4, and N_2O, based on 100 years are 1, 25, and 298 respectively (ReCiPe, 2008).

The GHG emissions of biomass feedstock production resulting from LUC can be determined from the carbon balances of previous land use and the land use for biocrops (the total GHG emissions ($GHGs_{Total}$)) is the sum of GHG emissions caused by the biodiesel production life cycle without LUC ($GHGs_{without\ LUC}$) and the GHG emissions from LUC ($GHGs_{LUC}$) as stated in Eqs. (7)–(9). The method and default data used for the calculation of emission from LUC is based on the 2006 IPCC Guidelines (IPCC, 2006).

$$GHGs_{Total} = GHGs_{without\ \ LUC} + GHGs_{LUC} \tag{7}$$

$$GHGs_{without\ \ LUC} = \sum(GHGs_{Feedstock\ \ production}, GHG_{sProduction}, GHGs_{Transportation}, GHGs_{End\ \ use}) \tag{8}$$

$$GHGs_{LUC} = \sum(\%\ \text{change in}\ A_i \times A_{i,2006} \times GHGs_{conversion\ \ i\ \ to\ palm}) \tag{9}$$

where

A_i is the planted area of crop i (Mha)
$A_{i,2006}$ is the planted area of crop i at year 2006 (Mha)
$GHGs_{conversion\ i,\ palm}$ is the net GHG emission from shifting crop i to oil palm (t CO_2 eq./yr).

Socio-economic impact assessment

Since biofuel production from agricultural commodities is rising, environmental and social repercussions are also increasing. The production of biofuels may lead to both positive and negative socio-economic impacts ($SEI_{without\ LUC}$). The consequences of these impacts are based on a study conducted by Kochaphum et al., 2013 which analyzes the impacts of biodiesel demand on the price of oil palm and associated products using a demand and supply function model. Positive impacts include currency savings and increases in farmers' income due to higher prices of oil palm, and negative impacts include increases in prices for food, such as bottled palm oil, and prices for biodiesel for energy use. The total socio-economic impacts (SEI_{Total}) are the sum of those impacts resulting from biodiesel blend production; $SEI_{without\ LUC}$, combined with those impacts arising from the land use change (SEI_{LUC}) as stated in Eqs. (10)–(12).

$$SEI_{Total} = SEI_{without\ \ LUC} + SEI_{LUC} \tag{10}$$

$$SEI_{without\ \ LUC} = \sum(CS, FI) - \sum(L_{BPO}, L_{biodiesel}) \tag{11}$$

$$SEI_{LUC} = \sum(\%\,\text{change in}\,Pi) \times Pi, 2006 \times Q_i^{after\ \ conversion} \tag{12}$$

where

CS is currency saving in MTHB
FI is increase in farmer income in MTHB

Table 2
Symbols of variables for LUC assessment.

Symbol	Variable
PA_coffee_C	Planted area of coffee in the Central region (Mha)
PA_ coffee _S	Planted area of coffee in the Southern region (Mha)
R_ coffee	Return of coffee (THB/ha)
PA_rambutan_C	Planted area of rambutan in the Central region (Mha)
PA_ rambutan _S	Planted area of rambutan in the Southern region (Mha)
R_ rambutan	Return of rambutan (THB/ha)
PA_rice_C	Planted area of rice in the Central region (Mha)
PA_ rice _S	Planted area of rice in the Southern region (Mha)
R_ rice	Return of rice (THB/ha)
TREND	Time trend (1–22 from year 1991 to 2012)
D_{2002}	Over supply due to high temperature , $D_{2002} = 1$, else, $D_{2002} = 0$
D_{2005}	Government policy , $D_{2005} = 1$, else, $D_{2005} = 0$
D_{2010}	Flooding, $D_{2010} = 1$, else, $D_{2010} = 0$
D_{2011}	Coffee from mixed plantation are significantly removed , $D_{2011} = 1$, else, $D_{2011} = 0$

Table 3
Elasticity and statistics of area change by region.

Statistic	Coffee area		Rambutan area		Rice area	
	Central	South	Central	South	Central	South
Constant	−7.165	−2.058	−0.836	−2.018	0.901	−1.638
Elasticity	−0.019	−0.008	−0.040	−0.292	−0.002	−0.107
R- squared	0.990	0.976	0.986	0.935	0.703	0.988
Durbin–Watson stat	2.032	2.182	1.957	2.576	2.645	1.865
Prob (F-statistic)	0.0000	0.0000	0.0000	0.0000	0.0013	0.0000

L_{BPO} is loss from BPO price in MTHB
$L_{biodiesel}$ is loss from biodiesel price in MTHB
$P_{i,2006}$ is the price of crop i in year 2006 (THB/t)
Q_i is the crop i production (Mt)
P_i is the price of crop i after conversion (THB/t).

Sustainability assessment

The sustainability indicator used in this study to integrate environmental, social and economic dimensions is eco-efficiency. Eco-Efficiency (EE) is fundamentally a ratio of some measure of economic value added to some measure of environmental impact. The higher the value added, the more efficient is the use of environmental resources. Alternately, this ratio can be inverted, which then generally becomes known as eco-intensity. Marginal value may be used to determine relative performance among alternatives (Ehrenfeld, 2005). Economic performance can also be measured by income, net revenue, sales revenue, etc., while environmental performance can be measured by CO_2 emissions, oil consumption, etc. (Burritt and Saka, 2006). EE can be used to measure the eco-efficiency of different sectors within the country (ESCAP, 2009). It can also be used to examine the effect of alternative governmental policies on an economy in the same way, by adding up the aggregate social welfare or value added and dividing by the total environmental impact (Ehrenfeld, 2005). In practice, one cannot account for all impacts, so some life cycle impacts have to be ignored as insignificant (Kuosmanen, 2005). In EE, environmental impacts and economic impacts both relate mainly to outcomes of the activities involved in production, consumption, and disposal management. Of course, such input–output concepts might be included under the eco-efficiency umbrella, leading to additional types (Huppes and Ishikawa, 2005).

In this study, the socio-economic impact is applied for the socio-economic performance and presented as the numerator of eco-efficiency, while GHGs is applied for environmental performance and presented as the denominator of eco-efficiency. This ratio forms the expression for eco-efficiency$_{GHGs}$. For assessing the effect of biodiesel, both the socio-economic and environmental performances are in the form of change relative to diesel (Eq. (13)).

$$\text{Eco-efficiency}_{GHGs} = \Delta \frac{\text{SEI}_{Total}}{\text{GHGs}_{Total}} \tag{13}$$

Apart from the numerical integration techniques, the indicators could be kept entirely separate but presented together in a single table or diagram, e.g., Dashboard of Sustainability or Radar diagram (ERIA, 2008; ESCAP, 2009).

Table 4
Elasticity and statistics of crop price change for whole country.

Price	Coffee	Rambutan	Rice
Elasticity	−1.134	−1.400	−0.154
R-squared	0.573	0.704	0.932
Durbin–Watson stat	1.584	2.1835	2.056
Prob (F-statistic)	0.0166	0.0029	0.0000

Data sources

The statistical data are from government sources collected during the period of 1991–2012. The GHGs for biodiesel and diesel production process and LUC, in addition to socio-economic impact from the oil palm market, are obtained from previous studies as shown in Table 1.

Results and discussion

Land use change assessment

Crop selection

According to a study conducted by Salvatore and Damen (2010), about one-third of Thailand's total land of about 51 million ha is dedicated to agricultural production. Rice is the country's largest crop, but the main cash crops are sugarcane and cassava. There are several annual crops including maize and also perennial crops such as oil palm, rubber, coconut and various fruits. The crops initially chosen for the correlation analysis are cash crops: cassava, coffee, mangosteen, rambutan, rice, rubber, soybean and sugarcane, in addition to abandoned land. Forest land is excluded because it is unlikely to occur in Thailand due to it being illegal to cultivate and restricted by the government (Silalertruksa and Gheewala, 2012). The crops affected by oil palm expansion are reflected with a negative sign, meaning that crop area declines as oil palm area increases. The crops having a negative sign as explained above and significance level at 5% level are selected for this study.

The results of this study reveal that the coffee, rambutan and rice land areas in the central and southern regions have declined significantly and satisfy the selected criteria, and there is no significant relationship between oil palm land area and abandoned land areas in all regions. Even though the government intends to promote cultivation of crops on abandoned land; most of the abandoned land has low organic matter and is unsuitable for crop cultivation. Furthermore, rubber land area responds with a positive sign to oil palm expansion. This means that rubber land area is not affected by biodiesel promotion but increases with oil palm expansion. The reason is that the return from rubber has been higher than oil palm (Fig. 2) so there is no incentive of crop shifting from rubber to oil palm. However, as a substitute for palm oil, soybean planted land area is affected in the central, north and northeast, but insignificantly. This is because soybean and oil palm require different weather conditions. The physical factors of rainfall, soil quality, and temperature, are limiting factors. Thus, the displaced crops for area and price change are coffee, rambutan and rice. This conforms the findings of a survey conducted by the Land Development Department (2013) which reported that the suitable lands for oil palm are in 26 provinces, in the central and southern regions in line with climatic zones defined in IPCC, 2006 that the Central and the South regions of Thailand have suitable climate conditions for oil palm. However, in addition to the three mentioned crops, other crops that are affected by increasing oil palm area, indicated by the negative sign, but insignificant at a 5% confidence interval, are cassava, soybean in the Central region of Thailand, soybean in the North and the Northeast, and mangosteen in the South (details in Appendix A).

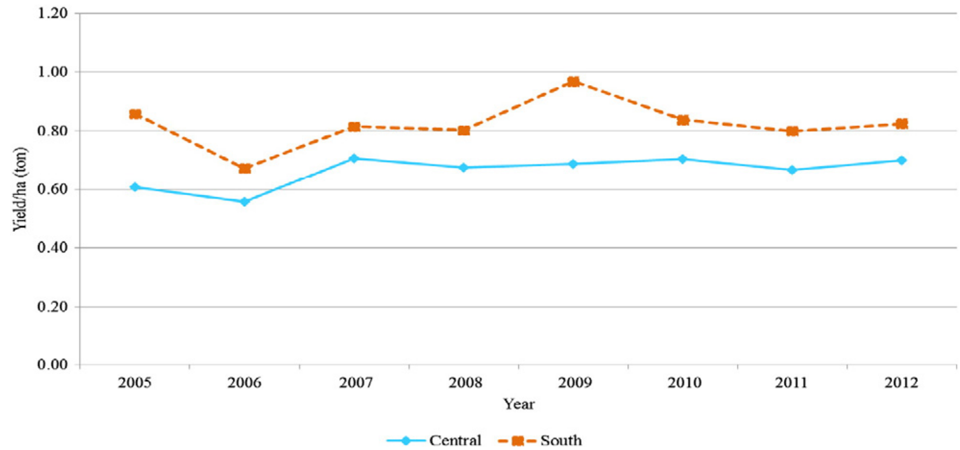

Fig. 3. Yield of coffee by region.

Change in crop area and price

The log–log model is applied to the system of equations to obtain the coefficient β as the elasticity between the endogenous and its exogenous variables (if an exogenous variable changes 1%, its endogenous variable will be changed β%). All estimated equations were examined for serial correlation through the Durbin Watson statistics (DW). The DW statistics indicate no serial correlation among the exogenous variables. Dummy variables are added differently but appropriately for each crop. The results of the planted area for each converted crop derived from Eqs. (1)–(6) are as follows (Eqs. (14)–(22)):

$$\begin{aligned}\log(\text{PA\_coffee\_C}) = &-6.89827580 + 0.00827152 \\ &* \log(\text{R\_ coffee \_C}(-1)) - 0.01858585 \\ &* \log(\text{R\_palm\_C}(-1)) * \text{D2005} - 0.60297134 \\ &* \text{D2011} + 0.04356687 \\ &* \log(\text{PA\_coffee\_C}(-1)) - 0.014956365 \\ &* \text{TREND} + [\text{AR}(1) = 0.53700067]\end{aligned} \tag{14}$$

$$\begin{aligned}\log(\text{PA\_coffee\_S}) = &-1.06293865 - 0.01135432 \\ &* \log(\text{R\_coffee\_S}(-1)) - 0.00768794 \\ &* \log(\text{R\_palm\_S}(\text{-}1)) * \text{D2005} - 0.19991577 \\ &* \text{D2011} + 0.55518954 * \log(\text{PA\_coffee\_S}(-1))\end{aligned} \tag{15}$$

$$\begin{aligned}\log(\text{P\_coffee}) = &\ 14.11143300 + 0.52369863 \\ &* \log(\text{R\_coffee\_World}(-1)) - 1.13429643 \\ &* \log(\text{PR\_coffee}) + 0.39728338 \\ &* \log(\text{coffee\_demand})\end{aligned} \tag{16}$$

$$\begin{aligned}\log(\text{PA\_rambutan\_C}) = &-0.44584402 - 0.09057610 \\ &* \log(\text{R\_rambutan\_C}(-1)) - 0.03989823 \\ &* \log(\text{R\_palm\_C}(-1)) * D_{2005} \\ &+ 0.37812225 * D_{2005} - 0.02185467 \\ &* \text{TREND} + 0.44746697 \\ &* \log(\text{PA\_rambutan\_C}(-1))\end{aligned} \tag{17}$$

$$\begin{aligned}\log(\text{PA\_rambutan\_S}) = &-1.47150752 - 0.07288602 \\ &* \log(\text{R\_rambutan\_S}(-1)) - 0.29223747 \\ &* \log(\text{R\_palm\_S}(-1)) * D_{2005} \\ &+ 3.18904868 * D_{2005} + 0.28829504 \\ &* \log(\text{PA\_rambutan\_S}(-1)) - 0.01374153 \\ &* \text{TREND}\end{aligned} \tag{18}$$

$$\begin{aligned}\log(\text{P\_rambutan}) = &\ 17.73025558\text{-}1.40051532 \\ &* \log(\text{PR\_rambutan}) + 0.05813266 \\ &* \log(\text{rambutan\_demand}) - 0.85811954 \\ &* D_{2002}\end{aligned} \tag{19}$$

$$\begin{aligned}\log(\text{PA\_rice\_C}) = &\ 0.51700199 - 0.02162536 \\ &* \log(\text{R\_rice\_C}(-1)) - 0.00201004 \\ &* \log(\text{R\_palm\_C}(-1)) * D_{2005} + 0.03469713 \\ &* D_{2005} - 0.05581545 * D_{2010} + 0.31321889 \\ &* \log(\text{PA\_rice\_C}(-1))\end{aligned} \tag{20}$$

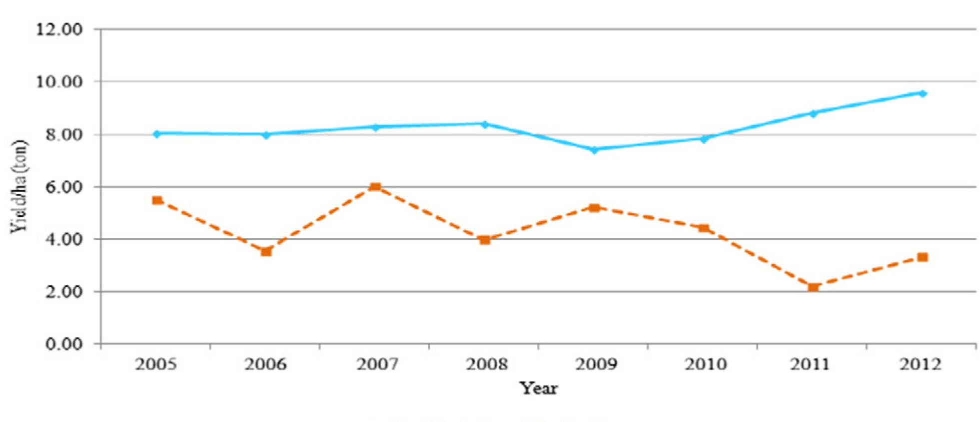

Fig. 4. Yield of rambutan by region.

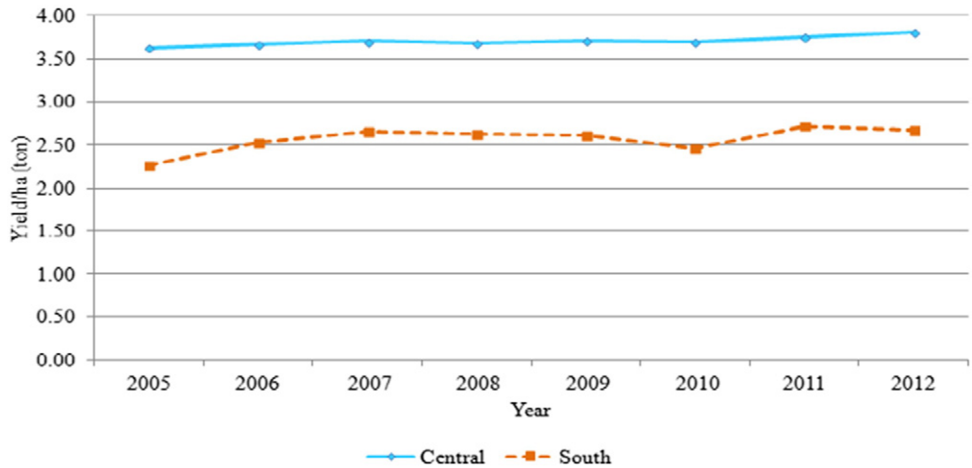

Fig. 5. Yield of rice by region.

$$\begin{aligned}\log(PA\_rice\_S) = {} & -1.45654519 + 0.09704248 \\ & * \log(R\_rice\_S(-1)) - 0.10704641 \\ & * \log(R\_palm\_S(-1)) * D_{2005} + 1.16407098 \\ & * D_{2005} - 0.41832187 * D_{2010} + 0.06835173 \\ & * \log(PA\_rice\_S(-1)) - 0.03500770 * TREND \qquad (21)\end{aligned}$$

$$\begin{aligned}\log(P\_rice) = {} & -6.11700237 - 0.15441965 * \log(PR\_rice) \\ & + 1.05505601 * \log(GDP) + [AR(1) = 0.48025215]. \qquad (22)\end{aligned}$$

Table 2 presents the list of symbols of the variables used in the LUC assessment. Tables 3 and 4 summarize the elasticity and the statistics test of area change for each crop in the Central and the South of Thailand and price change as a whole country, respectively. All signs and tests are satisfactory (details in Appendix B).

Table 3 presents the satisfactory results with high R^2 (higher than 0.7; mostly higher than 0.9), the correlations at a 95% level of confidence (F-statistic lower than 0.05). In addition, the Durbin–Watson statistics, which approach 2, show no autocorrelation among the independent variables.

The results indicate that as oil palm price changes, the percent change in land area of rambutan (0.292) and rice (0.107) in the south is higher than those in the central region (0.040 for rambutan and 0.002 for rice) whereas the percent change in coffee land area is higher in the central region (0.019) than in the south (0.008). This is because the yield of rambutan and rice in the south is lower than in the central region resulting in smaller returns per area. As a consequence, larger crop shifts occur in the south for rambutan and rice, the same as what occurred in the central region for coffee (Figs. 3–5). Furthermore, only rice in the central region has a constant with a positive sign.

The elasticities of the areas and prices of each displaced crop for the whole country responding to the AEDP biodiesel demand are presented in Table 5. Durbin–Watson statistics of those equations (close to 2) show that there are no autocorrelation among variables. The correlations are significant at the 95% confidence level (Prob. lower than 0.05). The percentages of change in area as well as in price of the displaced crops are higher as biodiesel demand increases. The increase in the biodiesel blending ratio results in the rise in incentive for farmers to shift their cultivation to oil palm. Consequently, the production of the displaced crops is reduced, causing the displaced crop prices to shift up. When the upward shift of price is high enough to be competitive with oil palm, there would be no incentive for farmers to convert their land. This is the reason that the percentage changes in the area of the converted crops are smaller as the biodiesel blending ratios are larger.

From Table 5, it is noticed that the percentage change in land area of rice is lower than that of coffee, even though the revenue per area of rice is quite similar to that of coffee. This may be because both coffee and oil palm are perennial crops, thus making it easy for the farmer to convert from one to the other, unlike rice which is annual crop. Meanwhile, percentage change in rambutan land area is high relative to coffee and rice. This may be due to its declining and unsteady return (OAE, 2012).

Greenhouse gas emission

GHGs of biodiesel (without LUC)

There are two streams in producing biodiesel blends, biodiesel (B100) and diesel (B0) production. Table 6 shows the GHGs arising from diesel and B100 in each stage of their life cycles. The results reveal that the B100 causes less GHGs than diesel. The total GHGs of B100 is approximately 78% lower than that of diesel at 0.660 kg CO_2 eq./L B100 or

Table 5
Percentage change in area and price by biodiesel blending ratio.

Crop	Item	% Change		
		B2	B5	B10
Coffee	Area	−0.30	−0.60	−0.91
	Price	0.34	0.67	1.03
Rambutan	Area	−6.47	−12.19	−17.71
	Price	7.27	14.56	22.54
Rice	Area	−0.17	−0.33	−0.50
	Price	0.05	0.09	0.14

Table 6
GHGs per liter of diesel and biodiesel (kg CO_2 eq.).

Stage of life cycle	B100	Stage of life cycle	Diesel
Palm plantation	0.495	Crude production	0.09
FFB transport	0.071	Crude transport	0.035
CPO production	−0.177	HSD production	0.145
CPO transport	0.035	HSD transport	0.103
B100 production	0.071	Vehicle use	2.616
Vehicle use	0.141		
B100 transport	0.024		
Total	0.660	Total	2.989

Table 7
GHGs of biodiesel blends per functional unit.

Biodiesel blends	$GHGs_{without\ LUC}$ (Mt CO_2 eq.)
B2	58.07
B5	56.71
B10	54.46

0.716 kg CO_2 eq./L diesel equivalent (1 L diesel equivalent = 1.085 L B100) with the GHGs of diesel at 2.989 kg CO_2 eq./L diesel. The benefit to GHGs, presented in a negative value, is the stage of CPO production due to CH_4 capture from wastewater treatment as biogas. The highest contribution of diesel to GHGs is in the stage of vehicle use whereas that of B100 is palm plantation due to fertilizer applications. It is noted that there is a small amount of GHGs in vehicle use of biodiesel, although the biodiesel is a renewable fuel. This results from non-biogenic GHGs generated from MeOH which is 5.56% of total GHGs from biodiesel (Pleanjai et al., 2009).

The result also reveals that the GHGs is lower with increases in the biodiesel blending ratio. It proves that biodiesel helps reduce GHGs. The GHGs of the biodiesel blends of 21,000 ML are presented in Table 7. The larger the biodiesel blending ratio, the lower the impact on GHGs is. A 1% increase in the biodiesel blending ratio results in the reduction of GHGs 0.45%.

GHGs of biodiesel blends (with LUC)

This section presents the GHGs arising from LUC. To estimate the GHG emissions from direct land use change (dLUC), the carbon stock changes (ΔC) of all pools are based on 2006 IPCC Guidelines. The pools include the change in biomass (ΔC_B), the change in dead organic matter (ΔC_{DOM}), the change in soil carbon stock (ΔC_{SOC}) from clearing land prior to oil palm cultivation, and non-CO_2 emissions (CH_4 and N_2O) from biomass burning in case burning is used to clear the land. The stock-difference method is used for GHG emission calculation.

A result of the previous section indicates that coffee, rambutan and rice are significantly affected by oil palm. Conversion of either coffee or rambutan to oil palm is calculated using the IPCC method of remaining cropland. Since coffee and rambutan are in the same category of crop, although in different sub-categories, the same default values are applied (IPCC, 2006). The results indicate that GHG emission factors from the conversion of coffee, rambutan and paddy field (rice) to oil palm are −6.84, −6.84 and −21.94 t CO_2 eq./ha/yr respectively (Appendix C). The results show a negative sign, meaning that the conversion of land from coffee, rambutan and paddy field to oil palm removes GHGs from the atmosphere. The total GHGs of the entire life cycle biodiesel blends without and with land use for B2, B5 and B10 are presented in Table 8.

Table 8
Total GHGs of biodiesel blends.

Biodiesel blends	Amount of biodiesel used (Mt)	$GHGs_{without\ LUC}$ (Mt CO_2 eq.)	$GHGs_{LUC}$ (Mt CO_2 eq.)			$GHGs_{with\ LUC}$ (Mt CO_2 eq.)
			Coffee	Rambutan	Rice	
B2	0.37	58.07	−0.002	−0.035	−0.346	57.68
B5	0.92	56.71	−0.003	−0.065	−0.673	55.97
B10	1.84	54.46	−0.004	−0.095	−1.011	53.35

Table 9
Symbols of variables for socio-economic assessment.

Symbol	Variable
$P_{FFB,fg}$	Oil palm price at farm gate
Con_{B100}	Biodiesel demand
MP_{CPO}	Malaysia crude palm oil price
T^S	Trend representing season output
P_{MeOH}	Methanol price
$SResid_{B100}$	Residual of B100 supply
CPOtoB100	Interpolated and extrapolated $\frac{Q^S_{CPO,t-2m}+Q^S_{RBD,t-2m}+Q^S_{ST,t-2m}}{g_1 Q^S_{CPO,t-2m}}$
$Q^S_{CPO,t-2m}$	CPO supply at time *t*
$Q^S_{RBD,t-2m}$	RBD supply at time *t*
$Q^S_{ST,t-2m}$	ST supply at time *t*
P_{CPO}	Crude palm oil price
RBD	Refined Bleached and Deodorized palm oil
ST	Palm oil stearin
D_1	If domestic CPO price is used, $D_1 = 1$, else, $D_1 = 0$
D_2	If Malaysia CPO price + 1 is used, $D_2 = 1$, else, $D_2 = 0$
D_3	If RBD & ST are used in B100 pricing, $D_3 = 1$, else, $1 - D_3 = 1$

Socio-economic impact

Price estimation

The estimate of FFB price and the demand of biodiesel are presented in Eqs. (23) and (24), respectively (Kochaphum et al., 2013). The demand of biodiesel is 5.97 million L/day as targeted in the AEDP target in 2021. All symbols are presented in Table 9.

$$\begin{aligned} P_{FFB,fg} = {} & D_1 * (Con_{B100} - (-0.037965392) - (0.0008281440) \\ & * MP_{CPO} - 0.0012685218 * T^S - ((1-D_3) \\ & * (0.0008622026 * (0.15 * P_{MeOH} + 3.32) + SResid_{B100}) \\ & + D_3 * (0.0008622026 * (0.1 * P_{MeOH} + 3.82) * CPOtoB100 + SResid_{B100}))) \\ & /(0.0002153858 + (1-D_3) * 0.97 * 0.0008622026 + D_3 * 0.94 \\ & * 0.0008622026 * CPOtoB100) + (1-D_1) * P_{CPO} \end{aligned} \tag{23}$$

R-squared = 0.9247	Adjusted R-squared = 0.9195
Durbin–Watson stat = 1.054916	F-statistic = 180.1798
Prob (F-statistic) = 0.0000	

$$\begin{aligned} Con_{B100} = {} & (1-D_3) * (0.97 \\ & * (D_1 * P_{CPO} + D_2 * (MP_{CPO} + 1) + (1-D_1-D_2) * (MP_{CPO} + 3)) \\ & + 0.1 * P_{MeOH} + 3.32) + D_3 * CPOtoB100 * (0.94 * (D_1 \\ & * P_{CPO} + (1-D_1-D_2) * (MP_{CPO} + 3)) + 0.15 * P_{MeOH} \\ & + 3.82) \end{aligned} \tag{24}$$

R-squared = 0.850801	Adjusted R-squared = 0.839950
Durbin–Watson stat = 0.618855	F-statistic = 78.40853
Prob (F-statistic) = 0.0000	

The results of the FFB price and the biodiesel demand are satisfactory in terms of high R^2 = 0.92, 0.85 respectively. The Durbin–Watson

Table 10
Estimated price of palm oil associated products.

Estimated price	Unit	B0*	B2	B5	B10
FFB	USD/kg	0.11	0.16	0.25	0.39
CPO	USD/kg	0.73	1.12	1.71	2.70
BPO	USD/L	1.17	1.56	2.14	3.11
Bi retail price	USD/L	0.89	0.90	0.96	1.13

Remarks: * conventional diesel.

Table 11
Net socio-economic impacts without LUC.

Items	Unit	B0	B2	B5	B10
Currency saving	MUSD/yr	0	235	587	1174
Farmer income	MUSD/yr	718	1097	1663	2605
Expenditure: BPO price	MUSD/yr	420	560	768	1115
Expenditure: fuel price	MUSD/yr	18,675	18,962	20,059	23,670
Net socio-economic impact	MUSD/yr	(18,377)	(18,191)	(18,577)	(21,006)
Change relative to B0	MUSD/yr	0	186	(200)	(2630)

Table 12
Total socio-economic impact (with LUC) of biodiesel blends.

Items	Unit	B0	B2	B5	B10
Currency saving	MUSD/yr	0	235	587	1174
Farmer income	MUSD/yr	718	7402	7989	8953
Expenditure: BPO price	MUSD/yr	420	560	1663	2605
Expenditure: fuel price	MUSD/yr	18,675	18,962	20,059	23,670
Net socio-economic impact (LUC)	MUSD/yr	(18,377)	(11,886)	(12,251)	(14,659)
Change relative to B0	MUSD/yr	0	6491	6126	3718

statistic of those two equations shows that there is no autocorrelation. Tests of unit root on the two variables are conducted. The result shows that the FFB price and the B100 consumption are stationary. Hence, their regression should not be spurious.

The estimated prices of FFB for B2, B5 and B10 are derived from Eq. 23. All variables are constant with the average values from year 2006 when biodiesel was launched, to 2011. The estimated prices of the associated palm oil products (CPO & BPO) are shown in Table 10.

Socio-economic impact related to the oil palm market ($SEI_{without\ LUC}$)

Currency savings. The average crude oil price during the years 2007–2011, 0.54 USD/L, is used for currency savings estimation. The conversion factor from crude oil to diesel is 1.03 L/L (BCP, 2010). The estimates indicate that the country can save the amounts of 235, 587 and 1174 MUSD/yr for the biodiesel blending ratios of B2, B5 and B10 respectively as shown in Table 11. As can be expected, the higher the biodiesel blending ratio, the larger the society is benefited due to larger crude oil replacement with biodiesel.

Farmer income. The FFB demand per year is calculated from diesel replaced with the conversion of 4.56 kg FFB/kg CPO and 0.86 L CPO/L B100 plus demand for food. According to the estimates, with the increasing biodiesel demand derived from the model, FFB prices would increase to 0.16, 0.25 and 0.39 USD/kg for B2, B5 and B10, respectively. As a result, the oil palm farmers would have incomes of the amounts of 718, 1097, 1663 and 2605 MUSD/yr for B0, B2, B5 and B10, respectively.

Expenditure from higher BPO price. The feedstock cost is a major cost in producing agricultural products. Higher prices of FFB cause not only increases in farmers' incomes but also increases in BPO production cost due to its feedstock cost. Consequently, the BPO price is higher. The results show the estimated BPO price would rise from 1.17 USD/L in the base year to 1.56, 2.14 and 3.11 USD/L as the biodiesel blending ratio is increased to B0, B2, B5 and B10, respectively. From the results presented in Table 11, total expenditures for the BPO consumption are 420, 560, 768 and 1115 MUSD/yr for B0, B2, B5 and B10 respectively.

Expenditure from higher biodiesel prices. The results show the estimated biodiesel blend prices would rise from 0.89 USD/L in the base year to 0.90, 0.96 and 1.13 USD/L as the biodiesel blending ratio is increased to B2, B5 and B10, respectively. The total expenditures from the blended biodiesel consumption are 18.67, 18.96, 20.06 and 23.67 MUSD/yr for B0, B2, B5 and B10 respectively.

Net socio-economic impact without LUC. All the social and economic impacts are summed as net socio-economic impacts of biodiesel promotion stated in Eq. (11). The results show that the net socio-economic impact for diesel (B0) and biodiesel blends (B2, B5, B10) are negative as detailed in Table 11. The largest factor of the negative socio-economic impact is fuel consumption while farmer income is the main factor of the positive impacts. In the case of no biodiesel (B0), either individuals or society at large, has to pay for energy (diesel) and food (BPO) at a higher cost than the farmers receive from oil palm sales, resulting in the negative values of the net socio-economic impact. The values of the net socio-economic impacts are also negative in all biodiesel blends. In order to compare the scenarios with and without biodiesel, the change in the net socio-economic impact of biodiesel blends relative to B0 is considered. The results show that B2 has positive sign, meaning that having B2 is more beneficial in terms of socio-economic impact than diesel. Nonetheless, B5 and B10 are worse in terms of socio-economic impact than diesel. This is caused by large increase in expenditure for biodiesel blends due to increases in the ratio of biodiesel which has a higher cost.

Socio-economic impact related to land use change (SEI_{LUC})

This section presents the socio-economic impact caused by crop area conversion. Table 12 shows the net socio-economic impact with LUC for each biodiesel blend. From Table 5, the prices of the displaced crops increase as their areas decline. The results show that, in addition to the associated palm oil market, the markets of the displaced crops are indirectly affected. The farmers who still retain those crops would have higher incomes. The additional positive socio-economic impact from LUC is the increase in farmers' incomes from the additional oil palm area converted from the coffee, rambutan and rice, plus the income of farmers from the increase in the converted crop prices. As a result, the change in the net socio-economic impact of B5 and B10 from B0 become positive but decline from B2. This is because, for biodiesel up to B2, the CPO demand is low and can be supplied by the excess CPO (DIT, 2011). When the CPO demand is higher due to increases in the biodiesel ratio (B3 to B10), there is a demand for CPO causing a sharp price rise of the associated palm oil commodities.

Sustainability assessment

Table 13 compiles the data of SEI, GHGs for the biodiesel blends without and with LUC from Tables 6, 8 and 12. The eco-efficiencies of the various biodiesel blends are presented in the form of two-dimensional graphs. The horizontal axis indicates the environmental

Table 13
SEI, GHGs of biodiesel blends.

Biodiesel (Bi)	$SEI_{without\ LUC}$ (MUSD)	$SEI_{with\ LUC}$ (MUSD)	$GHGs_{without\ LUC}$ (Mt CO_2 eq.)	$GHGs_{with\ LUC}$ (Mt CO_2 eq.)
B0	(18,377)	(18,377)	58.97	58.97
B2	(18,191)	(11,886)	58.07	57.68
B5	(18,577)	(12,251)	56.71	55.97
B10	(21,006)	(14,659)	54.46	53.35

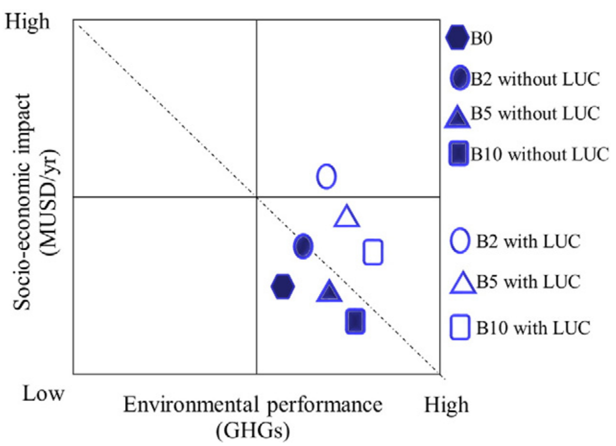

Fig. 6. Eco-efficiency of biodiesel blends; GHGs.

performance while the vertical axis indicates the economic performance. In the graph, the scaling of the axes is inverted; meaning the upper right corner is the "positive" region (indicating a high eco-efficiency) whereas the lower left corner is the "negative" region (low eco-efficiency). All alternatives lying on the same diagonal from top left to bottom right have the same eco-efficiency (Rüdenaue et al., 2005). Since the performances of the blending biodiesels with LUC are better than those without LUC in both economic and environment aspects, the position of marks representing blending biodiesels with LUC are in the right and a little bit upward to blending biodiesels without LUC. Fig. 6 shows the EE of the socio-economic performance in million baht against the environmental performance in term of GHGs in kg CO_2 eq. with and without LUC. Since the performances of biodiesel blends with LUC are better in both socio-economic and environment than those without LUC, the position of marks representing blending biodiesels with LUC are to the right and a little bit upward of the blending biodiesels without LUC. In addition, B2 has higher both socio-economic and environmental performance than diesel (B0), indicated by an upper and rightward shift.

The changes in GHGs and the socio-economic impact of the biodiesel blends relative to B0 are conducted to show the effect of biodiesel. In order to see the trend finely, the biodiesel blending ratios, B1, B8 and B9, are further studied. The results reveal that the changes in GHGs of the biodiesel blends are increasing, as shown in Fig. 7, because biodiesel helps reduce GHGSs and crude oil use. Whereas the net socio-economic changes of B2 to B10 relative to B0 are positive, the trend is decreasing as shown in Fig. 8 as a result of higher biodiesels price (negative impact) which more than offset the increase in farmers' income (positive impact).

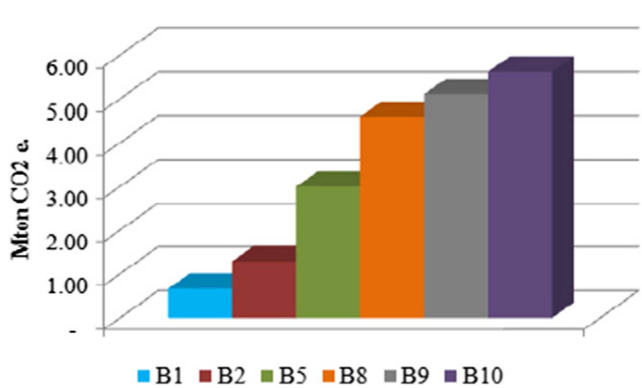

Fig. 7. Change in GHGs of Bi relative to B0.

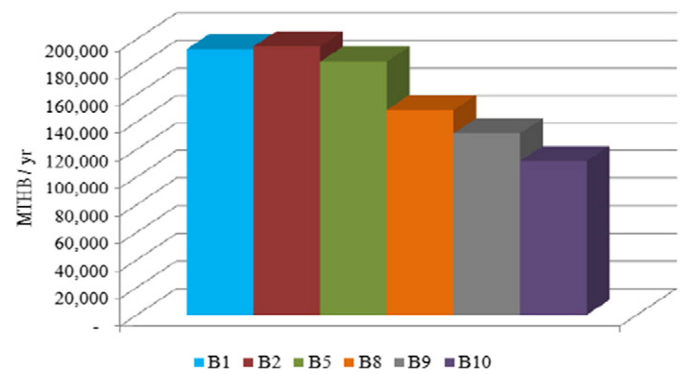

Fig. 8. Change in net socio-economic impact of Bi relative to B0.

Sensitivity analysis

A number of scenarios are analyzed for sensitivity to find out the effect of factors on the net socio-economic impact, the currency saving, the farmers' income, and the BPO and biodiesel blend price rise. Those factors are crude oil price, biodiesel consumption and crude palm oil price. The results are shown in Fig. 9.

The sensitivity analysis shows that the net socio-economic impact is mostly affected by crude palm oil price which partly depends on the domestic supply and the Malaysia palm oil price. The decrease in the price of crude palm oil by 10% would result in higher benefit to the net socio-economic impact by 47%. The impacts on the price of the cooking oil and the biodiesel are reduced. The second influencer is the crude oil price. The change in crude oil price by 10% would approximately change net socio-economic impact by 34%. The higher the crude oil price, the larger net socio-economic impact is obtained because the crude oil price would increase the positive factor i.e., currency saving and would reduce the negative factor i.e., price gap between diesel and biodiesel. On the contrary, the increasing of biodiesel consumption by 10% would decrease net socio-economic impact only 1%. Even though the higher consumption needs more crude oil and oil palm which is benefit to currency saving as well as farmer income by 10%, the increase in biodiesel price is also larger.

Conclusion

As targeted in the 10-Year Renewable and Alternative Energy Development Plan (AEDP: 2012–2021), by increasing the biodiesel ratio up to 10%, the study revealed that coffee, rambutan and rice are the crops significantly affected by oil palm expansion. The percentages of area conversion for B2 are 0.30%, 6.47% and 0.17% for coffee, rambutan and rice, respectively. The price increases of the converted crops corresponding to B2 increase are 0.34%, 7.27% and 0.05% for coffee, rambutan and rice, respectively. The percentage changes of the converted land area and prices are higher as the biodiesel blending ratio increases. The crops that require a similar environment (weather in particular) such as oil palm, but have a return per land area lower than that of oil palm, are more likely to be converted. Furthermore, the set-aside land and non-productive land are seldom affected by biodiesel promotion because more effort and fertilizer are needed to make those kinds of land suitable for oil palm, resulting in higher costs and less return.

Since biodiesel helps reduce greenhouse gases, the increase in the biodiesel blending ratio lowers GHGs. When LUC is integrated, the GHGs is smaller. This is because, according to the 2006 IPCC guidelines, the conversions of coffee, rambutan and rice to oil palm have negative signs due to more carbon absorption in stock and mineral soil.

The results reveal that compared to B0, the net socio-economic impact of B2 is better but B5 and B10 are worse. Furthermore, the

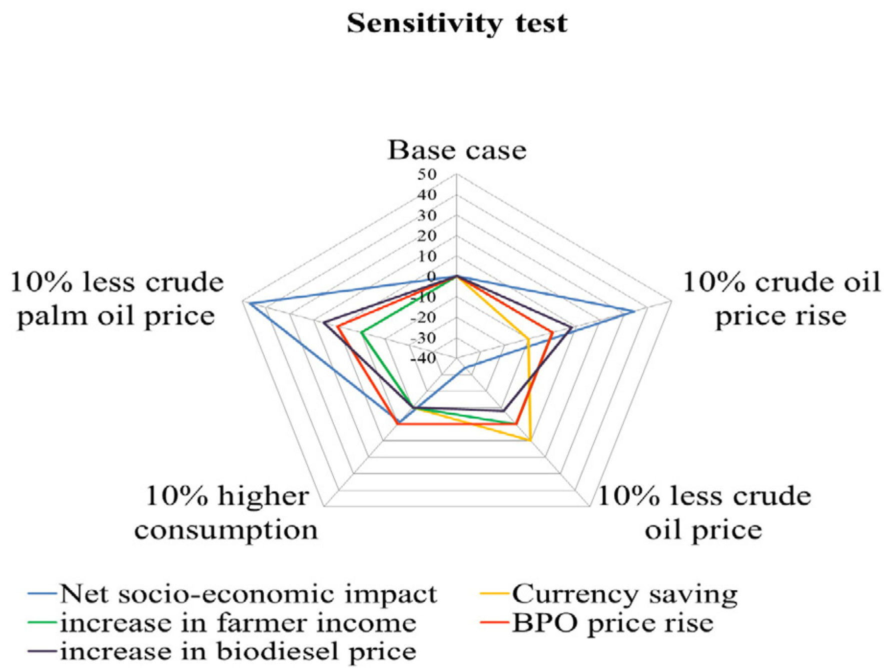

Fig. 9. Sensitivity analysis of factors to net socio-economic impact.

promotion of biodiesel affects the associated palm oil commodities, but minimally, relative to the prices of crude palm oil and crude oil. The price of biodiesel blends has a major effect on the socio-economic impact. When LUC is integrated, the net socio-economic impacts of B5 and B10 become better than those for B0. This is due to the additional farmers' income from oil palm expanded areas and the increase in price of the other crops (rambutan, coffee and rice) because of reduced supply from conversion of part of their land area to oil palm cultivation.

The eco-efficiency (EE) of the various biodiesel blends is an indicator of the sustainability of biodiesel promotion in Thailand. The changes in the socio-economic impacts, the GHGs of the biodiesel blends and B0, are assessed. The result shows that the EE of biodiesel blends from B2 to B10 are positive but decreasing due to the decrease in the net socio-economic values. Even though the results of EE indicate that the biodiesel blending ratio of 2% to 10% benefits the country, as a whole as shown by the positive values, it should be noted that the major effect of the increasing net income compared to diesel would be on the increasing biodiesel price, a burden on consumers. This may affect other activities and commodities resulting in higher negative socio-economic impact. Of further concern is the land use change. From the correlation, not only oil palm but also rubber affects land conversion. Since the competing crop of oil palm in terms of climatic conditions and revenue is rubber, the higher biodiesel blending ratio may cause the oil palm price to rise higher than the rubber price. The rubber cultivation is possibly converted to oil palm cultivation. The GHGs would be different. From the historical data (OAE, 2012), the return of oil palm plantation at B9 is slightly higher than that of rubber.

It is recommended that under the study B9 would be the optimal biodiesel blending ratio because the higher price of oil palm than the rubber possibly causes the conversion of rubber to oil palm. Consequently the EE would be worse due to increase in GHG emission. In case the government requires B10 as targeted, it could be achieved positively by reducing oil palm prices, which could be possible by increasing yields as well as the efficiency of feedstock production.

There are some limitations and recommendations for future study as follows:

1. Data uncertainty: There are two causes of uncertainty. One is the uncertainty caused from the different sources of data and collection methodology. The other is using the default data of the Tier 1 approach of IPCC (2006) which is rather coarse. For example, rambutan and coffee have a different structure and canopy that may result in different carbon stocks. But in the Tier 1 method, they are considered to have the same value of biomass as both are just classified as perennial crops in the same region. If available, it is recommended to use the national and crop specific data to calculate the greenhouse gases.
2. Model coverage: Even though the LUC results in higher income of the farmers who own the converted crop areas, the increase in prices of the displaced crops may cause negative impacts to consumers due to the higher price of the displaced crops, which involve a number of commodity related markets such as coffee, rambutan and rice. The results also show that in addition to the associated palm oil market, the markets of the displaced crops are indirectly affected. The larger the amount of commodities, the more the complexity would be. The Computable General Equilibrium Model (CGE) is recommended as the assessment tool.
3. Biodiversity: LUC for biodiesel may lead to monoculture that affects biodiversity. Due to the complexity and data limitation, biodiversity is not included in this study but is recommended for further study.

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