CHAPTER 1 INTRODUCTION

1.1 Problem Statement

With the advent of economic recovery after the 1997 economic crisis, Thailand's energy consumption has remarkably increased. Compared with the domestic demand, the production of crude oil from indigenous resources was very low therefore; there was a need to import crude oil at a high rate of 90%. In 2012 the total imported crude oil was 315 million barrels as shown in Figure 1.1. With regard to oil consumption by all economic sectors, the transportation sector is the largest consumer. This sector alone accounts for more than 60% of the total domestic oil consumption (Brundtland, 1987). It is projected that energy demand will keep increasing; efforts have been made to explore and develop other potential energy sources to accommodate the increasing demand. Renewable energy, energy which is inexhaustible, and alternative energy are considered potential options, which will help reduce not only the country's dependency on imported energy but also risks of volatility of imported fuel prices. As an agricultural and crude importing country, Thailand has also been affected by the above situation; the Thai cabinet resolution approved the strategy for gasohol promotion and appointed the Committee on Biofuel Development and Promotion to be charged with the determination of national policy and management plan for biofuels and to be the focal point in matters related to biofuel policy making, monitoring, following-up and promotion in 2005. The Royal Thai Government (RTG) had set the 15-Year Renewable Energy Development Plan (REDP: 2008–2022) where the national targets for biodiesel were set for the future share of renewable energy at B2 (98% conventional diesel blend with 2% of biodiesel B100) nationwide in year 2008, then up to B5 nationwide in 2010; and B10 as an option in year 2013 and mandated nationwide in year 2022 where the target of biodiesel demand was to be approximately 4.5 million liters per day (DEDE, 2009). More recently, this plan has been slightly revised in the new 10-Year Renewable and Alternative Energy Development (AEDP: 2012–2021) where the biodiesel production is targeted to be approximately 6 ML/d (DEDE, 2012).

Biofuels are not only a source of energy, but also are seen as prominent carbon neutral options in low- greenhouse gas technologies (Fritsche, 2006). Moreover their use can

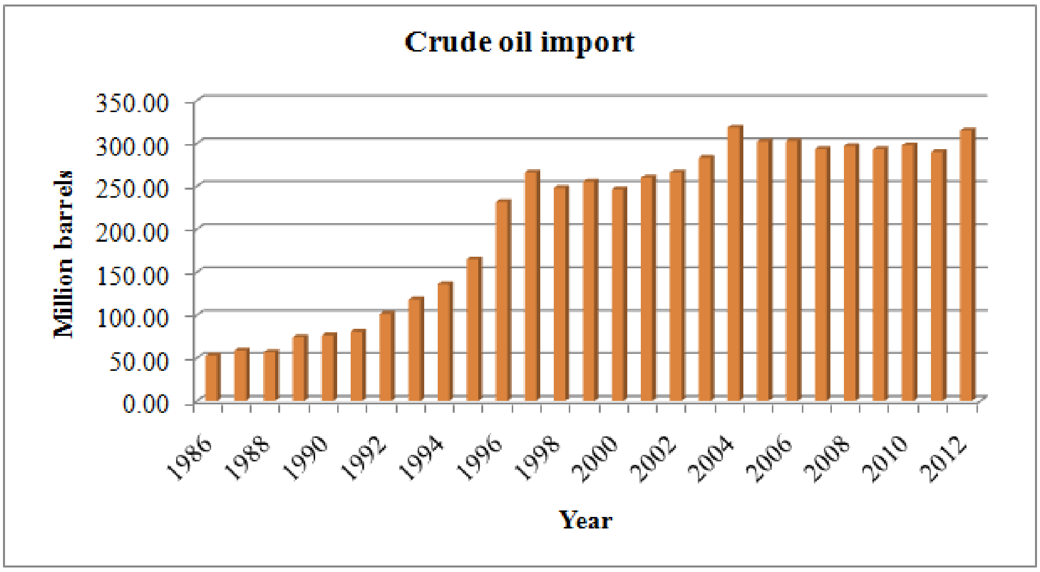

Figure 1.1 Crude oil import (EPPO, 2013)

reduce food surpluses and create demand resulting in increasing / stabilizing of agricultural product prices; consequently, stimulating increased land conservation efforts on agricultural land because of higher land values Therefore, they can provide benefit to the national economy as well as society (Dewulf and Langenhove, 2006). On the downside, the prices of related commodities e.g. bottled vegetable oil, animal feed etc. which use the same feedstock are affected. Furthermore, government subsidy for adjusting the price of renewable fuels to promote renewable energy decreases the national budget for the country's development. These have a negative impact on socio-economics. The substantial demand of biofuel crops will cause major land use changes and many feedstocks (although originally targeted at marginal lands) will compete with food crops in productive eco-regions. The supply of other crops will decrease and, in the short term, price will increase. This will give other farmers incentives to produce more of these crops (substitutes). Displacement will occur whenever it becomes more profitable to produce one crop than others (Kløverpris et al., 2008a) It is recommended in the expert consultation on biofuels sponsored by Appari, CIMMYT, ICRISAT, IRRI 27-29 August, 2007, Los Baños, Philippines that policy makers need to protect the poor from rising commodity prices likely to be triggered by diversion of crop produce or area expansion for biofuel crops. Therefore, there is an urgent need to strengthen policy research in order to avoid decisions that may lead to competition between food and bioenergy, and identify a complementary approach that benefits both sectors. Furthermore, as a result of the biofuel production expansion, there is a risk of moving into areas with fragile, marginal 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 and the area of the converted crop would indicate the environmental and socio-economic impacts.

In order to minimize land-use conflicts, the development of economically viable and environmentally sound options for making use of such land (also taking social implications into account) should be a priority for sustainable bioenergy (Fritsche et al., 2006). There are several indicators for assessing each category for environmental, social and economic performance. For sustainability assessment, all the three categories need to be looked at in parallel to avoid unintended tradeoffs among them.

1.2 Objectives

There have been a number of studies of biofuel impacts on environment and economics conducted worldwide and in Thailand (Schmidhuber, 2006; Chom-in et al., 2009; Dyer et al., 2010; Pleanjai et al., 2004; Silalertruksa et al., 2012). Studies on integration of those impacts, in particular combining with land use change are limited; none of those in the literature studies on what crops and how much of each crop would be converted. This study has objectives of the followings:

- To adapt existing tools for the assessment of the impact of biodiesel on land use change (LUC)
- To assess environmental impacts of biodiesel chain including LUC by using Life Cycle Assessment approach
- To assess socio-economic impacts arising from biodiesel promotion
- To assess sustainability of biodiesel due to government policy in increasing blending ratio of biodiesel (B100) in diesel using the adapted methodology

1.3 Organization of this Dissertation

Sustainability must have the balance of three pillars i.e. a good return on economics as well as on environment and society. The scope of this study is constructed upon the analysis of environmental and socio-economic impacts focusing on land use throughout the life cycle assessment for comparison of diesel and biodiesel blends (B2, B5, B10) using crude palm oil (CPO) as feedstock. The works can be divided into four phases as follows:

Phase I: to adapt existing tools for estimate the magnitude of change in land use and consequently crop prices

Phase II: to perform LCA of biodiesel blends that cover the stages of feedstock production, transportation, production process, product use and LUC for the categories of Global Warming Potential (GWP) and Abiotic Depletion Potential (ADP).

Phase III: to analyse socio – economic impacts of biodiesel blends. Those include the currency saving, the farmer income, and the prices of the biodiesel and the bottled palm oil.

Phase IV: to assess the sustainability of biodiesel with eco-efficiency indicator.

CHAPTER 2 RELATED WORK AND THEORETICAL ISSSUE

2.1 Biodiesel

Biodiesel defined by the American Society for Testing and Materials (ASTM) as monoalkyl esters of long chain fatty acids derived from renewable lipid feedstocks such as vegetable oil or animal fat. As an alternative fuel, biodiesel can be used in neat form or mixed with petroleum based diesel. Four oil crops clearly dominate the feedstock sources used for worldwide biodiesel production. Those are rapeseed oil, sunflower seed oil, soybean oil and palm oil. They are the most popular biodiesel feedstock in Germany and France, Southern European countries, USA and South Asia, respectively. The choice of raw material in a specific region mainly depends on the respective climatic condition. Countries in which pure Fatty Acid Methyl Ester (FAME) fuels are marketed include Germany and Austria. In France and Spain, blends of biodiesel in fossil diesel fuel range from 30% to 36% and 20% in USA. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatic compounds (Stockley et al., 1999; Mittelbach and Remschmidt, 2004; Bank of Thailand, 2006; Dewulf and Langenhove, 2006).

2.1.1 Biodiesel production

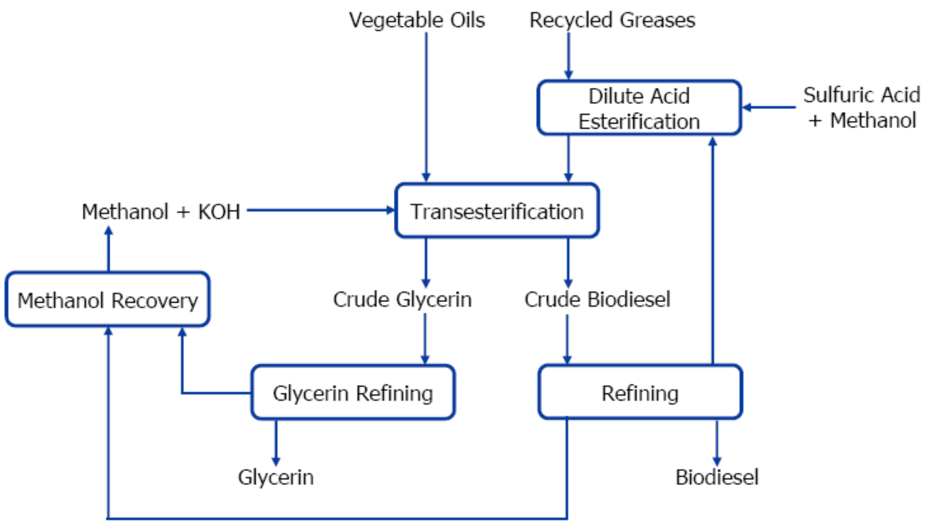

Figure 2.1 Basic biodiesel production process (Smaling, 2006)

Biodiesel is derived from transesterification process of oil seeds or animal fats and alcohol, shown in Figure 2.1. Transesterification is the term used to describe the transformation of vegetable oil into biodiesel. Vegetable oil is made up of three ester attached to glycerin molecule – a triglyceride. An ester is a hydrocarbon chain available to bond with another molecule. During transesterification, the esters in vegetable oil are separated from the glycerin molecule, resulting in the by-product glycerin. The esters then attached to alcohol molecules (either methanol or ethanol) to form biodiesel. In order to prompt the esters to break from the glycerin and bond with the alcohol, a catalyst (sodium hydroxide or potassium hydroxide) must be used as shown in Figure 2.2. The glycerin by-product can be further processed to make soap. Transesterification reactions can be alkali-catalyzed, acid-catalyzed or enzyme catalyzed. An excess of methanol is used to shift the reaction to the right side in order to achieve high yield of methyl esters/ biodiesel. Most biodiesel industries use the alkali catalyzed process. One limitation to the alkali catalyzed process is its sensitivity to both water and Free Fatty Acids (FFAs). Free fatty acids are present in vegetable oil when it has been used in cooking. When fatty acids are present, more base catalyst is required to neutralize the FFAs, which renders the biodiesel fit for use. Free fatty acids can react with the alkali catalyst to produce soaps and water. The presence of water may cause saponification and can consume the catalyst and reduce the catalyst efficiency. The presence of water has a greater negative effect than that of free fatty acids (Jaijong et al., 2012, Hogan, 2005; Kim and Dale, 2005; Puppán, 2002].

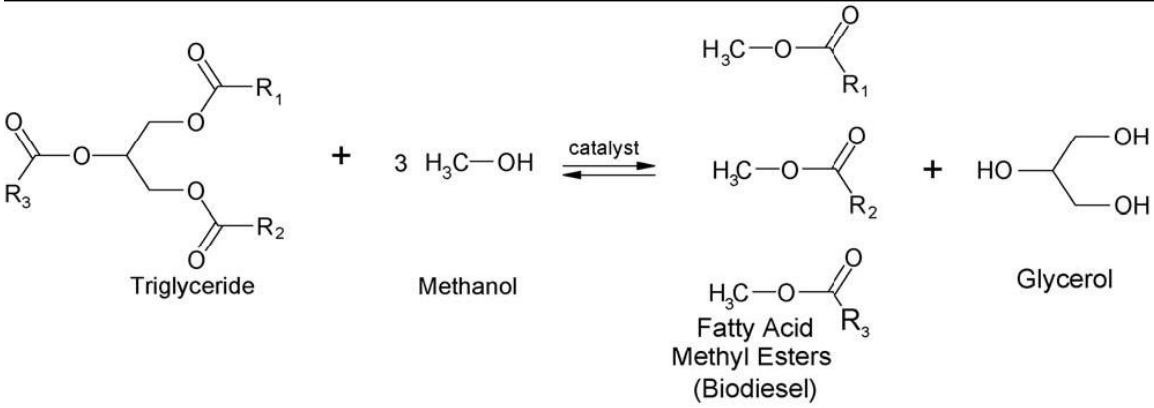

Figure 2.2 Transesterification reaction (Hogan, 2005)

2.1.2 Petroleum production

Diesel, a conventional product from petroleum refineries, is a main energy source for transportation in Thailand. There are two streams of the petroleum production process. The core refining process is a simple distillation. This first and basic refining process separates the crude oil into its "fractions", the broad categories of its component hydrocarbons.

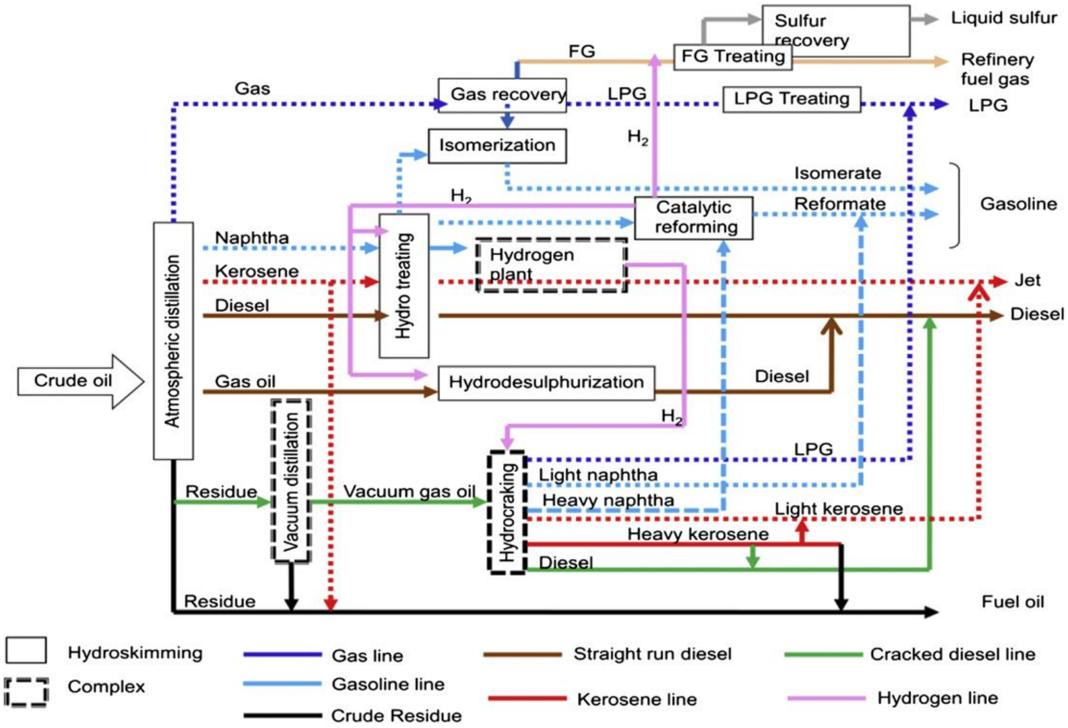

Figure 2.3 Petroleum refining process (Kochaphum et al., 2012)

The crude oil is heated and put into a distillation column then different products boil off and can be recovered at different temperatures. The lighter products—liquefied petroleum gas (LPG), naphtha, and gasoline—are recovered at the lowest temperatures. Middle distillates—jet fuel, kerosene, distillates (such as diesel fuel)—come next. Finally, the heaviest product (fuel oil or atmospheric residue; AR) is used as energy for industry. The simplest type of refinery is so-called a hydroskimming refinery. At this point, the products from the hydroskimming refinery are called “straight run” e.g. straight run gasoline and straight run diesel (S-HSD). The associated units of the hydroskimming refinery are shown in solid boxes in Figure 2.3. The other stream is the reprocessing the heavier fractions by breaking down large, heavy hydrocarbon molecules into lighter products by the additional processes. This kind of refinery is called complex refinery. The additional processes include a vacuum distillation recovering heavy distillates or residue from the first distillation under vacuum**,** a hydrocracker, a catalytic cracking in the presence of hydrogen using the gasoil (heavy distillate) output from the vacuum distillation as its feedstock and a process for diesel production with a high cetane number at a low cloud point (Han et al., 1997; Rana et al., 2007) and a hydrogen plant. The diesel from the cracking unit is called cracked diesel (C-HSD). The related units for the complex refinery are shown as dotted boxes in Figure 2.3. The volatile fractions, in both cases, have greater economic value and the distillation residues produced – atmospheric residue (AR) and vacuum residue (VR) – represent a significant portion of a barrel of crude. Thus, residue must be converted into cleaner and more valuable products (Goncalves et al., 2010; Luo et al., 2010).

2.2 Life cycle assessment

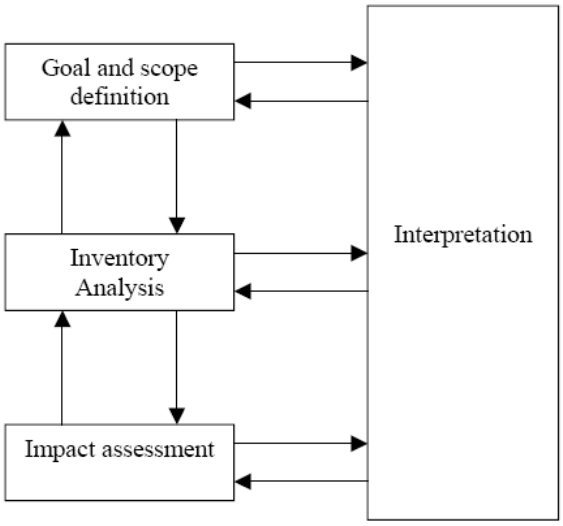

Figure 2.4 LCA framework (ISO 14040, 2006)

Life cycle assessment (LCA) is a technique to quantitatively assess the environmental impact and the energy requirements of a product or service from its initial raw materials to its final disposal (i.e. cradle to grave). One of the key advantages of using LCA is it allows a direct and fair comparison between two products or services with regards to the environmental and energy impacts. The environmental burden covers all types of impacts upon the environment, including extraction of different types of resources, emission of hazardous substances and different types of land use. Most important, a cradle to grave analysis involves a "holistic" approach, bringing the environmental impacts into one consistent framework, wherever and whenever these impacts have occurred, or will occur. The general framework for an LCA is described in ISO 14040 (2006) including four phases as following as shown in Figure 2.4. Besides avoiding problem shifting, LCA is chosen due to the reasons of; firstly, LCA may encompass all elements from other methods, e.g. energy balance, material input per unit of service, ecological footprint etc. Secondly, LCA ideally includes all affected processes and emissions in a life cycle perspective. Thirdly, LCA can be used for assessing potential environmental effects rather than proxies or aggregate indicators (energy, mass flow, needed productive land etc.) of the environmental impacts as in the other methods. Fourthly, the method of LCA is more developed and widespread than any of the others (standardized as ISO 14040). Fifthly, there is an increased use of LCA in policy decisions (Cooper, 2003; Kanzig et al., 2003; Schmidt, 2007)

2.2.1 Phase 1: Goal and scope definition

The process of conducting an LCA as well as its outcomes is largely determined by the goal and scope of a study. In full LCA studies, the system boundary is drawn to encompass all stages in the life cycle from extraction of raw materials to the final disposal, i.e. from cradle to grave. However, in some cases, the scope of the study will demand a different approach, where it is not appropriate or even possible to include all the stages in the life cycle. The scope of such studies can be from ‘cradle to gate’ as they follow a product from the extraction of raw materials to the factory gate. One of the most important elements of LCA is the functional unit. The functional unit represents a quantitative measure of the output of product(s) or service(s) which the system delivers. In comparative LCA studies, it is crucial that alternative systems are compared on the basis of an equivalent function, i.e. functional unit. This phase should also include assessment of data quality with respect to time, geographical location and technologies covered. Completeness, representativeness, consistency and reproducibility are some of the criteria that are used to assess the quality of data. Finally, assumptions and limitations of the study should also be stated clearly in this phase. Goal and scope are constantly reviewed and refined during the process of carrying out an LCA, as additional data and information become available.

2.2.2 Phase 2: Life cycle inventory analysis

Life cycle inventory (LCI) analysis involves the collection of environmental burdens data necessary to meet the goals of the study. The environmental burdens (or interventions) are defined by the materials and energy used in the system, emissions to air, liquid effluents and solid wastes discharged into the environment. If the system under study produces more than one functional output, then the environmental burdens from the system must be allocated among these outputs. This is the case, for example, with co-product, reuse and recycling systems; in LCA, such systems are known as multiple-function systems. Allocation is the process of assigning to each function of a multiple-function system only those environmental burdens which that function generates. ISO 14044 (2006) recommends three methods for dealing with allocation:

- if possible, allocation should be avoided by disaggregating the given process into different sub-processes or by system expansion;
- if it is not possible to avoid allocation, the allocation problem must be solved by using system modeling which reflects the underlying physical relationships among the functional units;
- where physical relationships cannot be established, other relationships, including economic value of the functional outputs, can be used

The allocation method used will usually influence the results of LCA study so the identification of an appropriate allocation method is crucial. Sensitivity analysis should be carried out in cases where the use of different allocation methods is possible to determine the influence of the allocation method on the results.

2.2.3 Phase 3: Life cycle impact assessment (LCIA)

The environmental impact of product derives from the processes into which it enters. It is the processes which exchange substances or energy with the surroundings and only if there is an exchange with the surroundings can be an environmental impact. An *exchange* with the environment is defined as and *input* to a process, an *output* from the process, or an internal interaction with an operator (a worker) of the process. Its main purpose is to translate the environmental burdens quantified in LCI into the related potential environmental impacts (or category indicators). This is carried out within the following three mandatory steps (Figure 2.5):

1. The selection of impact categories: category indicators and LCIA models must be consistent with the goal and scope of the LCA study and must reflect the environmental issues of the system under study.

2. Classification: involves aggregation of environmental burdens into a smaller number of environmental impact categories to indicate their impacts on human and ecological health and the extent of resource depletion. The identification of impacts of interest in then followed by their quantification in the next step.
3. Characterization step, as follow;

$$E_k = \sum_{j=1}^{j} e_{k,j} B_j$$

where $e_{k,j}$ represents characterization factor k for burden B_j showing its relative contribution to impact E_k. The characterization factors are calculated using appropriate LCIA models.

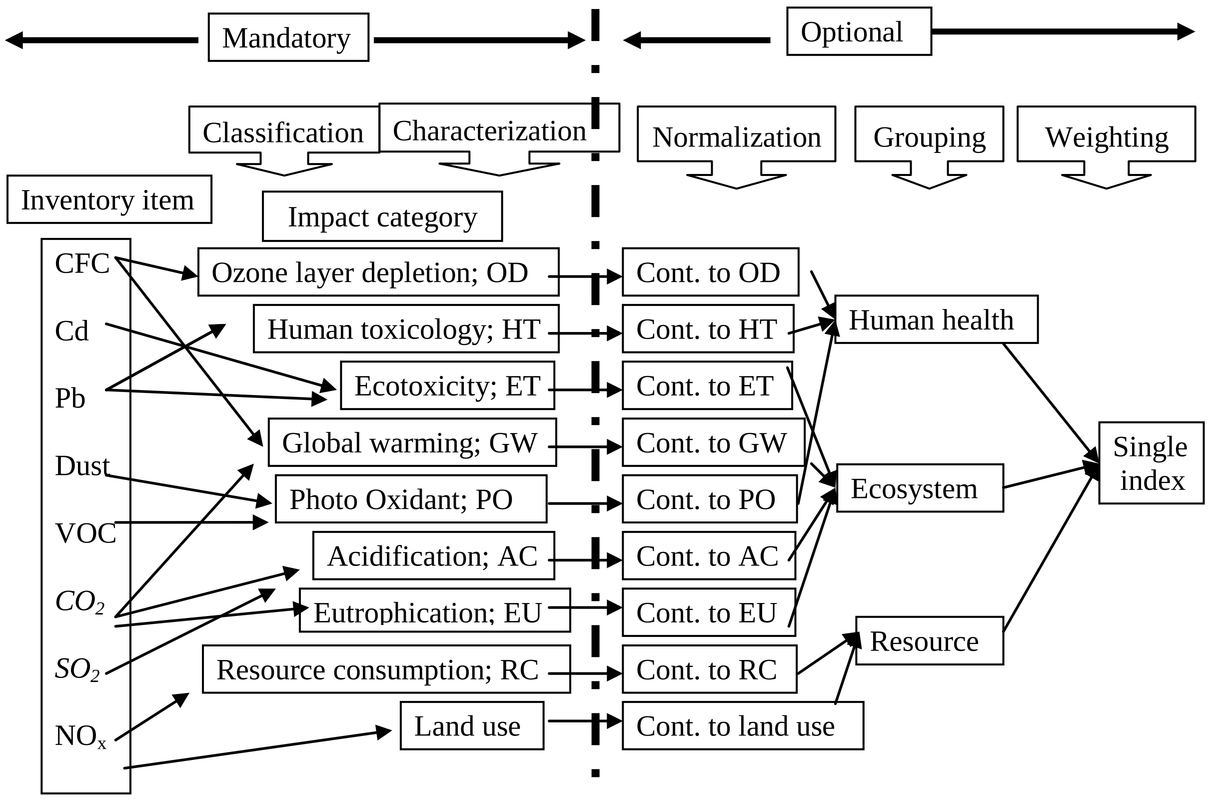

Figure 2.5 Life cycle assessment (ISO 14040, 2006)

A further three optional steps are also included within this phase. Those are *normalization; grouping; and weighting* of impacts. The impacts can be normalized with respect to the total emissions or extractions in a certain area and over a given period of time. This can help assess the extent to which an activity contributes to the regional or global environmental impacts. However, normalization results should be interpreted with care because of the lack of reliable data for many impacts at both the regional and global scales. Grouping involves qualitative or semi-quantitative sorting and - or ranking of impacts and it may result in a broad ranking or hierarchy of impact categories with respect to their importance. For example, categories could be grouped in terms of high importance, moderate importance and low priority issues. Some methods that include grouping are the verbal-argumentative approach and the ranking method.

The final stage within LCIA is weighting of impacts, often referred to as valuation. It involves assigning weights of importance to the impacts to indicate their relative importance. As a result, all impact categories are aggregated into a single environmental impact function (EI) as Follows:

$$EI = \sum_{k=1}^{k} w_k, E_k$$

where w_k is the relative importance of impact E_k. Weighting is probably the most controversial step of the methodology mainly because it involves social, political and ethical value choices. At present, there is no consensus on how to aggregate the environmental impacts into a single environmental impact function, or even on whether such aggregation is conceptually and philosophically valid.

2.2.4 Phase 4: Life cycle interpretation / improvement

The main objectives of this phase are to analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of LCI and/or LCIA. Quantification of environmental impacts carried out in LCI and LCIA enables identification of the most significant issues and life cycle stages that contribute to these issues. This information can then be used to target these ‘hot spots’ for system improvements or innovation.

Sensitivity analysis should be carried out before the final conclusions and recommendations of the study are made. Data availability and reliability are some of the main issues in LCA since the results and conclusions of an LCA study will be determined by the data used. Sensitivity analysis can help identify the effects that data variability, uncertainties and data gaps have on the final results of the study and indicate the level of reliability of the final results of the study (Dewulf and Langenhove, 2006; Wenzel, et al., 1997).

2.3 Environmental Impacts

The biodiesel from different crops has different yields and impacts on environment dependent on location, agricultural management, production processes and by-product / waste utilization efficiency (Kim and Dale, 2005). The environmental concerns relevant to biofuels currently are GWP, ADP and LUC as follows:

2.3.1 Global warming potential

This refers to the impact on radiative forcing from changes in atmospheric concentrations of greenhouse gases (GHGs) caused by human activities. GHGs are CO_2, N_2O, CH_4, CFC and SF_6. They have different potential of influencing global warming. CO_2, due to amount of them, is the most important and mainly from energy use. The potential for biofuels considered to be "carbon neutral" depends upon the carbon that is emitted being reused by further plant growth. Thus using biofuel as a liquid fuel for vehicle results in environmental credit for global warming. Nonetheless, there are many sources of CO_2 associated with biofuel production. More of the emissions come from production process of biofuel, fertilizer and oil extraction from seed (Kim and Dale, 2005; www.nbb.org/pdf.files/fuelfactsheet/lifecycle.summary.pdf). Figure 2.6 shows average emission impacts of biodiesel for heavy-duty highway engines.

2.3.2 Abiotic Depletion Potential

The term abiotic depletion can be described as quantitative aspects of non-renewable resource use; in this context is fossil fuel in form of crude oil. Fossil fuels have been the major source of energy since the industrial revolution; increasing usage has raised concerns as fossil fuels are limited resources and the rate of depletion is higher than that of production. Biofuel application could conserve crude oil consumption, non-renewable energy. It was found that using biofuels as transportation fuels help reduce crude oil consumption (www.nbb.org/pdf.files/fuelfactsheet/lifecycle. summary; Kim and Dale, 2005).

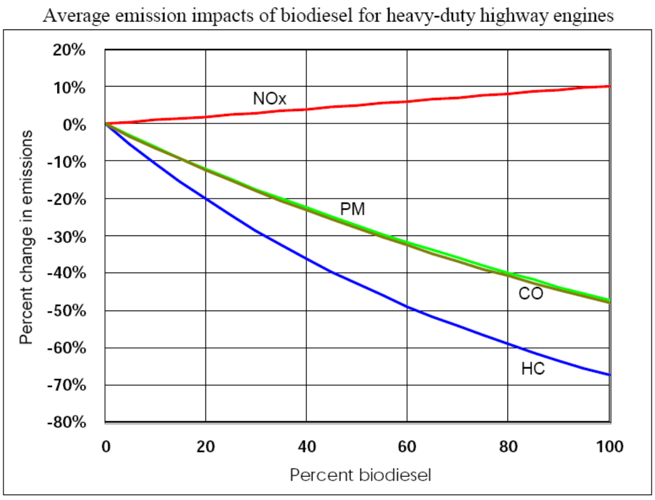

Figure 2.6 Average emission impacts of biodiesel for heavy-duty highway engines (US EPA, 2002)

2.4 Land use change

An increased demand for bioenergy affects the agricultural systems and food prices. When profit from biomass plantations exceed profit from food production, farmers will, if they behave as profit maximizers, respond by shifting toward energy crop cultivation unless agricultural commodity prices increase (Johansson and Azar, 2007; Schnepf, 2005). Because of the agricultural land constraint, there is a change in comparative benefits, which in turn leads to the change in the production structure of agricultural crops. The rise in price of the energy crops motivates the farmers to grow more energy crops (Johansson and Azar, 2007; Schnepf, 2005; Kløverpris et al., 2008a; Fritsche et al., 2010; Ubolsook, 2010). This change in the production structure indicates the Thai farmers based their decision on economic reasons; they shifted from growing low-return crops such as rice to higher value crops that are more profitable. 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 influencing oil palm plantation areas significantly 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 shift together with the rising trend in the price of fossil fuel gained support in many countries (Kongrithi and Isvilanonda, 2009).

Miyake et al., 2012 reviewed the patterns and dynamics of LUC associated with bioenergy crops (called bioenergy-driven land-use changes) focusing on four regions i.e. Brazil, Indonesia and Malaysia, the United States of America, and the European Union. They revealed that the bioenergy-driven land-use changes of the four regions have four pathways i.e. direct clearing of primary forests, savannas, and native grasslands to make way for bioenergy crop expansion, conversion of cattle pasture, conversion of existing cropland to bioenergy crop production and the conversion of marginal, degraded, or abandoned agricultural land to bioenergy crop production. However, farmers cannot choose freely to produce one crop rather than another since several constrains apply. These are constituted by climate conditions, soil properties, and crop rotation schemes. Oil palm requires soil with good drainage, flat and deep, pH between 4 and 7, water with even distribution of rainfall between 1,800 and 5,000 mm throughout the year. Low nutrients are needed but tropical and subtropical climate with temperature of 25-32^{o}C is required (Escobar et al., 2009; Salvatore and Damen, 2010).

Basically, there are three main mechanisms to increase the production of a specific crop: displacement of other crops, expansion of croplands, and intensification of existing production (Kløverpris et al., 2008b). The study of Salvatore and Damen, 2010 indicates that the increase in production in Thailand will come largely from the expansion of land in case of oil palm. The magnitude of such impacts essentially depends on the amount of biomass produced by ecosystems each year. Increase in demand for bioenergy has mainly two impacts due to land use change; direct impact for bioenergy itself and indirect impact for other crops. The impacts from land-use changes cause both environmental and socio-economic concerns (Miyake et al., 2012; Ubolsook, 2010). Susanto et al. (2008) analysed the impact of ethanol production on corn area planted using regression analysis, the area planted as a function of relative price ratio and competing commodities. Their study showed that a relatively large increase in corn prices led to substantial increases in corn acreage. Their results are consistent with the study of Ubolsook (2010) that developed a partial equilibrium econometric model to project the impacts of an increase in ethanol production on the Thai agriculture sector over the next ten years. The model is applied to three scenarios for analyzing the effect of government ethanol production targets. The results from the baseline model and scenario analysis indicated that an expansion in ethanol production increases cassava price. An increase in cassava price encourages increase in production while the production of other crops trend to decrease. The study also indicated that maize and sugarcane, which are the competing crops sharing land use are shifted for planting cassava. With reduction in production, the price of maize tends to rise in the future.

As a mitigation abatement for GHGs and replacement of petroleum products, biofuel use helps reduce global warming, abiotic resource depletion and increase farmer income. On the other hand, it causes increase in food price and land competition between food and energy. Furthermore, when competing crops are converted from food to energy, it causes less supply of such crops. Economically those converted crop prices may be higher and consequently, may affect positively those owning the remaining of those crops at the same time negatively to 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 change (Siangjaeo et al., 2011; Silalertruksa and Gheewala, 2012). In order to minimize land-use conflicts, the development of economically viable and environmentally sound options for making use of such land (also taking social implications into account) should be a priority for sustainable bioenergy (Fritsche et al., 2006).

2.5 Socio-economic impacts

It is anticipated that their use can reduce food surpluses and create demand for agricultural feedstock resulting in increasing of agricultural product prices. Consequently, farmers' incomes would be higher contributing positively to the Gross Domestic Product (GDP). Therefore, they can provide benefit to the national economy as well as society. CPO from FFB of oil palm is the main feedstock for biodiesel production in Thailand. However, CPO is primarily a feedstock for food and consumer products in various forms such as cooking oil for industry and household use, instant noodles, chemical products, etc. On the downside, biodiesel for energy would affect the prices of related commodities e.g. cooking oil, animal feed, etc. which use the same feedstock. Moreover, the rising prices of biofuel feedstock put pressure on producers to plant more of the biofuel crops and less of other crops (Dyer et al., 2010). According to

Finco and Doppler's study, the relationship between oil seed production and local food production is negative meaning that oil seed production diminishes local food production (Finco and Doppler, 2010).

In principle, it is anticipated that the use of CPO for biofuel production will increase feedstock prices mainly due to increases in feedstock demand (Ajanovic, 2011; Gheewala et al., 2013). However, estimating the contribution of biofuel production to food price increases is difficult (Ajanovic, 2011; Duer and Christensen, 2010). Several recently available analyses (Mitchell, 2008; Mueller et al., 2011) suggest that biofuel production has had a modest to relatively significant contribution (3–30%) to the increase in commodity food prices observed in 2007/2008. There are a number of factors that have contributed to the rise in food prices. Among these are the increase in energy prices and the related increases in prices of fertilizers and chemicals. Higher energy prices have also increased the cost of transportation, and increased the incentive to produce biofuels and encouraged policy support for biofuel production (Duer and Christensen, 2010). A World Bank report concluded that a stronger link between the prices of energy and commodities which is magnified in periods of high prices is likely to be the dominant influence on commodity (and food) markets (Baffes and Haniotis, 2010). The study by Timilsina, 2011 and colleagues reveals that the production of biofuels is highly sensitive to oil price. The share of biofuels in Thailand would reach around 10% in 2020 if oil price doubles from baseline values in 2009 (Timilsina et al., 2011). Biodiesel production cost has often been reported to be more than diesel; it is not able to compete with diesel if no subsidies are provided by the government (Andress et al., 2011; Bell et al., 2011; Silalertruksa et al., 2012). Zhang and colleagues reported that biodiesel costs are approximately one and a half times that of petroleum-based diesel depending on the feedstock oils (Zhang et al., 2003). Such policies result in direct social impacts within the country though indirect impacts may be felt elsewhere too; mainly on world commodity price (van der Horst and Vermeylen, 2011). The impacts of the biodiesel promotion policy can be both positive and negative on the value chain of palm oil associated products and to different groups of people. Though there have been some studies on the economic impact of biofuels, most have assessed their cost performances within the supply chain in order to evaluate different investment alternatives of either with or without or different processes/ feedstocks (Hanff et al., 2011; Silalertruksa et al., 2012; Varanda et al., 2011; Zhou et al., 2007). Moreover the study of Silalertruksa and colleagues also revealed that the stabilization of farmers' income and reduction of the country's dependence on oil imports are social benefits the country gained from biodiesel in Thailand (Silalertruksa et al., 2012). In setting the AEDP, the economic benefits gained for Thailand considered are reducing oil import and promoting investment from the private sector. However, the biodiesel promotion may also cause food price rise and loss to the national exchequer from subsidies which need to be assessed for a holistic view of the biodiesel promotion plan.

2.6 Sustainability assessment

It can be seen that biofuels have impacts in various perspectives which should be integratedly assessed for sustainability. Sustainability assessment is an extremely complicated and a challenging task due to the lack of a unique, objective, and commonly agreed methodology. Consequently, the definitions of system boundary, reference scenario, and other assumptions will have a significant impact on the results and are subject to significant uncertainties and sensitivities (Markevicius, 2010). Nonetheless, indicators are useful for presenting relatively complex situation in a simplified form to facilitate understanding (ERIA, 2008). In particular, sustainability indicators are essential in illustrating to policymakers and the public alike the relationship and trade-offs among the three dimensions of sustainable development.

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 services. Alternately, some invert the ratio, which then generally becomes known as eco-intensity. Marginal value may be used to determine relative performance among alternatives (Ehrenfeld, 2005). Because the needs of different users (policy makers, business managers, and consumers) differ quite dramatically, there is no “one size fits all” (Kuosmanen, 2005). In micro-level, LCA can be combined with approaches such as life cycle costing (LCC) or total cost of ownership for EE (Garbriel and Braune, 2005; Rüdenauer et al., 2005). The economic performance can also be income, net revenue, sales revenue, etc. while environmental performance can be 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 alternative governmental policies in the same way of an economy 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, the environmental impacts and the economic impacts both relate mainly to outputs of the activities involved in production, consumption, and disposal management. Of course, such input-output concepts might be subsumed under the eco-efficiency umbrella, leading to additional types (Huppes and Ishikawa, 2005a and b).

CHAPTER 3 METHODOLOGY

3.1 Phase 1: Impact on land use change

3.1.1 Goal and scope definition

The goals of the study are the following:

- to evaluate the effect of biodiesel demand on land use change for feedstock cultivation,
- 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),
- to assess the sustainability by integrating environmental and socio-economic impacts from the entire life cycle of biodiesel combining with those impacts arising from LUC.

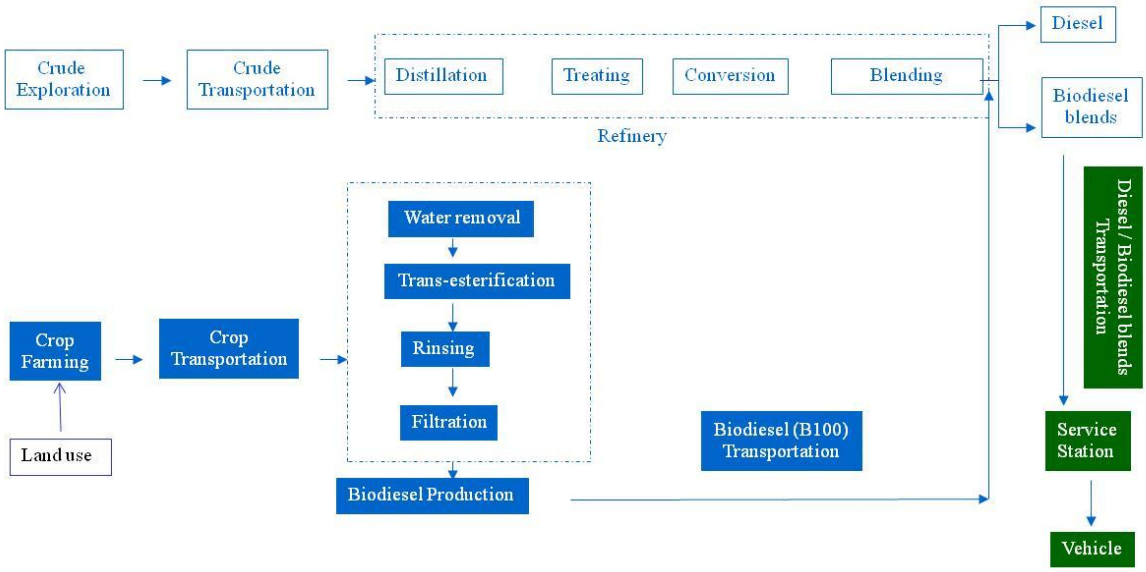

Figure 3.1 System boundaries for diesel and biodiesel

Functional unit: The amount of 21,000 million liters of biodiesel blends which is converted from the neat biodiesel (B100) demand per day targeted in AEDP serves as the functional unit. The blending ratios are 2%, 5% and 10% presented as B2, B5 and B10, respectively.

System boundary*:* In this study, the life cycle assessment of biodiesel blends, i.e. B2, B5, B10, are performed covering the stages of feedstock production, transportation, production process, product use and LUC as shown in Figure 3.1.

The environmental impacts under study are GWP and ADP while the socio – economic impacts of biodiesel blends include the currency saving, the farmer income, and the higher prices of the biodiesel, the bottled palm oil and the replaced crops. All aspects under this study are scoped in Thailand.

Technological scope*:* Petroleum production technology in this study is in so called complex refinery that combines the cracking section to the simple distillation section. And technology for biodiesel production both crude palm oil is what currently used in Thailand.

Temporal scope*:* The data/ situations under consideration cover year 2006 – 2012.

Spatial scope*:* The focus of the project is to assess sustainability of biofuels use in Thailand. The biodiesel plants, refining process and oil palm plantation under study are located in Thailand. In addition, diesel and biodiesel properties will be under Thai specification.

Allocation procedure: Inputs, outputs and the related environmental impacts can be allocated to products according to physical properties of the product flows (mass and energy flows). For energy, heating value is used for allocation whereas mass / volume allocation are used for others depending on availability of data.

3.1.2 Biodiesel induced changes in area and price

3.1.2.1 Area and price estimation

In order to evaluate the impacts of LUC either on environment or socio-economics, change in areas and prices have to be estimated. Firstly, the 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 in negative sign (Kim and Dale, 2011). 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 (details in Appendix A). Secondly, the 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 as shown in the framework of LUC equation system (Figure 3.2).

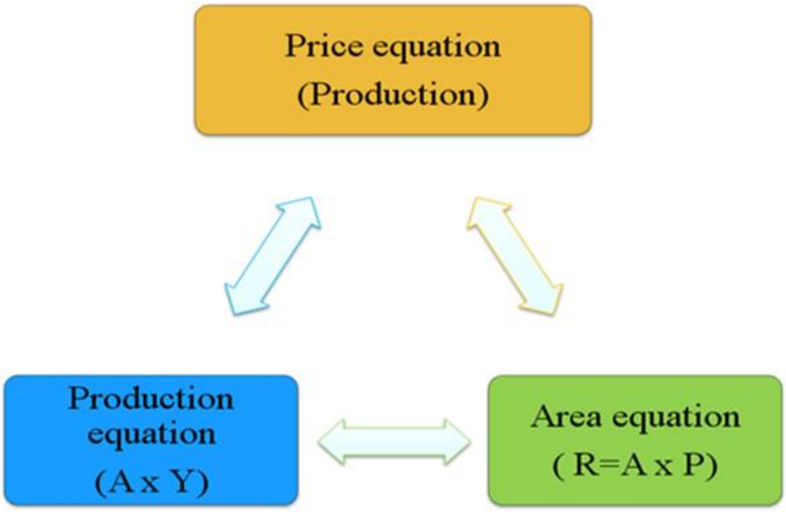

Figure 3.2 Framework of LUC equation system

3.1.2.2 Planted area equation system

The interplay between sectors and regions is determined by so-called elasticity expressing the relative change in one variable caused by the change in another variable. An economic model represents an economic equilibrium (supply equals demand). A change in the economy (e.g. increased crop demand) can be studied by adjusting the relevant model parameters to simulate the change of interest. The model then adapts to the new conditions by establishing a new economic equilibrium. This adaptation is driven by price signals resulting in production changes in the different sectors. If the 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 (Kløverpris et al., 2008a).

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 previous year's return of oil palm, competitive crop prices and their planted areas (Eq. 3.1) (Leaver, 2004; Eaur-amnuay, 2005; Ubolsook, 2010; Imai et al., 2011). The expected sign of the crop area response to palm return is negative.

$$PA_{i,r,t} = f(R_{i,r,t-1}, R_{palm,r,t-1}, PA_{i,r,t-1}, T)$$

$$= h_0 + h_1 R_{i,r,t-1} + h_2 R_{palm,r,t-1} + h_3 PA_{i,r,t-1} + h_4 T + \varepsilon_h \quad (3.1)$$

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 time trend

ε is the error term

3.1.2.3 Production equation system

Price determination is simply as it will relate with its own demand and supply. The expected sign follows the economics theory, demand side will shift the price rise (+) in the same way and supply side will force the price down (-). Crop production equals harvested area times crop yield (Eq. 3.2). 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. 3.3.

$$\mathrm{Pr}_{i,r,t} = \mathrm{Y}_{i,r,t} \times \mathrm{HA}_{i,r,t} \quad (3.2)$$

$$\mathrm{HA}_{i,r,t} = a_{i,r,t} \times \mathrm{PA}_{i,r,t} \quad (3.3)$$

where

$Pr_{i,r,t}$ is the production of crop i, region r, year t (Mton)

$Y_{i,r,t}$ is the yield of crop i, region r, year t (Mton/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; $0 \leq a_{i,r,t} \leq 1$

$PA_{i,t}$ is the planted area of crop i, year t (Mha)

3.1.2.4 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 for energy demand, the biodiesel demand for food is assumed to be constant while the demand for energy is based on AEDP. The supply is determined by the production as stated in Eq. 3.2. The equilibrium price is a function of demand and supply as presented in Eqs. 3.4 – 3.6.

$$Q^D_i = f\,(Price_{i,t}) \quad (3.4)$$

$$Q^S_i = f\,(Price_{i,t}) \quad (3.5)$$

$$Q^D_i = Q^S_i \quad (3.6)$$

where

$Price_{i,t}$ is the price of crop i in year t (THB/ton)

Q^S_i is the supply of crop i in year t

Q^D_i is the demand of crop i in year t

3.2 Phase 2: Environmental impact assessment

3.2.1 Life cycle inventory

Inventory analysis involves data collection and calculation procedures to quantify the relevant inputs and outputs of a product system. Those in each stage in system boundary which can be resources, materials, energy, ancillary substances, products /co-products, and emission to water / air and waste are considered. Since there have been a number of studies on LCA of biofuels in Thailand, the data can be obtained from those studies. Missing data are obtained from literature, calculation and field interview. The details of information sources are illustrated in Table 3.1

Table 3.1 Information sources

Data	Source of data
Crude extraction	Eco-invent: Crude oil production Middle East Onshore
Crude transportation	BCP, 2007
Refining process	BCP, 2007
Diesel/ biodiesel blends transportation	BCP, 2007
Diesel, biodiesel end use	Secondary data from PTT
Oil palm plantation	Vanichseni, 2002
Biodiesel price, supply	Development and Efficiency , 2007 http://www.dede.go.th
FFB transportation,	Department of Alternative Energy http://www.dede.go.th
Environmental impact of biodiesel	Silalertruksa and Gheewala, 2013
Biodiesel for energy consumption	Department of Energy Business, Ministry of Energy; http://www.doeb.go.th
Bottled palm oil price	Department of Internal Trade, Ministry of Commerce; http://trade.dit.go.th
Bottled palm oil production and consumption,	Office of Industrial Economics, Ministry of Industry; http://www.oie.go.th/
Crude palm/ soybean oil production cost, price and consumption	Office of Industrial Economics, Ministry of Industry; http://www.oie.go.th/
Exchange rate and crude oil price	http://www.indexmundi.com/
Farmer income, oil palm production, cost and price, land use	Office of Agricultural Economics, Ministry of Agriculture and Cooperatives http://www.oae.go.th/
Petroleum price, consumption and subsidy	Energy Policy and Planning Office, Ministry of Energy http://www.eppo.go.th\statistics

The inventory of each individual terminal exchange can be expressed as:

$$Q_i = T.\Sigma Q_{i,up} + T/L\ \Sigma\ Q_{i,,p}$$

where Q_i = sum of terminal exchanges i computed per functional unit

T = duration of functional unit (years)

L = life span of the product (years)

$Q_{i,p}$ = the terminal exchange from process i computed per the number of key units of the process entering into the product system; (p) designates all processes

$Q_{i,up}$ = the terminal exchange per annum from the use process (up) including the process specified by all of the use process's non-terminal exchanges

3.2.2 Life cycle impact assessment

The main reasons of biofuels promotion include, but are not limited to, energy security and climate change mitigation (DEDE, 2012; Awudu and Zhang, 2012). The energy security can be assessed in term of abiotic resource depletion potential while climate change can be assessed in terms of global warming potential. The characterisation of ReCiPe (ReCiPe , 2008) is used in the study to assess those two environmental impacts.

3.2.2.1 Global warming potential (GWP); equals to the sum of emissions of greenhouse gases (CO_2, CH_4, N_2O, CFCs) multiplied by their respective GWP factors, GWP_j:

$$GWP = \sum_{j=1}^{J} GWPjBj \qquad (\text{kg } CO_2 \text{ eq.})$$

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 GWPs 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 dLUC can be determined from the carbon balances of previous land use and the land use for biocrops (The total GHG emission (GHG_{Total}) is the sum of GHG emission caused by the biodiesel production life cycle without LUC ($GHG_{without\ LUC}$) and the GHG emission from LUC (GHG_{LUC}). The method and default data used for the calculation of emission from LUC is based on the 2006 IPCC Guidelines (IPCC, 2006).

$$GHG_{Total} = GHG_{without\ LUC} + GHG_{LUC} \quad (3.7)$$

$$GHG_{without\ LUC} = \sum (GHG_{Feedstock}, GHG_{Prod}, GHG_{Trans}, GHG_{End\ use}) \quad (3.8)$$

$$GHG_{LUC} = \sum (\%\ \text{change in}\ A_i \times A_{i,2006} \times GHG_{conversion\ i\ to\ palm}) \quad (3.9)$$

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)

$GHG_{conversion\ i,\ palm}$ is the net GHGs from shifting crop *i* to oil palm (ton CO_2 eq/yr)

3.2.2.2 Abiotic resource Depletion Potential (ADP)*;* includes depletion of fossil fuels, metals and minerals. The total impact is calculated as:

$$ADP = \sum_{j=1}^{J} ADPjBj \qquad \text{(kg oil eq.)}$$

where B_j is the quantity of abiotic resource j used and ADP_j represents the abiotic depletion potential of that resource. This impact category is expressed in kg oil eq. The ADP is derived from the conversion of fossil fuels and all forms of energy into crude oil. There is no ADP in LUC due to insignificance relative to ADP without LUC.

3.3 Phase 3: Socio-economic perspectives

The prices of palm oil associated commodities affected by biodiesel promotion plan are estimated. Then the net socio-economic impact of Thai energy policy for biodiesel to the country is analyzed. In this study, bottled cooking palm oil hereafter called BPO is focused on in terms of the non-biodiesel commodity affected by biodiesel for energy since about 60% of total refined palm oil is used for food as cooking oil (Chuanruktham, 2007). The biodiesel blending ratios under the study are 2%, 5%, and 10% (referred to as B2, B5 and B10 respectively). The positive impacts consist of currency saving (oil import reduction) and increase in farmer income while the negative impacts are BPO and biodiesel price rise.

3.3.1 Price estimation

Fundamentally, a commodity price is determined by supply and demand which relates price and quantity (Leftwich, 1979; Samuel, 1973). To estimate the change in oil palm price with increase in demand of palm oil for energy, the demand and supply of three associated markets shown in Figure 3.3 are modeled. Those are the markets of oil palm (i.e. FFB), crude palm oil (CPO) and biodiesel (B100). The basic equations of the demand and supply are presented in Eqs. 3.4 - 3.6. Unlike Malaysia and Indonesia which are the main palm oil exporters accounting for roughly 90% of both global production and global trade in palm oil (Shri Dewi et al., 2011; Thoenes, 2006), imports and exports of palm oil in Thailand are rather modest and have been regulated by the government; thus, the price of palm oil mainly depends on the domestic market (Apinyanon, 2007). This is supported by Yang's report (Yang et al., 2009) that the impacts of biofuel development in the Greater Mekong Sub-region (GMS) covering Cambodia, Lao PDR, Myanmar, Thailand and Vietnam on the world prices of agricultural commodities are minimal. The domestic price of biodiesel is more stable than international price of petroleum (Bell et al., 2011; Yang et al., 2009). Hence the import, export and related international trade variables are excluded in this study.

$$Q^D_x = f(P_x) \quad (3.10)$$

$$Q^S_x = f(P_x) \quad (3.11)$$

where

x is commodity

Q^D_x is commodity demand (Mton)

Q^S_x is commodity supply (Mton)

P_x is commodity price (THB/kg)

3.3.1.1 Oil palm or FFB Market

Supply of the commodity depends on the lagged supply, lagged price. Lagged price and change in inventory can be used to explain the price (Shri Dewi et al., 2011). The supply of oil palm herein after called FFB (fresh fruit bunch) is assumed to depend on FFB farm gate price which farmers obtain from their products at year‘t’ and FFB farm gate price lag 3 years (Bateman, 1968; Shri Dewi et al., 2011). The demand of FFB price at the palm oil extraction mill year't' and the crude palm oil price are assumed as variables. Oil palm supply and demand can be specified as follows;

$$Q^S_{FFB}\,(P_{FFB,fg},\,P_{FFB,fg,\,t-3}) = a_0 + a_1\,P_{FFB,fg} + a_2\,P_{FFB,fg,\,t-3} + \varepsilon_a \quad (3.12)$$

$$Q^D_{FFB}\,(P_{FFB,em},\,P_{CPO,domestic}) = b_0 + b_1\,P_{FFB,em} + b_2\,P_{CPO,domestic} + \varepsilon_b \quad (3.13)$$

where

Q^S_{FFB} is the FFB supply (Mton)

Q^D_{FFB} is the FFB demand (Mton)

$P_{FFB,fg}$ is the current price of fresh fruit bunch sold at farm gate (THB/kg)

$P_{FFB,fg,\,t-3}$ is the price of fresh fruit bunch sold at farm gate lag 3 years (THB/kg)

$P_{FFB,em}$ is the current price of fresh fruit bunch sold at extraction mill (THB/kg)

$P_{CPO,domestic}$ is the current domestic price of crude palm oil (THB/kg)

ε is error term

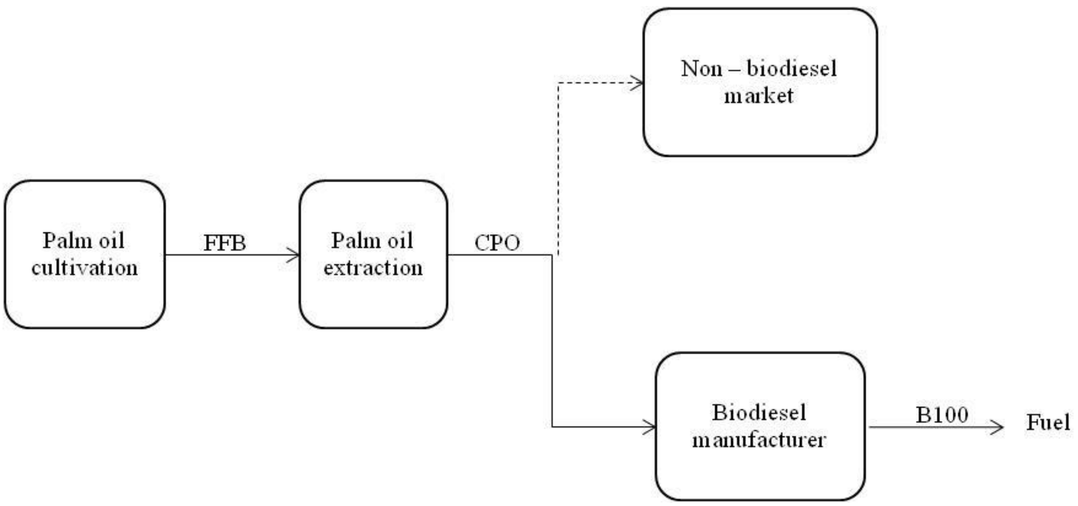

Figure 3.3 Schematic diagram of biodiesel associated market under study

3.3.1.2 CPO Market

From Figure 3.2, CPO is used for biodiesel and non-biodiesel purposes. Domestic demand is assumed to depend on the real domestic price of CPO from biodiesel and non-biodiesel use, CPO import in addition to economic activity represented by GDP and domestic price of soybean oil which is a substitute for palm oil. The demand and supply of CPO can be presented as follows;

$$Q^{S}_{CPO}\,(P_{CPO,domestic},\, P_{FFB,em}) = c_0 + c_1\, P_{CPO,domestic} + c_2\, P_{FFB,em} + \varepsilon_{c} \qquad (3.14)$$

$$\begin{aligned} Q^{D}_{CPO} &= Q^{D,bio}_{CPO}\,(P_{CPO,domestic},\, P_{CPO,import},\, P_{B100,CPO}) \\ &\quad + Q^{D,non\text{-}bio}_{CPO}\,(P_{CPO,domestic},\, P_{CPO,import},\, P_{SBO},\, GDP) \\ &= (d_0 + d_1P_{CPO,domestic} + d_2P_{CPO,import} + d_3P_{B100,CPO} + \varepsilon_{d}) \\ &\quad + (e_0 + e_1P_{CPO,domestic} + e_2P_{CPO,import} + e_3P_{SBO} + e_4\, GDP + \varepsilon_{e}) \qquad (3.15) \end{aligned}$$

where

$Q^{D,bio}_{CPO}$ is the CPO demand for biodiesel (Mton)

$Q^{D,non\text{-}bio}_{CPO}$ is the CPO demand for non-biodiesel uses (Mton)

$P_{CPO,import}$ is the CPO import price (THB/kg)

$P_{B100,CPO}$ is the price of B100 produced from CPO (THB/kg)

P_{SBO} is the soybean oil price (THB/kg)

GDP is the gross domestic product

3.3.1.3 B100 Market

The domestic and import prices of CPO are assumed to be the variables of B100 supply in Eq. 3.16 as well as the trend which indicates season output. During seasonal output, the CPO price is expected to decline due to oversupply. Biodiesel (Bi) is the composition of the neat biodiesel (B100) and conventional diesel. The proportion of each component is varied by the Government regulation. Thus the demand of B100 depends on the domestic price of B100 and crude oil, main material for the conventional diesel. Besides, GDP representing the economic activity is included (Eq. 3.17).

$$\begin{aligned} Q^{S}_{B100}\,(P_{B100},\, P_{CPO,domestic},\, P_{CPO,import},\, ,T) &= f_0 + f_1P_{B100} + f_2P_{CPO,domestic} + f_3P_{CPO,import} \\ &\quad + f_4\, T^{S} + \varepsilon_{f} \qquad (3.16) \end{aligned}$$

$$Q^{D}_{B100}\,(P_{B100},\, P_{crudeoil},\, GDP,\, T) = g_0 + g_1P_{B100} + g_2P_{crudeoil} + g_3GDP + g_4\, T^{D} + \varepsilon_{g} \qquad (3.17)$$

where

T^{S} is the trend representing season output

T^{D} is the consumer preference

$P_{crudeoil}$ is the crude oil price (THB/kg)

To obtain the relationship between the FFB farm gate prices (P_{FFB}) and the biodiesel demand (Q^D_{B100}), FFB market is set in equilibrium (Eq.3.18) using time series data from 2007 to 2011 on monthly basis. The multiple regression analysis and ordinary least squares (OLS) method is employed to estimate the coefficients.

$$Q^S_{FFB} = Q^D_{FFB} \tag{3.18}$$

The neat biodiesel price has been determined by the Energy Policy Management Committee (EPMC). According to the latest EPMC resolution, the biodiesel price formula is stated in Eq. 3.19. Since biodiesel can be derived from various forms of palm oil, the biodiesel price is calculated as stated in Eq. 3.20.

$$P_{B100} = 0.94P_{CPO} + 0.1P_{MeOH} + 3.82 \tag{3.19}$$

$$P_{B100} = \frac{(P_{B100,CPO} * Q_{CPO}) + (P_{B100,RBD} * Q_{RBD}) + (P_{B100,ST} * Q_{ST})}{Q_{Total}} \tag{3.20}$$

where

P_{MeOH} is the methanol price (THB/kg)

$P_{B100,CPO}$ is the price of biodiesel derived from crude palm oil (THB/L)

$P_{B100,RBD}$ is the price of biodiesel derived from RBD (THB/L)

$P_{B100,ST}$ is the price of biodiesel derived from palm oil stearin (THB/L)

Q_{CPO} is the biodiesel quantity produced from CPO in 1 previous month (ML/d)

Q_{RBD} is the biodiesel quantity produced from RBD in 1 previous month (ML/d)

Q_{ST} is the biodiesel quantity produced from ST in 1 previous month (ML/d)

RBD is the refined bleached and deodorized palm oil

ST is the palm oil stearin

The equation system of price estimation runs simultaneously as shown in the framework presented in Figure 3.4.

3.3.2 Currency saving

For a petroleum importing country, biodiesel production can lower crude oil to be imported (Urbanchuck, 2006; van Dyne et al., 1996). The currency saved due to crude oil import reduction would vary depending on the amount of crude oil replaced. The currency saving can be estimated as stated in Eqs. 3.21 - 3.22.

$$CS = Q_{crudeoil} \times P_{crudeoil} \quad (3.21)$$

$$Q_{crudeoil} = Q_{diesel} \times CF_{crudeoil} \quad (3.22)$$

where

CS is the currency saving in MTHB/yr

$P_{crudeoil}$ is the crude oil price in THB/L

$Q_{crudeoil}$ is the quantity of crude oil saved in ML/yr

Q_{diesel} is the quantity of diesel substituted in ML/yr

$CF_{crudeoil}$ is the conversion factor from crude oil to diesel

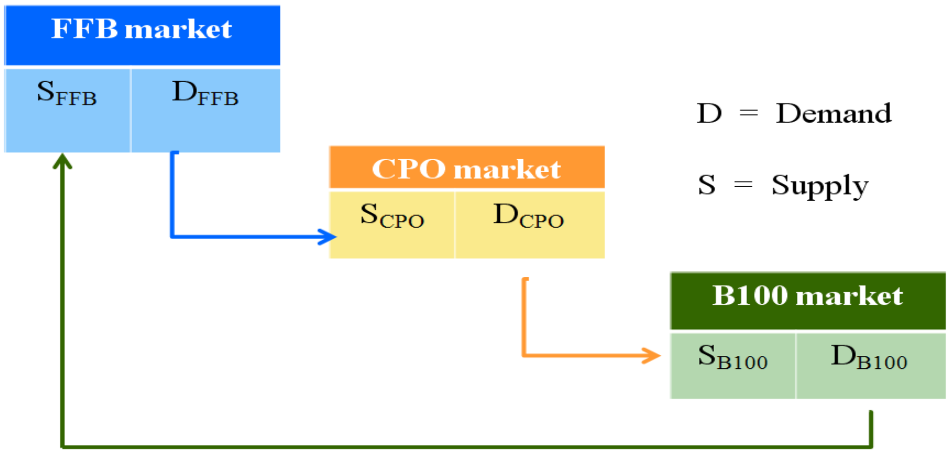

Figure 3.4 Framework of price estimation equation system

3.3.3 Farmer income

As the demand of palm oil increases with increasing production of biodiesel for energy, it is anticipated that the FFB price would rise and the farmers would have more income. To evaluate the effect of biodiesel demand on farmers' incomes, the increase in FFB price with increasing biodiesel demand is considered as benefit of biodiesel promotion to farmers. It is assumed that there is no change in the factors affecting farmers' income except income from increase in FFB price. The models are indicated in Eqs. 3.23.

$$FI = P_{FFB}B_i \times Q_{FFB} \quad (3.23)$$

where

FI is the farmer income in MTHB/yr

Q_{FFB} is the FFB quantity in Mton

$P_{FFB}B_i$ is the FFB price for blending ratio *i* % in THB/kg

3.3.4 BPO price rise

The increase in biodiesel demand would tend to shift the commodity price upward. It is assumed that the additional burden to consumers in the whole country due to the commodity price rise results in higher expenditure consequently; lower amount of money for other needs e.g. better education, houses, entertainment, etc. Therefore the change in BPO price due to increase in biodiesel demand is considered as a social impact or public loss. The impact of biodiesel to consumers is estimated from the difference in the estimated BPO price when there was no biodiesel (B0) and the specified blending ratio (B2, B5, B10). However, to alleviate consumers' burden, the RTG has set ceiling retail price for the BPO causing losses to cooking oil manufacturers. Thus, when the BPO retail price is higher than the ceiling or controlled price, one part of the impact, the value of BPO retail price between the price of base year and the ceiling price, belongs to the BPO consumers considered as public impact and the other part, the value of the BPO retail price exceeding the ceiling price, belongs to the BPO producers considered as private loss (Lam Soon, 2007; 2010). The public and private loss from rise in the BPO retail price can be presented in Eqs. 3.24 - 3.25.

$$E_{BPO}^{Public} = (\text{controlled } P_{BPO}B_i - \text{estimated } P_{BPO}B_0) \times Con_{BPO} \quad (3.24)$$

$$E_{BPO}^{Private} = (\text{estimated } P_{BPO}B_i - \text{controlled } P_{BPO}B_i) \times Con_{BPO} \quad (3.25)$$

where

E_{BPO}^{Public} is the expenditure from BPO to the public in MTHB/yr

$E_{BPO}^{Private}$ is the expenditure from BPO to the private sector in MTHB/yr

$P_{BPO}B_i$ is the BPO price for blending ratio *i* in THB/L

$P_{BPO}B_0$ is the BPO price base case in THB/L

Con_{BPO} is the BPO consumption in ML/yr

3.3.5 Biodiesel blend prices

Biodiesel is generally more expensive than traditional fossil fuels. As a result, when biodiesel is blended into diesel, the production cost and finally the retail price is higher. The retail price is the price at which consumers purchase fuel at petrol service stations.

For Thailand, the retail price structure is composed of ex-refinery price plus marketing margin, excise tax, municipal and VAT, oil and energy conservation funds (ENCON). The Oil Fund comprises of a monetary reserve that will be used to maintain domestic retail price level at a set ceiling in times when global petroleum prices soar by subsidizing domestic oil producers and importers (EPPO, 2012a) while the ENCON Fund has been imposed directly for the purpose of generating money for solving energy related environmental problems, and also to promote sustainable use of energy. The Fund is a fixed rate charged per litre. It is announced by the Energy Policy and Planning Office (EPPO) on an irregular basis depending on influencing circumstances. Oil fund and energy conservation fund for diesel are set at 0.20 and 0.25 THB/L (EPPO, 2012b). The optimal marketing margin for diesel or biodiesel is 1.50 THB/L (Apinyanon, 2007). The retail price of biodiesel can be calculated as expressed in Eq. (3.26). The impact of biodiesel from higher price estimated from the difference in the conventional diesel price and the estimated biodiesel price at the specified blending ratio (B2, B5, and B10) multiplied by the total consumption per year as expressed in Eq. 3.27. Like the BPO price, the retail price of diesel has been controlled not to exceed 29.99 THB/L. Hence, one portion is allocated to the consumers' expense; the other is the government's subsidy. However both are considered as public loss.

$$P_{Bi} = [[(exP_{diesel} \times Br_{diesel}) + (P_{B100} \times Br_{B100}) + taxes + funds] \times VAT\ ] + MM \tag{3.26}$$

$$E_{biodiesel}^{\ Public} = P_{Bi} \times Con_{Bi} \tag{3.27}$$

where

P_{Bi} is the biodiesel price in *i* ratio (THB/L)

exP_{diesel} is the ex-refinery price of diesel (THB/L)

P_{B100} is the price of B100 (THB/L)

VAT is the value added tax (7 %)

MM is the marketing margin (THB/L)

Br_{diesel} is the diesel blending ratio (%)

Br_{B100} is the B100 blending ratio (%)

Con_{Bi} is the consumption of biodiesel (ML)

$E_{biodiesel}^{\ Public}$ is the expenditure from biodiesel to public in MTHB/yr

The socio – economic impact excluding LUC ($SEI_{without\ LUC}$) is the difference in the sum of positive and negative impacts. It can be modeled as in Eq. 3.28.

$$SEI_{without\ LUC} = \sum (CS, FI) - \sum (E_{BPO}, E_{biodiesel}) \quad (3.28)$$

where

CS is the currency saving in MTHB

FI is the increase in farmer income in MTHB

E_{BPO} is the expenditure from BPO price in MTHB

$E_{biodiesel}$ is the expenditure from biodiesel price in MTHB

When the other competing crops are replaced, it causes less supply of such crops. Economically those crop prices may be higher and consequently, may affect positively to the remaining of those crops' owners at the same time negatively to consumers. The socio – economic impact arising from the land use change is combined with socio – economic impact resulting from biodiesel blend production. The sum of the net socio – economic impact in palm oil market and the economic impact from the replaced crop price rise causing from the AEDP plan is the economic performance for sustainability assessment. The total socio – economic impacts (SEI_{Total}) as stated in Eq. 3.29 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}), (Eq. (3.30)).

$$SEI_{Total} = SEI_{without\ LUC} + SEI_{LUC} \quad (3.29)$$

$$SEI_{LUC} = \sum (P_{i,}^{after\ conversion} \times Q_{i}^{after\ conversion}) + (P_{palm,}^{after\ conversion} \times Q_{palm}^{after\ conversion}) \quad (3.30)$$

$P_{i,}^{after\ conversion}$ is the price of crop i after conversion (THB/ton)

$Q_{i}^{after\ conversion}$ is the crop i production after conversion (Mton)

3.4 Phase 4: Sustainability assessments

The sustainability indicator used in this study to integrate environmental, social and economic dimensions is eco-efficiency. The socio-economic impact is applied for the socio-economic performance and presented as the numerator of eco-efficiency while either GWP or ADP is applied for environmental performance, the denominator of eco-efficiency, as eco-efficiency$_{GWP}$ and eco-efficiency$_{ADP,}$ respectively. For assessing the effect of biodiesel, both the socio-economic and environmental performances are in form of change relative to diesel (Eq. 3.31 and 3.32).

$$\text{Eco-efficiency}_{GWP} = \Delta \frac{\text{SEI}Total}{\text{GWP}Total} \tag{3.31}$$

$$\text{Eco-efficiency}_{ADP} = \Delta \frac{\text{SEI}Total}{\text{ADP}Total} \tag{3.32}$$

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, Radar diagram (ERIA, 2008).

CHAPTER 4 RESULTS AND DISCUSSION

This section shows the results of biodiesel promotion as targeted in AEDP on (1) crop area and price change, (2) environmental impact i.e. GWP and ADP of biodiesel blends along its life cycle without and with LUC, (3) socio- economic impacts of biodiesel blends without and with LUC, and (4) sustainability assessment of the biodiesel blends combined with land use change comparing to conventional diesel.

4.1 Biodiesel production system

4.1.1 Oil palm plantation

Oil palm starts bearing bunches 2 ½- 3 years after field planting. The plantation has 21-22 trees per rai (1 ha=6.25 rai), and yields at 2.7-2.8 ton FFB per rai per year. The fertilizer used varies from nutrient need at each period of growing. The formula of 21-0-0, 0-46-0 and 0-0-60 in the forms of N, P_2O_5 and K_2O fertilizer, respectively are applied resulting in oil yield at 18% of FFB and production of 3 ton /rai. This rate of production is considered as suitable land for oil palm plantation (Vanichseni et al., 2002). The interventions from seed production have been regarded as insignificant for oil palm cultivation. Several pesticides are used in oil palm cultivation. On a mass basis glyphosate comprises 88% of the active ingredients in the used pesticides in mature oil palm plantation (Eongprkornkeaw, 2006).

Figure 4.1 presents the exchanges for 1 ton FFB in oil palm. The 9.88 kg of seed is required to obtain 1 ton of Fresh Fruit Bunch (FFB). The various kinds of fertilizer are applied in the amount of 0.28, 17.84, 0.56 and 8.80 kg for glyphosate, K_2O,P_2O_5 and N, respectively.

4.1.2 Oil palm (FFB) transportation

The frequency of a harvesting round is 10-15 days or 2-3 times a month. The FFBs are generally transported to palm oil mill on the day of harvesting. They are manually harvested and transported to palm oil mill by 10 wheel truck at the round trip distance of 68 km. The details of oil palm transport are shown in Table 4.1.

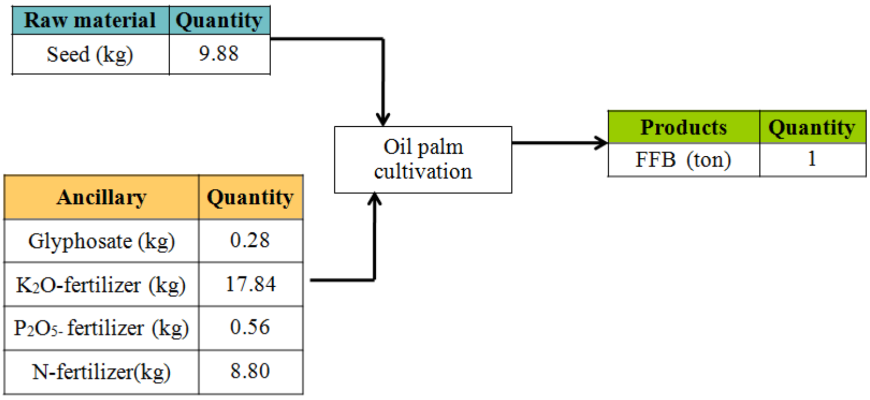

Figure 4.1 Exchanges for oil palm cultivation (Vanichseni, 2002)

Table 4.1 Oil palm (FFB) transport

Type of transport	Round trip distance (km)	Fuel economy (km/l)
10 wheel truck	68	4

Source: DEDE, 2007

4.1.3 Crude Palm oil (CPO) production

There are 2 types of palm oil mills: dry processing mills and wet processing mills. The palm oil mill is utilizing the standard wet production processes. The wet process differs from the dry process with respect to the oil extraction stage: the wet process applies large amounts of hot water and steam to convert palm fruits into a homogeneous oily mass before feeding into the continuous screw press to extract the palm oil. For the wet process, the extraction of palm oil from FFB involves 5 major operations - sterilization, fruit separation, digestion, oil extraction and oil purification shown in Figure 4.2 (Vanichseni et al., 2002).

- **Loading ramp**: The FFBs are transported and unloaded at the mill. After being weighted, the fruits have to be stored for a time until they can enter the first stage of processing.
- **Sterilization:** Sterilization of the FFBs is done batch wise in an autoclave with the application of steam at 120 –140 °C for 75 min. The objectives of the sterilization are to prevent the formation of fatty acids, to facilitate stripping of fruits, and to prepare the fruit fiber for subsequent processing.

- **Threshing**: The container with the sterilized bunches are unloaded into a rotary drum thresher where the fruits are separated from the bunch stalks. This process generates the Empty Fruit Bunches (EFB).
- **Digestion:** The separated fruits are put into digesters and screw press to separate oil from nuts and fibers. There are two process lines after this stage. One is for palm oil, liquid line. The other is solid line for nuts and fibers.
- **Palm oil purification**: palm oil from the digester still consists of water and impurity. They are separated with steam in clarifiers. Palm oil is skimmed and purified in purification tank and vacuum dryer prior to storing in storage tank as CPO. The CPO is transported to palm oil refinery for B100 production. The separated purity in form of sludge then passes through sand cyclone and decanter coming out as decanter cake which is sold as animal feed. Wastewater is sent to wastewater treatment.
- **Nut/ Fiber Separation**: the fiber and nuts from the screw press are separated in a cyclone. The fiber is used as boiler fuel while nuts are further cracked.
- **Nut Cracking**: the nuts are cracked in a centrifugal cracker. After this cracking process, the kernels and shells are separated by clay bath. The separated shells are sold to other mills as fuel. The kernels, co-product, are sent to the kernel drying process in a silo dryer for sale (for further extraction) to other mill.
- **Wastewater treatment**: the wastewater from the above processes is treated with anaerobic and aerobic processes in series. The first 6 ponds are anaerobic digestion ponds following with 5 ponds of aerobic treatments. The treated effluent is used as cooling water and oil palm watering.

The raw materials needed for production processes are FFB, lime, alum, anionic polymer, diesel oil, NaCl, electricity and water. Lime is used for preparing the solution to separate the shell from palm kernel. Alum and anionic polymer are used in the water treatment plant before introducing into the production process. Electricity is the main energy source for the mill. The electricity is obtained from a turbine generator using EFB, fiber and shell materials, by-products/solid waste as solid fuel and fuelled with diesel for start up. Thus, Palm oil mills are generally self-sufficient in terms of energy due to the availability of adequate quantities of fuel. Nevertheless, the electricity of the mill is generated only at sufficient level. The main sources of wastewater are from the sterilization and the oil separation process. The combined wastewater from the production process has a high organic content. After the wastewater is treated in anaerobic, main source of methane, and aerobic ponds, it is discharged to the palm field (Vichitbhun, 2007).

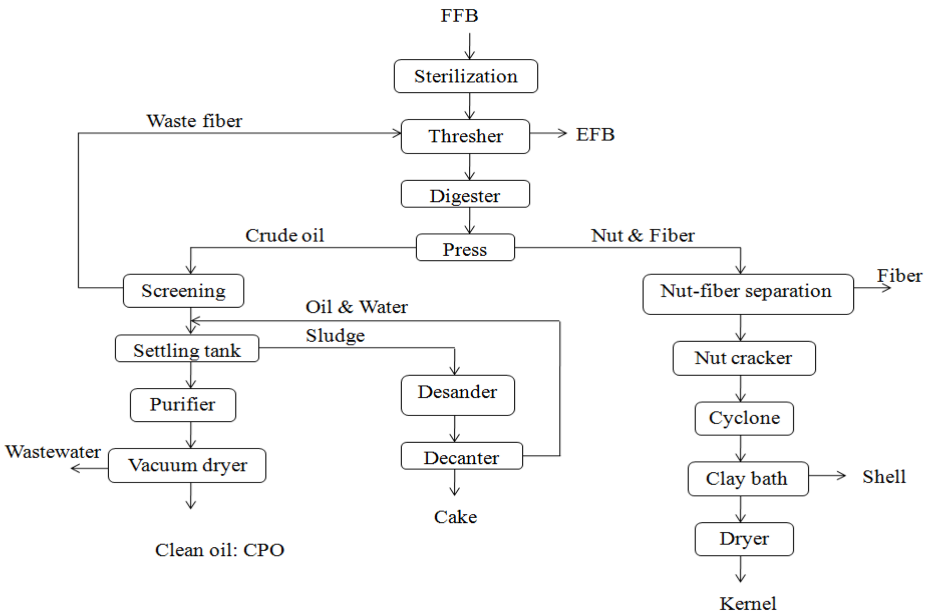

Figure 4.2 Flow diagram of palm oil mill

Wastewater from this process contains some solid wastes, greases, and high COD and BOD thus needs to be treated before release. The anaerobic pond is a part of wastewater treatment, methane generated during the treatment process is released into the atmosphere due to no biogas-trapping system. Methane emission was estimated by using the equation adopted from a study under Clean Development Mechanism (CDM) and presented in the study of Siangjaeo et al., 2011, as follows:

$$CH_{4ww,d} = Q_{ww,d} \times COD \times B_o \times MCF \times GWP_{CH4}$$

where

Q is the amount of wastewater produced (ton/ton CPO)

COD is the Chemical Oxygen Demand for conversion which, in this study, is the average COD value obtained available from the palm oil mill from 7th June to 7th September in 2008, 0.041 ton COD/ton wastewater

B_o is the maximum methane producing capacity of the inlet effluent (Mg CH_4/ton

COD), 0.21 Mg CH_4/ton COD

MCF is the methane conversion factor of the baseline storage system, 0.356

GWP_{CH4} is the Global Warming Potential of methane, default value 25

The palm oil mill in this study is located in Ta- saie District, Chumporn Province. The data used in the study were on the basis of annual average in year 2007. The FFBs, feedstock of oil mill, are from its own farm, 34 km away from the mill. 1 ton of CPO require 4.56 ton FFB. Since this process produce not only CPO but also Palm Kernel Oil (PKO), the exchanges for CPO production are allocated by mass. The allocation factor is 0.73 (mass of CPO/total mass of CPO and PKO). Figure 4.3 shows the mass allocated exchanges for 1 ton of CPO.

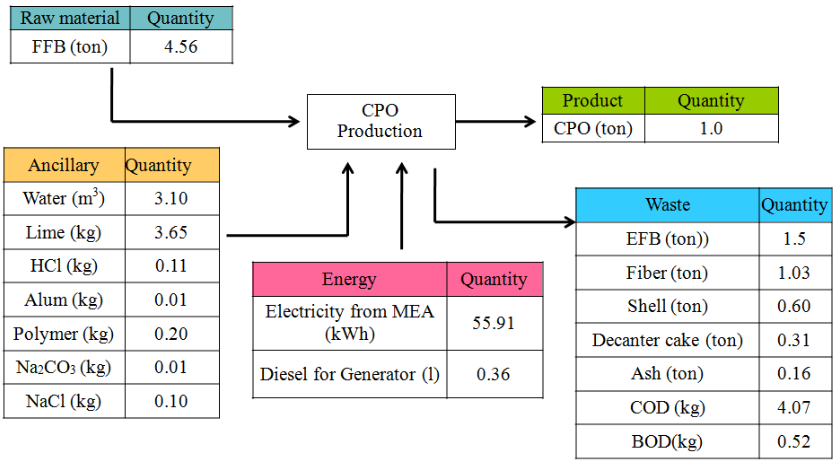

Figure 4.3 Mass allocated exchanges for CPO production (Vichitbhun, 2007)

About 84% of total electricity consumption in the mill is used for production, 5% for the office buildings and dormitory, the rest of 11% is for operating wastewater treatment as shown in Table 4.2. As renewable energy sources, the CO_2 emission from combustion of biomass fuels are considered as CO_2 neutral. The energy consumption for production after allocation is about 55.91 kWh/ ton CPO. 1 ton of CPO generates 0.63 ton of wastewater with the average COD of 4.06 kg. It is noticed that the outputs from the CPO extraction mill in this study are in the range of outputs from other studies except energy consumption which is lower in this study (Pleanjai et al., 2004; Pleanjai and Gheewala, 2009; Silalertruksa and Gheewala, 2012).

4.1.4 Crude palm oil transportation

Large-scale biodiesel production for blending into fossil diesel began in 2007. Large-scale biodiesel refineries are concentrated in the south of Thailand near oil palm plantations and around Bangkok near fossil fuel refineries and fuel distributors (Salvatore and Damen, 2010). The CPO is transported to biodiesel production plant in Samutprakarn Province at the distance of 800 km round trip by 40 ton tank trucks. They use diesel as fuel and are empty on the way back (Vichitbhun, 2007). Table 4.3 presents crude palm oil transport.

Table 4.2 Electricity used by activity from 1MW produced in Palm Oil Mill (unit: kW)

Process	Dormitory	Wastewater
840	50	110

Table 4.3 CPO transport

Type of transport	Fuel consumption/round trip (L/L)
40 ton tank truck	0.005

4.1.5 Biodiesel production

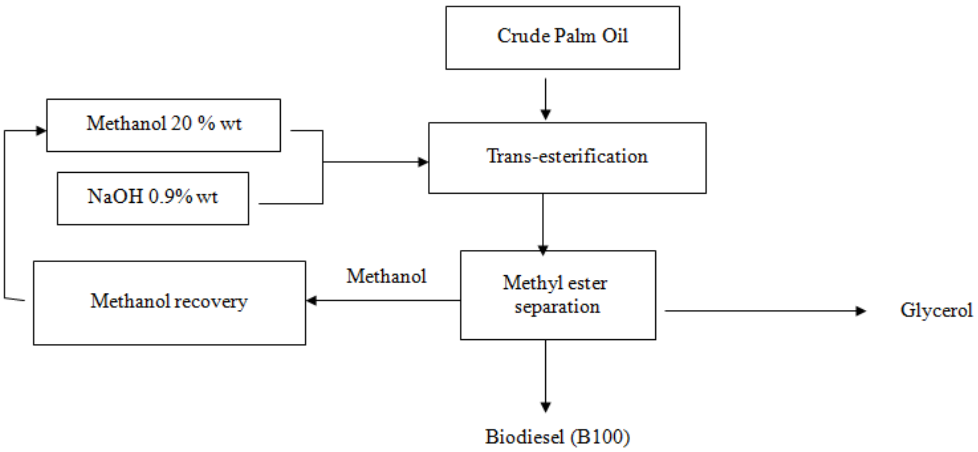

Figure 4.4 Biodiesel production process

Main source of biodiesel production in Thailand is CPO. The data of CPO feed biodiesel is secondary from the study of Pleanjai et al., 2004. Typically, the biodiesel production process with CPO feed is shown in Figure 4.4. The trans- esterification of

CPO with methanol (MeOH) and sodium hydroxide (NaOH) as catalyst produces palm oil methyl ester (B100) and glycerol. The MeOH is recovered.

The main inputs of B100 production are CPO, MeOH, NaOH and water. Glycerol is a by-product. The mass allocation is applied in this process. The allocation factor is 0.81. The exchanges after mass allocation of B100 are presented in Figure 4.5.

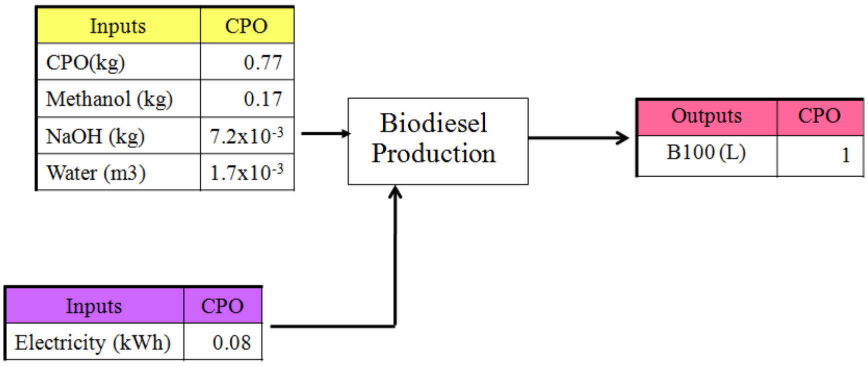

Figure 4.5 Mass allocated exchanges for biodiesel production (Pleanjai et al., 2009)

4.1.6 Biodiesel transportation

B100 is transported by 40 ton tank truck from biodiesel plant located at the central region of Thailand to the Bang Pa-In (BPI) terminal for blending with diesel at the average distance of 165 km/round trip. The B100 transport is fueled with diesel at the consumption rate of 0.0013 l/l of B100 as shown in Table 4.4.

Table 4.4 Fuel consumption for B100 transport

Type of transport	Fuel consumption/round trip
	(l/l)
40 ton tank truck	0.0013

Source: BCP, 2007

4.2 Petroleum production system

4.2.1 Crude oil extraction

Crude oil in Thailand mainly comes from Middle East Asia via ship. Small portion is the local crude. The inventory for crude oil extraction is based on Simapro 7.0, crude oil production Middle East onshore. It includes infrastructure, drilling and flaring/blow off.

The crude oil mainly comes from the Middle East countries. The data of crude oil extraction are based on eco-invent, Crude oil production Middle East onshore. 1 kg of crude oil production requires 1.02 kg of crude oil in ground and generates emission presented in Table 4.5.

4.2.2 Crude oil transportation

Crude oil is mainly raw material for petroleum production. There are various modes of transportation depending on sources of crude and location of refinery. The refinery under study transports crude oil from overseas and the Gulf of Thailand via large vessels to onshore terminal at Sriracha Terminal (SRT), Chonburi province, the East of Thailand and then transfer to the refinery in Bangkok by barge. Those from inland are transported from exploration sites via 40 t truck and train. Table 4.6 shows that tanker and barge is the major mode of crude oil transportation. Therefore, only tanker and barge from overseas to the refinery is taken into account in this study.

The total crude of 2,188,403 ton was delivered from the Philippines, Indonesia, Malaysia and Sudan and the gulf of Thailand to the SRT by tanker at the average round trip distance of 3,481 km and then transported to the refinery in Bangkok by barge at the distance of 260 km. Bunker oil is used as fuel in tanker whereas barge uses both diesel and bunker oil. Crude oil transport is presented in Table 4.7.

Table 4.5 Inputs and outputs in crude oil production 1 kg

Substances	Compartment	Unit	Amount
Oil, crude in ground	Raw	kg	1.02
Carbon dioxide	Air	kg	0.08
Carbon monoxide	Air	kg	2.50E-04
Dinitrogen monoxide	Air	kg	2.72E-06
Methane	Air	kg	7.96E-04
Nitrogen oxide	Air	kg	6.90E-04
Sulfur oxide	Air	kg	1.75E-04
COD	Water	kg	2.80E-04
Sulfide	Water	kg	1.16E-09
Nitrate	Water	kg	1.40E-07

Table 4.6 Mode of crude transportation

Crude transport mode	Ratio (%)
Tanker and Barge	80
40 t truck	3
Train	17

Source: BCP, 2007

4.2.3 Diesel production

Conventionally, in diesel production, crude oil is distillated in an atmospheric distillation unit (ADU), prior to treating in units such as hydrotreating (HDTU) and hydrodesulphurization (GO-HDSU) for sulfur removal. The treated products i.e. the diesel and the gas oil are mixed and become the straight run diesel (S-HSD). In order to maximize customer demand on lighter distillates, the low value products i.e. crude residues or atmospheric residues (AR) from the bottom of the ADU are redistillated in a vacuum distillation unit (VDU) followed by a hydrocracking unit (HCU) which is connected with another sulfur removing process. The hydrocracking is the most efficient method for producing light fractions from heavy oil (Matsumura et al., 2005; Rana et al., 2007). This kind of cracking process is the reaction in the presence of hydrogen generated by a hydrogen production unit (HPU). The diesel from the HCU is the cracked diesel (C-HSD). The removed sulfur from the treating units is presented in form of both gas and water. The rich sulfur sour gas and sour water are sent to the fuel gas treating unit (FGTU) and sour water stripping unit (SWSU) respectively for further treatment. Finally the removed sulfur is recovered as liquid sulfur and sold to acid manufacturers outside the refinery. Thus diesel products from the refinery are both S-HSD and C-HSD. The inventories of the diesel produced are proportionally averaged between S-HSD and C-HSD.

Table 4.7 Crude oil transport

Transport mode	Average Distance (km/round trip)	Fuel consumption (l/l)	
		Diesel	Bunker oil
Tanker	3,481	-	0.0017
Barge	260	0.0006	0.0003

Source: BCP, 2007

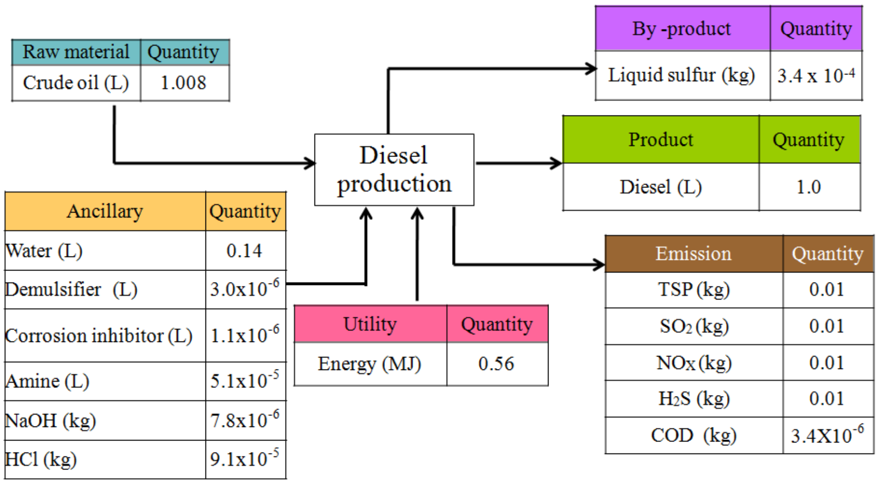

Figure 4.6 Heating value allocated exchanges for diesel production (BCP, 2010)

The energy carriers used in the refinery are in several forms such as fuel gas (FG), fuel oil (FO), electricity from the Metropolitan Electricity Authority (MEA) and steam together with electricity produced by a co-generation plant (CHP). This study focused on CO_2, CH_4, and N_2O emissions because these are the most prevalent GHGs emitted from oil industry operations. The combustion of carbon-containing fuels in stationary equipment such as engines, burners, heaters, boilers, flares, and incinerators results in formation of CO_2 due to the oxidation of carbon. Very small quantities of N_2O may be formed during fuel combustion by reaction of nitrogen and oxygen at high temperatures. Methane may also be released in exhaust gases as a result of incomplete fuel combustion (API, 2009); however complete oxidation to CO_2 has been assumed for this study. Not only emissions from combustion but also CO_2 from the reaction in the HPU is considered. The quantity of CO_2 vented depends on the carbon to hydrogen ratio of the feed gas. The chemical reaction can be expressed as:

$$C_xH_{(2x+2)} + 2x\, H_2O \longrightarrow (3x+1)\, H_2 + x\, CO_2$$

This equation shows that one mole of CO_2 is formed for every mole of carbon in the hydrocarbon species. IPCC method (IPCC, 2006; Eggleston et al., 2006) is used for estimating GHG emissions based on primary activity data of the energy carriers since primary data on GHG emissions in the refinery in Thailand are not available. The full chain energy consumption at the gate to gate level was taken into account, unit by unit, for both types of HSD, S-HSD as well as C-HSD. The approach follows material and energy flows through individual refining process, and distributes energy use of a given refining process to products via economic allocation (Table 4.8). However, it must also be mentioned that the estimation for fuel market value introduces uncertainties into allocation factors because refinery intermediate streams are generally intended to be used internally instead of being sold in the marketplace (Bredeson et al., 2010). The CO_2 emission is derived from the multiplication of total energy consumed by the HSD production (including that from stationary equipment) in MJ with emission factors derived from the IPCC method based on the type of energy carrier, i.e. steam, fuel oil, fuel gas and electricity. The emission factors for fuel oil and fuel gas produced in the refinery are 77.4 ton CO_2/TJ, 57.6 ton CO_2/TJ, respectively. The results show that 1 liter of the straight run diesel required 0.934 MJ whereas 1 liter of the C-HSD consumed 3.847 MJ as detailed in Table 4.9. The highest energy consumption units of the S-HSD are the ADU followed by the GO-HDSU and that of the C-HSD is the HCU because the feed of HCU is from the residue which is a heavy part from crude oil. In addition, the HCU uses high pressure steam (40 bars) which requires high energy for its production. According to the study of Burgess and Brennan (2001), the hydrotreater, one of the processing steps, has been identified as causing the largest cost and environmental burdens in GO_HDSU. The energy consumption in the HPU is negative because the reaction in the unit produces high pressure steam (40 bars) sufficient not only for itself but also for export to other units. Thus the amount of energy from exported steam is credited.

Table 4.10 presents emission factors per unit of energy sources. The steam and electricity are generated from the CHP fueled by natural gas and have emission factors of 0.09 kg CO_2/kg steam and 0.03 kg CO_2/kWh. Besides CO_2 emission from fuel combustion, there is an additional CO_2 emission from the reaction in the HPU. Modern hydrogen plants use a cyclical pressure swing adsorption (PSA) unit to remove impurities (CO_2, CO, CH_4) from raw hydrogen exiting the shift reactor. The purged PSA or tail gas is a low-Btu fuel gas consisting mostly of CO_2, CO, and CH_4, and some H_2. The tail gas is then routed to the reformer furnace and provides 50 to 90% of the heat input to the furnace (API, 2009). The PSA purged gas flow rate and composition in this study are from the PSA design after incineration.

Table 4.8 Fuel prices for allocation

Type of fuel	Price (USD/BBL)
LPG	29.38
Light naphtha	83.92
Heavy naphtha	78.57
Jet fuel	96.12
Diesel	98.08
Fuel oil	69.39
Liquid sulfur (Baht/kg)	2.90

Source: BCP, 2010

Table 4.9 Energy consumption (MJ) per liter of different types of diesel

Process unit	S-HSD (MJ/L)	C-HSD (MJ/L)
Atmospheric distillation unit	0.584	0.407
Vacuum distillation unit	-	0.824
Hydrogen producing unit	-	(0.003)
Hydrocracking unit	-	2.440
Gas oil hydrodesulphurization unit	0.338	-
Fuel gas treating unit	0.003	0.161
Sour water stripping unit	0.009	0.047
Wastewater treating unit	5.33E-05	2.58E-04
Sulfur recovery unit	3.24E-04	0.018
Total energy consumption	0.934	3.847

Source: BCP, 2010

4.3 Biodiesel blending and transport

To produce various biodiesel blends for engine, B100 has to be blended with fossil diesel from the refinery. The diesel is sent to BPI terminal for biodiesel blends via pipeline at the distance of 63 km then distributed to petrol service stations in the North, the Northeastern and the West of the country by 40 ton tank truck in the average round trip distance of 735 km whereas the products are transported to petrol service stations in Bangkok and peripheral by 40 ton tank truck within the radius of 50 km from the refinery. Those trucks are fuelled by B5 whereas pipeline transport uses electricity of

250 kWh in delivering of 400,000 l/hr product. Table 4.11 shows transport mode and fuel consumption in biodiesel transport.

Table 4.10 Emission factors of energy carriers

Fuel	Emission factor	Unit
Steam	0.09	kgCO_2/kg steam
Refinery Fuel Gas	1.43	kg CO_2/m^3
Fuel Oil	2.93	kg CO_2/l
Electricity from MEA	0.51	kg CO_2/kWh
Electricity from CHP	0.03	kg CO_2/kWh

Table 4.11 Biodiesel transport

Transport mode	Fuel economy (km/l)	Average distance (km/roundtrip)	Fuel consumption (l/l)
40 ton-truck from BKK to S/S	4.0	100	0.0021
40 ton-truck from BPI to S/S	4.0	735	0.02
Pipeline from BKK to BPI	250 kWh	63*	0.0006 kWh/l

Source: BCP, 2007 * no return trip

The emission factors for the studied commodities transport are based on 1tkm Tanker oceanic ETH, 1 tkm Truck 40 t ETH (system model transport), 1 tkm Transport, lorry 16t/RER U (eco - invent), and 1tkm transport, van < 3.5 t (eco-invent) as appropriate**.**

Table 4.12 Fuel economy, heating value and density of biodiesel blends

	Fuel of economy (km/l)	HHV (MJ/kg)	Density (kg/l)
Diesel	11.69	45.84	0.8268
B2	11.73	45.90	0.8287
B5	11.60	45.59	0.8303
B10	11.52	45.19	0.8338
B100	10.80	40.17	0.8754

Source: PTT Research and Technology Institute, 2008

4.3.2 Biodiesel end use

Table 4.12 shows test result of fuel economy, high heating value and density of various blend ratio of biodiesel i.e. diesel, B2, B5, B10, and B100. Table 4.13 presents tailpipe emission tested with light duty truck (pick up) at 4 year age, 2499 cc engine with Euro 3 test cycle.

Table 4.13 Tailpipe emissions from light duty truck for various biodiesel blends

Fuel type	(g/km)				
	CO_2	CO	NO_X	HC	PM
Diesel	223.48	0.56	0.48	0.05	0.08
B2	221.26	0.56	0.46	0.05	0.07
B5	223.38	0.57	0.46	0.05	0.08
B10	226.73	0.48	0.51	0.03	0.06
B100	227.54	0.44	0.58	0.04	0.03

Source: PTT Research and Technology Institute, 2008

4.4 Land use change assessment

4.4.1 Crop selection

According to the study of Salvatore and Damen, 2010, about one-third of Thailand's total land of about 51 million hectares is dedicated to agricultural production. Rice is the country's largest crop, but the main cash crops are sugar cane 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. Those are cassava, coffee, mangosteen, rambutan, rice, rubber, soybean and sugarcane in addition to abandoned land. The forest land is excluded because it is unlikely to occur in Thailand due to illegal and restricted by the government (Silalertruksa and Gheewala, 2012). The crops affected by oil palm expansion are reflected in negative sign, meaning that crop area declines as oil palm area increases.

The crops having a negative sign as explained above and significance at 5% level are selected for this study. The results reveal that the declined coffee, rambutan and rice area in the central and southern regions are satisfactory with the selected criteria and there is no between oil palm area and abandoned area 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, unsuitable for the crop cultivation. Furthermore, rubber area responds in positive sign with oil palm expansion. It means that rubber area is not affected by biodiesel promotion but increases as oil palm expansion. The reason is that the return from rubber has been higher than oil palm (Figure 4.7) so there is no incentive of crop shifting from rubber to oil palm. However as a substitution of palm oil, soybean planted area is affected in the central, the north and the northeast but insignificantly. This is because soybean and oil palm required different condition. The physical factors, rainfall, soil quality, temperature, are limiting factors. Thus, the displaced crops for area and price change are coffee, rambutan and rice (see the statistics details in Appendix B). This conforms to the survey of the Land Development Department, 2013 reporting that the suitable lands for oil palm are in 26 provinces, and in the central, and the south in line with climatic zone defined in IPCC 2006 that the Central and the South 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 0.05 % confidence are cassava, soybean in the Central of Thailand, soybean in the North and the Northeast, and mangosteen in the South (details in Appendix B).

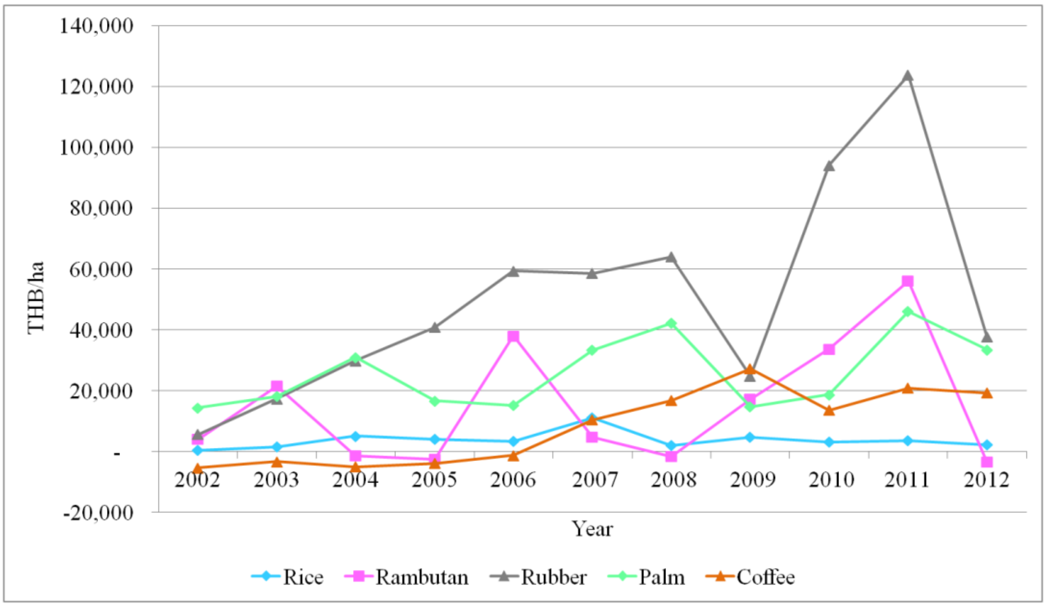

Figure 4.7 Return by crop, (OAE, 2012)

4.4.2 Change in crop area and price

The log-log model is applied to the system 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 exogeneous variables. Dummy variables are added differently but appropriately for each crop. The results of the planted area for each converted crops derived from Eq.3.1-3.6 are as follows (Eqs. 4.1-4.9):

log (PA_coffee_C) = -6.89827580 + 0.00827152*log(R_ coffee _C(-1)) – 0.01858585* log (R_palm_C (-1))*D2005 – 0.60297134 *D2011 + 0.04356687 * log (PA_ coffee _C (-1)) - 0.014956365*@TREND + [AR(1)=0.53700067] (4.1)

log (PA_ coffee _S) = -1.06293865 - 0.01135432*log (R_ coffee _S(-1)) –0.00768794 * log (R_palm _S(-1))*D2005 - 0.19991577*D2011 + 0.55518954 * log (PA_ coffee _S(-1)) (4.2)

log (P_ coffee) = 14.11143300 + 0.52369863 * log (R_ coffee _World (-1)) - 1.13429643 * log (PR_ coffee) + 0.39728338 * log (coffee _demand) (4.3)

log (PA_rambutan_C) = -0.44584402 - 0.09057610* log (R_ rambutan _C(-1)) - 0.03989823* log (R_palm _C (-1))*D2005 + 0.37812225* D2005 - 0.02185467*@TREND + 0.44746697* log (PA_ rambutan _C(-1)) (4.4)

log (PA_ rambutan _S) = -1.47150752 - 0.07288602* log (R_ rambutan _S(-1)) - 0.29223747* log (R_palm _S (-1))*D2005 + 3.18904868* D2005 + 0.28829504* log (PA_ rambutan _S (-1)) – 0.01374153 *@TREND (4.5)

log (P_rambutan) = 17.73025558 - 1.40051532 * log (PR_ rambutan) +

0.05813266 * log (rambutan _demand) - 0.85811954 * D2002 (4.6)

log (PA_ rice _C) = 0.51700199 - 0.02162536* log (R_ rice _C(-1)) - 0.00201004* log (R_palm _C(-1))*D2005 + 0.03469713*D2005 - 0.05581545 *D2010 + 0.31321889* log (PA_ rice _C (-1)) (4.7)

log (PA_rice_S) = -1.45654519 + 0.09704248* log (R_ rice _S(-1)) - 0.10704641* log (R_palm_S(-1))*D2005 + 1.16407098*D2005 - 0.41832187 *D2010 + 0.06835173* log (PA_ rice _S (-1)) -0.03500770 * @TREND (4.8)

log (P_rice) = - 6.11700237 - 0.15441965 * log (PR_rice) + 1.05505601* log(GDP) + [AR (1) = 0.48025215] (4.9)

Table 4.14 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 4.15 and Table 4.16 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 C).

Table 4.15 Elasticity and statistics of area change by region

Statistic	Coffee area		Rambutan area		Rice area	
	Central	South	Central	South	Central	South
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

Table 4.15 presents the satisfactory results with high R^2 (higher than 0.7; mostly higher than 0.9). The correlations at 0.05% 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, % change in area of rambutan (0.292) and rice (0.107) in the south are higher than those in the central (0.040 for rambutan and 0.002 for rice, respectively) whereas % change in coffee is higher in the central (0.019) than in the south (0.008). This is because the yield of rambutan and rice in the south is lower than those in the central resulting in small return per area. As a consequence, larger crop shift occurs, the same as what happened in the central region for coffee (Figure. 4.8-4.10). Furthermore, the constant for only rice in the central is positive.

Table 4.16 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

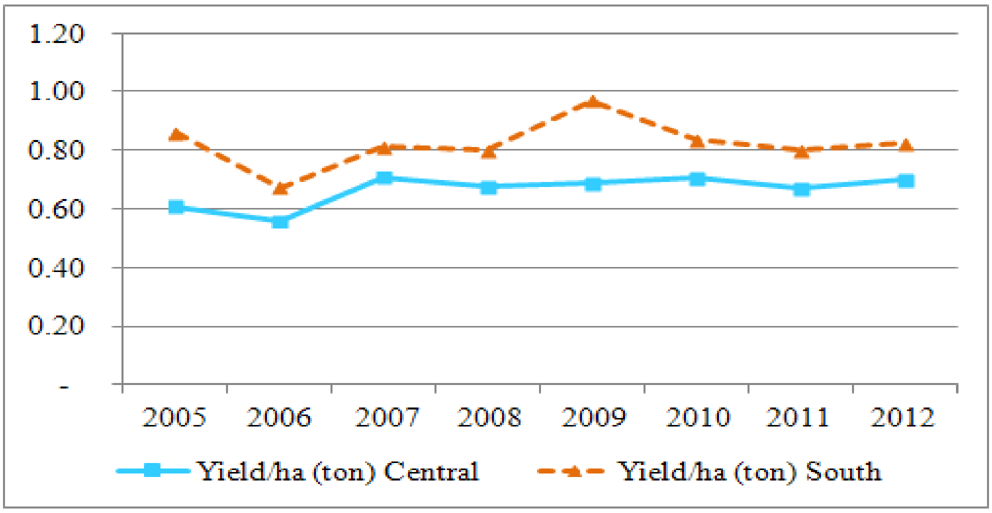

Figure 4.8 Yield of coffee by region

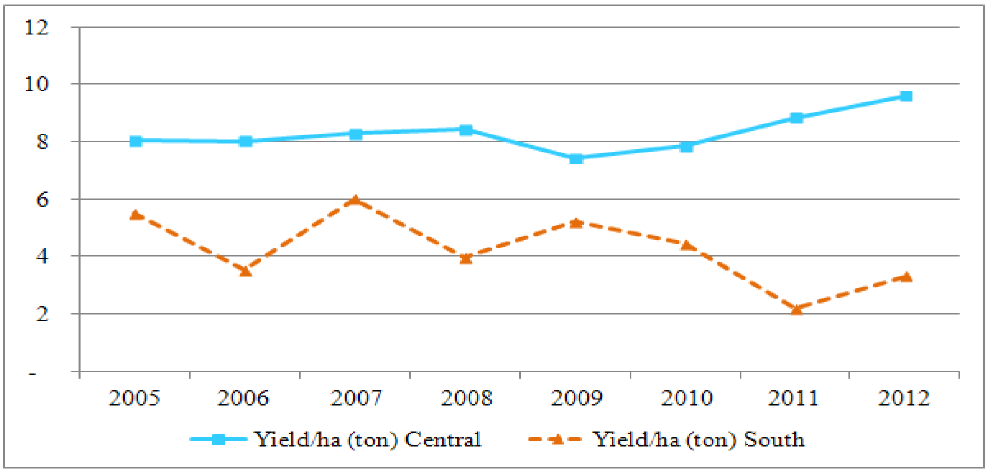

Figure 4.9 Yield of rambutan by region

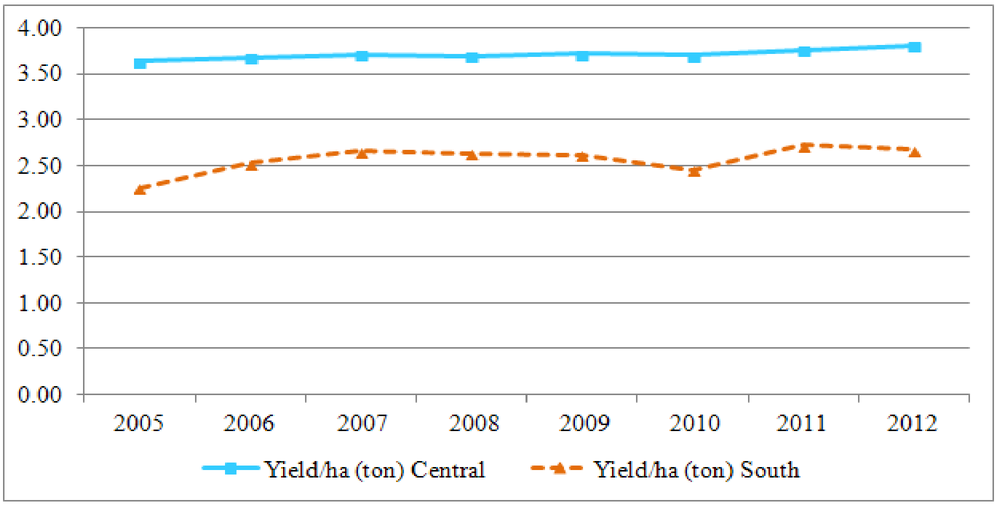

Figure 4.10 Yield of rice by region

Table 4.17 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

The elasticities of the area and prices of each displaced crops for the whole country responding to the AEDP biodiesel demand are presented in Table 4.16. Durbin-Watson statistics of those equations (close to 2) show there are no autocorrelation among variables. The correlations are significant at the 0.05% confidence (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. The percentage changes in the area of the converted crops are smaller as the biodiesel blending ratios are larger; consequently, the percentage changes in the converted crop prices are also less because the increased prices of the converted crops are more competitive to oil palm.

From Table 4.17, it is noticed that the percentage change in 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 area is high relative to the coffee and the rice; this may be due to its declining and unsteady return (OAE, 2012).

4.5 Environmental impact assessment

4.5.1 Environmental impact of biodiesels (without LUC)

Table 4.18 Environmental impacts per liter of diesel and biodiesel

Stage of life cycle	B100		Stage of life cycle	Diesel	
	ADP	GWP		ADP	GWP
	(kg oil eq.)	(kg CO_2 eq.)		(kg oil eq.)	(kg CO_2 eq.)
Palm plantation	0.015	0.495	Crude production	0.862	0.09
FFB transport	0.023	0.071	Crude transport	0.01	0.035
CPO production	0.0002	-0.177	HSD production	0.042	0.145
CPO transport	0.027	0.035	HSD transport	0.018	0.103
B100 production	0.132	0.071	Vehicle use	0	2.616
Vehicle use	0	0.141			
B100 transport	0.007	0.024			
LCA of 1 L	**0.206**	**0.660**	**LCA of 1L**	**0.923**	**2.808**

There are two streams in producing biodiesel blends, biodiesel (B100) and diesel production. Table 4.18 shows the GWP and ADP arising from diesel and B100 in each stage of their life cycles. The results reveal that the B100 causes less GWP and ADP than diesel. The total GWP of B100 is approximately 58 percent lower than that of diesel at 1.271 kg CO_2 eq./L B100 or 1.379 kg CO_2eq./L diesel equivalent (1L diesel equivalent = 1.085 L B100) with the GWP of diesel at 2.988 kg CO_2eq./L diesel. The highest contribution of diesel to GWP is in the stage of vehicle use whereas that of B100 is palm plantation due to fertilizer applications followed by CPO production due to CH_4 from wastewater treatment. It is noted that there is a small amount of GWP 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).

Table 4.19 Environmental impacts of biodiesel blends per functional unit

Biodiesel blends	$GWP_{without\ LUC}$ (Mton CO_2 eq.)	$ADP_{without\ LUC}$ (Mton oil eq.)
B2	58.07	19.08
B5	56.71	18.63
B10	54.46	17.88

The total ADP of B100 is approximately 78 percent lower than that of diesel at the amount 0.206 kg CO_2eq./L B100 or 0.223 kg oil eq./L diesel. The highest ADP of diesel is from crude exploration as expected whereas the stage of B100 production has the highest contribution but still small relative to diesel production. The lowest contribution comes from the CPO production stage because the energy sources are the by–products considered renewable and C-neutral. The result also reveals that the GWP and ADP are lower with increase in the biodiesel blending ratio. It proves that biodiesel helps reduce GHGs and replaces the crude oil consumption.

The GWP and ADP of the biodiesel blends of 21,000 ML are presented in Table 4.19. The larger the biodiesel blending ratio, the lower the impacts on the environment; both for GWP and ADP are. A 1% increase in the biodiesel blending ratio results in the reduction of GWP and ADP 0.45% and 0.15%.

4.5.2 Environmental impact of biodiesel blends (with LUC)

This section presents the GWP 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 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.

As a result from the previous section, 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 cropland 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 to oil palm are -6.84, -6.84 and -21.94 ton CO_{2eq} /ha/ year respectively as shown in Table 4.20 (Appendix D). The results show negative sign meaning that the conversion of land from coffee, rambutan and paddy field to oil palm removes GHG from the atmosphere. The total GWP of the entire life cycle biodiesel blends without and with land use for B2, B5 and B10 are presented in Table 4.21.

Table 4.20 GWP emission factors of land use change

Crops changed	GWP emission factors for LUC ($Mg\ CO_{2eq}$/ha-yr)
Coffee	-6.84
Rambutan	-6.84
Paddy field	-21.94

Source: IPCC, 2006

Table 4.21 Total GWP of biodiesel blends

Biodiesel blends	$GWP_{\text{without LUC}}$ (Mton CO_2 eq.)	GWP_{LUC} (Mton CO_2 eq.)			$GWP_{\textit{with LUC}}$ (Mton CO_2 eq.)
		Coffee	Rambutan	Rice	
B2	58.07	-0.002	-0.035	-0.346	57.68
B5	56.71	-0.003	-0.065	-0.673	55.97
B10	54.46	-0.004	-0.095	-1.011	53.35

4.6 Socio–economic impact

Price estimation

The estimate of FFB price is presented in Eq. 4.10 (details in Appendix E). The demand of biodiesel is 5.97 million liters per day as targetted in the AEDP target in 2021.

$$P_{FFB,fg} = D_1*(Con_{B100} -(-0.037965392)-(0.0008281440)*MP_{CPO} -0.0012685218$$

$$*T^{S} - ((1-D_3)*(0.0008622026*(0.15* P_{MeOH} +3.32) + SResid_{B100}) + D_3*(0.0008622026 *(0.1* P_{MeOH} +3.82)*CPOtoB100+ SResid_{B100})))/ (0.0002153858 + (1-D_3)*0.97*0.0008622026 + D_3*0.94*0.0008622026 *CPOtoB100) + (1-D_1)* P_{CPO} \quad (4.10)$$

R-squared = 0.9247 Adjusted R-squared = 0.9195

Durbin-Watson stat = 1.054916 F-statistic = 180.1798

Prob (F-statistic) = 0.0000

$$Con_{B100} = (1-D_3)*(0.97*(D_1*P_{CPO}+D_2*(MP_{CPO}+1)+(1-D_1-D_2)*(MP_{CPO} +3)) +0.1*P_{MeOH}+3.32) +D_3*CPOtoB100*(0.94*(D_1* P_{CPO}+ (1-D_1-D_2) *(MP_{CPO}+3)) +0.15* P_{MeOH}+3.82) \quad (4.11)$$

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. Durbin-Watson 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. All symbols are presented in Table 4.22.

The estimated prices of FFB for B2, B5 and B10 are derived from Eq. 4.10. 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 4.23.

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

4.6.1.1 Currency saving

The average crude oil price during years 2007-2011, 16.28 THB/L, is used for currency saving estimation. The conversion factor from crude oil to diesel is 1.03L/L (BCP, 2010). The estimates indicate that the country can save the amount of 7,043, 17,607 and

35,214 MTHB/yr for the biodiesel blending ratios of B2, B5 and B10 respectively as shown in Table 4.23. As can be expected, the higher the biodiesel blending ratio, the larger the society is benefited due to larger crude oil replacement with biodiesel.

Table 4.22 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 $\frac{Q^S_{CPO,t-2m} + Q^S_{RBD,t-2m} + Q^S_{ST,t-2m}}{g_1 Q^S_{CPO,t-2m}}$
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, $1\text{-}D_3=1$

4.6.1.2 Farmer income

Table 4.23 Estimated palm oil associated products

Estimated price	Unit	B0*	B2	B5	B10
FFB	THB/kg	3.21	4.90	7.43	11.64
CPO	THB/kg	21.82	33.70	51.37	80.92
BPO	THB/L	35.11	46.81	64.20	93.29
Bi retail price	THB/L	26.68	27.09	28.66	33.81

Remarks: * neat diesel

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 price would increase to 4.90, 7.43 and 11.64 THB/kg for B2, B5 and B10, respectively. As a result, the oil palm farmers would have income at the amount of 21,544, 32,904, 49,892 and 78,163MTHB/yr for B0, B2, B5 and B10, respectively.

Table 4.24 Net socio-economic impacts without LUC

Items	Unit	B0	B2	B5	B10
Currency saving	MTHB/yr	0	7,043	17,607	35,214
Farmer income	MTHB/yr	21,544	32,904	49,892	78,163
Expenditure: BPO price	MTHB/yr	12,594	16,790	23,029	33,463
Expenditure: fuel price	MTHB/yr	560, 245	568,872	601,780	710,099
Net socio-economic impact	MTHB/yr	(551,295)	(545,715)	(557,309)	(630,186)
Change relative to B0	MTHB/yr	0	5,580	(6,014)	(78,891)

4.6.1.3 Expenditure from higher BPO price

The feedstock cost is the main cost of agricultural product. Higher price of FFB causes not only increase in farmer income but also increase 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 35.11 THB/L in base year to 46.81, 64.20 and 93.29 THB/L as the biodiesel blending ratio is increased to B0, B2, B5 and B10, respectively. From the results presented in Table 4.24, total expenditures for the BPO consumption are 12,594, 16,790, 23,029 and 33,463 MTHB/yr for B0, B2, B5 and B10 respectively.

4.6.1.4 Expenditure from higher biodiesel price

The results show the estimated biodiesel blend price would rise from 26.68 THB/L in base year to 27.09, 28.66 and 33.81 THB/L as the biodiesel blending ratio is increased to B2, B5 and B10, respectively. The total expenditures from the blended biodiesel consumption are 560,245, 568,872, 601,780 and 710,099 MTHB/yr for B0, B2, B5 and B10 respectively.

4.6.1.5 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. 3.28. The results show that the net socio-economic impact for diesel (B0) and biodiesel blends (B2, B5, B10) are negative as detailed in Table 4.24. The largest portion of the negative socio-economic impact is fuel consumption while the farmer income is the main portion of the positive impacts. In the situation of no biodiesel (B0), the country either by individual or society, has to pay for energy (diesel) and food (BPO) at a higher cost than the farmers receive from oil palm sale resulting in the negative value 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 situation 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 better than diesel. Nonetheless, those for 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 increase in the ratio of biodiesel which has higher cost.

4.6.1.6 Sensitivity analysis

A number of scenarios are analysed 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 Figure 4.11.

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 crude palm oil price consequently results in the reduction of the cooking oil and the biodiesel price. A decrease in the price of crude palm oil by 10% would result in higher benefit to the socio-economic impact by 47%.
The second influencer is the crude oil price. The change in crude oil price by 10% would approximately change socio-economic impact by 34%. The higher the crude oil price, the larger the net socioeconomic impact 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 by only 1%. Even though the higher consumption needs more crude oil and palm oil which is a benefit to currency saving as well as farmer income by 10%, the increase in biodiesel price is also larger.

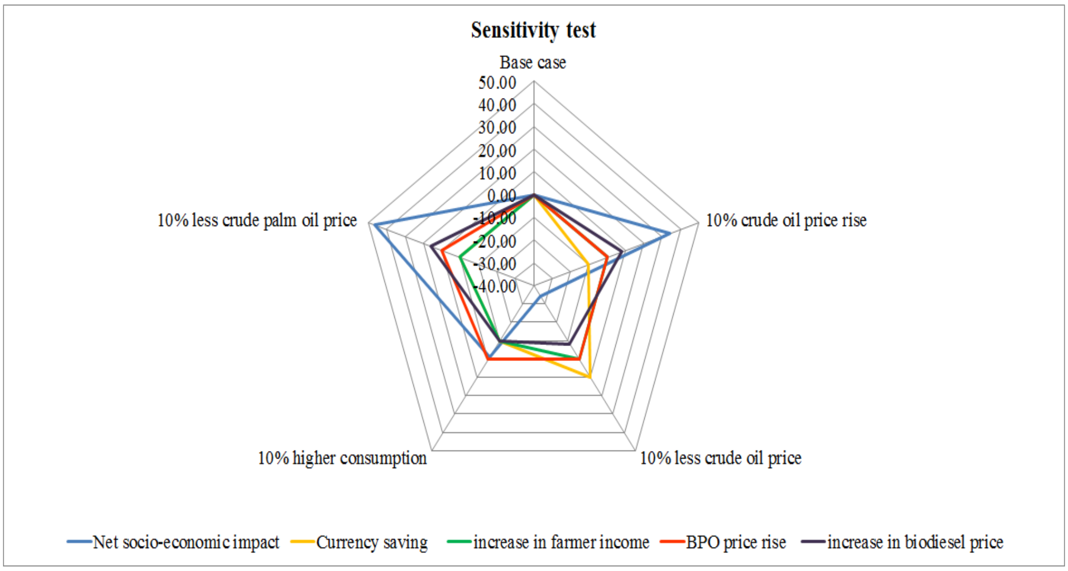

Figure 4.11 Sensitivity analysis of factors to net socio-economic impact

4.6.2 Socio–economic impact related to land use change *(SEI_{LUC})*

Table 4.25 Total socio-economic impact (with LUC) of biodiesel blends

Items	Unit	B0	B2	B5	B10
Currency saving	MTHB/yr	0	7,043	17,607	35,214
Farmer income	MTHB/yr	21,544	222,049	239,675	268,589
Expenditure: BPO price	MTHB/yr	12,594	16,790	23,029	33,463
Expenditure: fuel price	MTHB/yr	560, 245	568,872	601,780	710,099
Net socio-economic impact (LUC)	MTHB/yr	(551,295)	(356,570)	(367,527)	(439,759)
Change relative to B0	MTHB/yr	0	194,725	183,768	111,536

This section presents the socio–economic impact caused from crop area conversion. Table 4.25 shows the net socio-economic impact with LUC for each biodiesel blend. From Table 4.17, 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 keep those crops would have higher income. The additional positive socio-economic impact from LUC is the increase in farmer income from the additional oil palm area converted from the coffee, rambutan and rice plus income of farmers from the increasing of 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 increase in biodiesel ratio (B3 to B10), there is a shortage of CPO causing a sharp price rise of the associated palm oil commodities.

4.7 Sustainability assessment

Table 4.26 compiles the data of SEI, GWP and ADP for the biodiesel blends without and with LUC from Tables 4.19, 4.21 and 4.25. It is noticed that there is no ADP with LUC because ADP in LUC is insignificant relative to ADP from the production phase (without LUC). The eco-efficiencies of the various biodiesel blends are presented in form of two-dimensional graphs. The horizontal axis indicates the environmental performance while the vertical axis indicates the economic performance. In the portfolio, the scaling of the axes is inverted; thus the upper right corner is the "good" area, indicating a high eco-efficiency, whereas the lower left corner is the "bad" area (low eco-efficiency). All alternatives lying on the same diagonal from top left to bottom right have the same eco-efficiency (Rüdenaue, 2005). Since the performances of the blending biodiesels with LUC are better than those without LUC in both economic and environment, the position of marks representing blending biodiesels with LUC are in the right and a little bit upward to blending biodiesels without LUC. Figure 4.12 shows the EE of the socio-economic performance in million baht against the environmental performance in term of GWP in kg CO_2 eq. with and without LUC while Figure 4.13 shows the EE of the socio-economic performances in million baht against the environmental performance in term of ADP in kg oil eq. without LUC in matrix form. 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 in the right and a little bit upward to the blending biodiesels without LUC. In addition, B2 has higher both the socio-economic and the environmental performances than diesel (B0), showing in the upper and the right shift.

Table 4.26 SEI, GWP and ADP of biodiesel blends

Biodiesel (Bi)	$SEI_{without\ LUC}$ (MTHB)	$SEI_{with\ LUC}$ (MTHB)	$GWP_{without\ LUC}$ (Mton CO_2eq.)	$GWP_{with\ LUC}$ (Mton CO_2eq.)	$ADP_{without\ LUC}$ (Mton oil eq.)
B0	(551,295)	(551,295)	58.97	58.97	19.38
B2	(545,715)	(356,570)	58.07	57.68	19.08
B5	(557,309)	(367,527)	56.71	55.97	18.63
B10	(630,186)	(439,759)	54.46	53.35	17.88

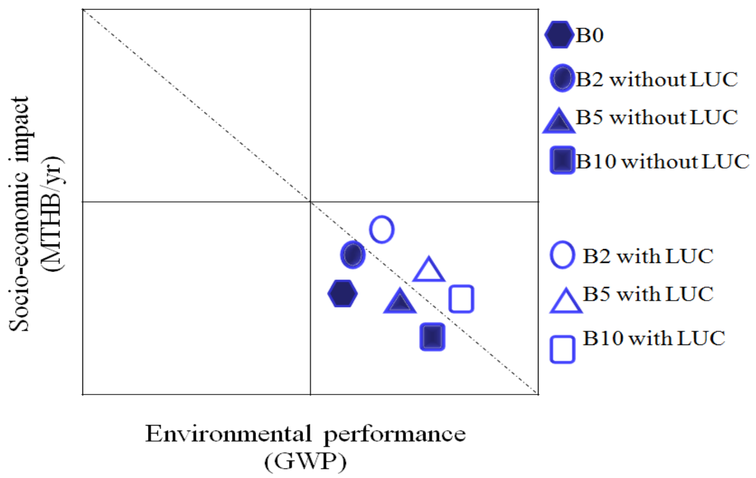

Figure 4.12 Eco-efficiency of biodiesel blends; GWP

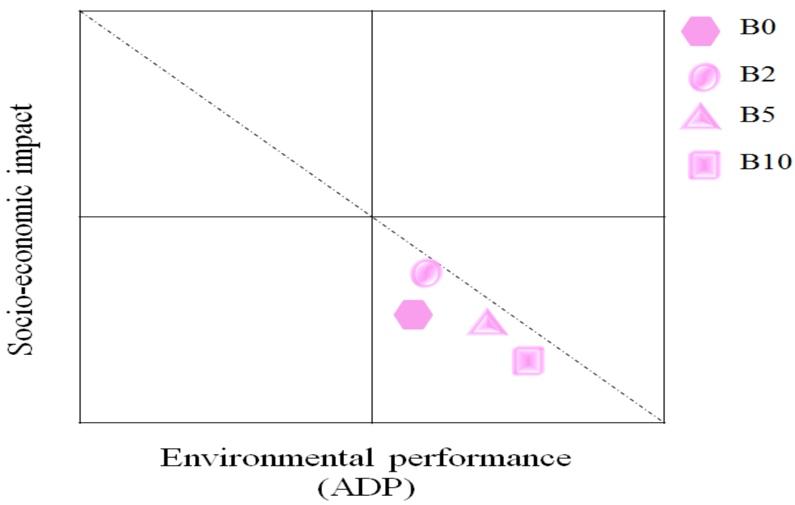

Figure 4.13 Eco-efficiency matrix of biodiesel blends; ADP

The changes in GWP, ADP 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 GWP and ADP of the biodiesel blends are increasing as shown in Figure 4.14 because biodiesel helps reduce GHGs 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 Figure 4.15 as a result of higher increase in biodiesel price (negative impact) which more than offsets the increase in farmer income (positive impact).

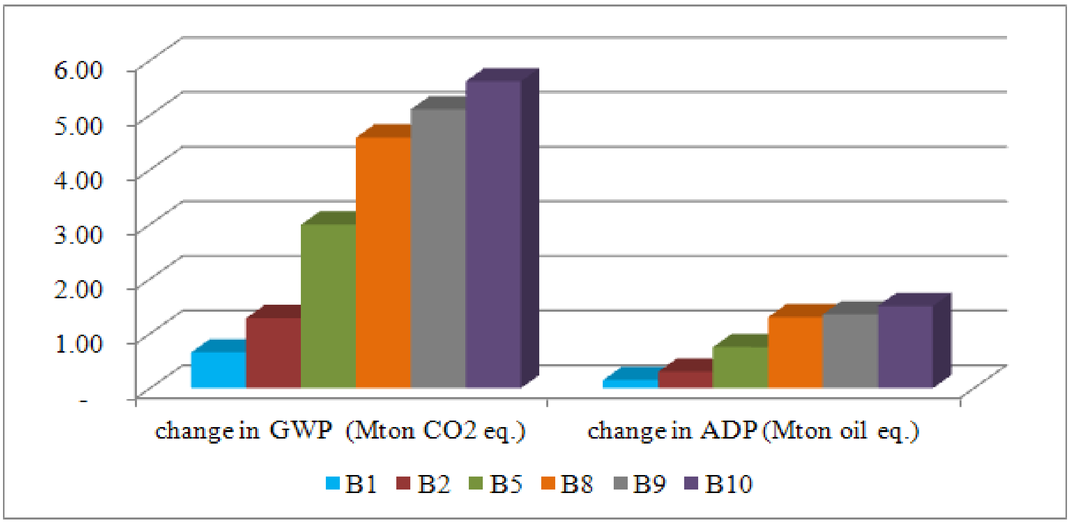

Figure 4.14 Change in GWP and ADP of Bi relative to B0

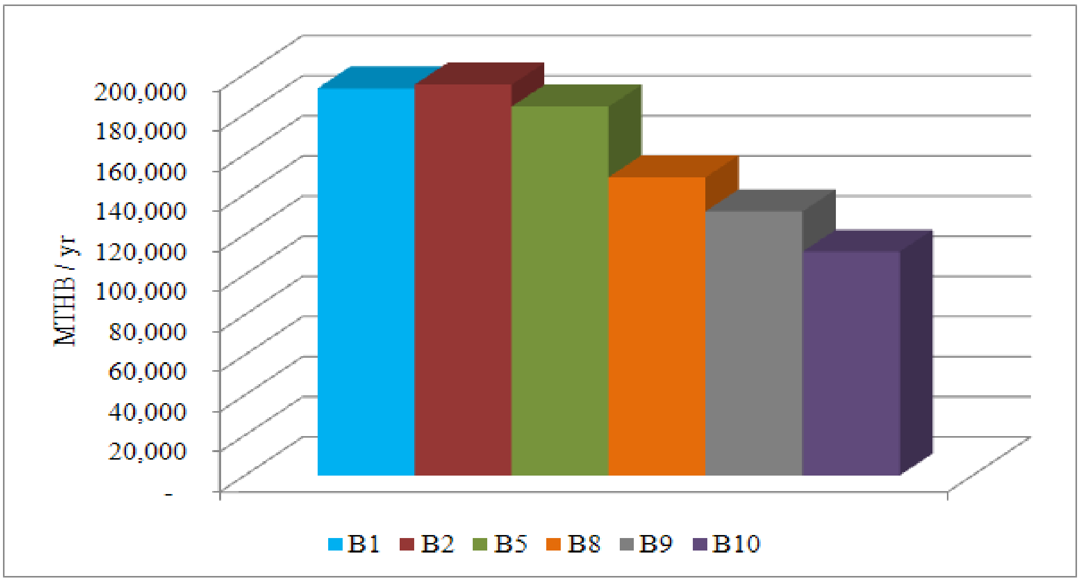

Figure 4.15 Change in net socio-economic impact of Bi relative to B0

CHAPTER 5 CONCLUSION AND FUTURE WORK

5.1 Conclusions

Biodiesel is widely used to replace conventional diesel due to consideration on energy security, resource depletion and global warming mitigation. The Royal Thai Government had set 15- Year Renewable and Alternative Energy Development Plan (REDP: 2008-2022) and the 10- Year Renewable and Alternative Energy Development Plan (AEDP: 2012-2021). Biodiesel demand is targeted for approximately 6 ML/d in 2021 by blending the neat biodiesel (B100) into diesel by ratio from 2% to 10%. The biodiesel blends are called B2 to B10. The renewable energy helps oil independence and currency saving as well as the greenhouse gas reduction. The renewable energy promotion would affect the feedstock price resulting in more demand and consequently, increasing feedstock price. Farmers obtain this benefit. However the price of palm oil associated products also increases. Therefore the effect can be positive and negative. The feedstock of biodiesel in Thailand mainly oil palm. To achieve the biodiesel target, area expansion is needed causing land use change. By combining land use change, the result of global warming may be different depending upon the type of area converted.

This study has the objectives to 1) adapt existing tools for the assessment of the impact of biodiesel on land use change (LUC), 2) assess environmental impacts of biodiesel chain including LUC by using Life Cycle Assessment approach 3) assess socio-economic impacts arising from biodiesel promotion and 4) assess sustainability of biodiesel due to government policy in increasing blending ratio of biodiesel (B100) in diesel using the adapted methodology. The biodiesel blending ratios of 2, 5 and 10 percent, namely B2, B5 and B10, respectively are studied with 21,000 ML neat biodiesel (B100) as functional unit.

The tools used for assessing the impact of biodiesel on crops affected, percentage change in the converted crop area and prices are correlation analysis, multiple regression, and econometric modeling. 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 prices of the converted crops for B2 increase 0.34%, 7.27% and 0.05% for coffee, rambutan and rice, respectively. The percentage changes of the converted area and prices are higher as the biodiesel blending ratio increases. The crops that require the similar environment, weather in particular, as oil palm but have the return per area lower than that of oil palm are more likely 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 cost and less return.

The environmental impacts under the study are GWP and ADP. There are two streams of the biodiesel blends. One is the life cycle of biodiesel production including oil palm plantation, FFB transportation, crude palm oil extraction, crude palm oil transport, biodiesel production and biodiesel blending. The other is the life cycle of diesel including crude oil extraction, crude oil transport, diesel production and use. The GWP and ADP of 1 liter of biodiesel are 0.660 kg CO_2 eq. and 0.206 kg oil eq. whereas those of 1 L diesel are 2.808 kg CO_2 eq. and 0.923 kg oil eq., respectively. Since biodiesel helps reduce greenhouse gases and crude oil consumption, the increase in the biodiesel blending ratio lower GWP and ADP. When LUC is integrated, the GWP is smaller. This is because, according to 2006 IPCC guideline, the conversion of coffee, rambutan and rice to oil palm have negative sign due to more carbon absorption in stock and mineral soil.

As production of biofuels from agricultural commodities is expanding, concerns about social and environmental implications are also rising. The production of biofuels may lead to both positive and negative socio-economic impacts. The positive socio-economic impacts are currency savings and increase in farmers' income due to higher price of oil palm, and the negative impacts are increase in food price represented by bottled palm oil, and biodiesel for energy. The results reveal that compared to B0, the net socio-economic impact of B2 is better but B5 and B10 are worse. Furthermore the 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 impact of B5 and B10 becomes better than B0. This is due to the additional farmers' income from oil palm expanded area and the increase in price of the other crops (rambutan, coffee and rice) because of reduced supply from conversion of part of them to oil palm.

The eco-efficiency (EE) of the various biodiesel blends is the indicator for the sustainability of the biodiesel promotion in Thailand. The changes in the socio-economic impacts, the GWP and the ADP 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.

5.2 Future Work

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, the burden of consumers. This may affect other activities and commodities resulting in higher negative socio-economic impact. Further concern is the land use change. From the correlation, not only oil palm but also rubber affects land conversion (Appendix B). Since the competitive 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 rubber price. The rubber is possibly converted to oil palm. The GWP would be different. From the historical data (OAE, 2010), the return of oil palm plantation at B9 is slightly higher than that of rubber.

It is recommended that B9 would be the optimal ratio under the study. In case the government requires B10 as targeted, it could be achieved positively by reducing oil palm price which could be possible by increasing yield as well as efficiency of feedstock production.

There are some limitation and recommendation for future study as follows:

1. Data uncertainty; There are two causes of uncertainties. 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 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 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 area, the increase in prices of the displaced crops may cause negative impact 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 for the assessment tools.

3. Biodiversity; LUC for biodiesel may lead to monoculture that affect biodiversity Due to the complexity and data limitation the biodiversity is not included in this study but recommended for further study

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Appendix A

Geographical Regions The geographical regions in Thailand are divided into 4 regions:

1) **Northern region** consists of 17 provinces namely Chiang Rai, Phayao, Lampang, Lamphun, Chiang Mai, Mae Hong Son, Tak, Kamphaeng Phet, Sukhothai, Phrae, Nan, Uttaradit, Phitsanulok, Phichit, Nakhon Sawan, Uthai Thani and Phetchabun.

2) **Northeastern region** consists of 20 provinces namely Loei, Nong Bua Lam Phu, Udon Thani, Bueng Kan, Nong Khai, Sakon Nakhon, Nakhon Phanom, Mukdahan, Yasothon, Amnat Charoen, Ubon Ratchathani, Si Sa Ket, Surin, Buri Ram, Maha Sarakham, Roi Et, Kalasin, Khon Kaen, Chaiyaphum and Nakhon Ratchasima.

3) **Central Plain region** consists of 26 provinces namely Saraburi, Lop Buri, Sing Buri, Chai Nat, Suphan Buri, Ang Thong, Ayutthaya, Nonthaburi, Bangkok, Pathum Thani, Nakhon Nayok, Prachin Buri, Chachoengsao, Sa Kaeo, Chanthaburi, Trat, Rayong, Chon Buri, Samut Prakan, Samut Sakhon, Nakhon Pathom, Kanchanaburi, Ratchaburi, Samut Songkhram, Phetchaburi and Prachuap Khiri Khan.

4) **Southern region** consists of 14 provinces namely Chumphon, Ranong, Surat Thani, Phangnga, Phuket, Krabi, Trang, Nakhon Si Thammarat, Phatthalung, Songkhla, Satun, Pattani, Yala and Narathiwat.

Appendix B

Covariance Analysis: Ordinary

Date: 01/20/14 Time: 12:44

Sample (adjusted): 2005 2012

Included observations: 8 after adjustments

Pairwise samples (pairwise missing deletion)

Correlation Probability	PA_Cassava_C	PA_Coffee_C	PA_Mangosteen_C	PA_Rambutan_C	PA_Rice_C	PA_Rubber_C	PA_Soybean_C	PA_Sugarcane_C	PA_Palm_C	AB_C
PA_Cassava_C	1.000000									

PA_Coffee_C	0.508983	1.000000								
	0.1977	-----								
PA_Mangosteen_C	0.093027	-0.624173	1.000000							
	0.8266	0.0981	-----							
PA_Rambutan_C	-0.002906	0.681929	-0.987772	1.000000						
	0.9946	0.0625	0.0000	-----						
PA_Rice_C	0.421545	0.576726	-0.701702	0.777140	1.000000					
	0.2982	0.1345	0.0524	0.0233	-----					
PA_Rubber_C	-0.148071	-0.775945	0.887905	-0.939388	-0.825793	1.000000				
	0.7264	0.0236	0.0032	0.0005	0.0116	-----				
PA_Soybean_C	0.266251	0.260286	-0.033373	0.121908	0.283391	-0.107849	1.000000			
	0.5239	0.5336	0.9375	0.7737	0.4964	0.7993	-----			
PA_Sugarcabe_C	-0.708159	-0.903795	0.313793	-0.367837	-0.365082	0.486502	-0.185716	1.000000		
	0.0493	0.0021	0.4491	0.3700	0.3739	0.2215	0.6597	-----		
PA_Palm_C	-0.038198	-0.722198	0.971531	-0.989981	-0.771127	0.962286	-0.061929	0.434050	1.000000	
	0.9284	0.0431	0.0001	0.0000	0.0251	0.0001	0.8842	0.2826	-----	
Abandoned_C	-0.445911	0.154073	0.057105	-0.176366	-0.683838	0.160185	-0.780926	-0.134379	0.110319	1.000000
	0.3755	0.7707	0.9144	0.7382	0.1341	0.7618	0.0667	0.7996	0.8352	-----

Covariance Analysis: Ordinary

Date: 01/20/14 Time: 12:44

Sample (adjusted): 2005 2012

Included observations: 8 after adjustments

Pairwise samples (pairwise missing deletion)

Correlation Probability	PA_Cassava_N	PA_Coffee_N	PA_Mangosteen_N	PA_Rambutan_N	PA_Rice_N	PA_Rubber_N	PA_Soybean_N	PA_Sugarcane_N	PA_Palm_N	AB_N
PA_Cassava_N	1.000000									

PA_Coffee_N	0.622836	1.000000								
	0.0991	-----								
PA_Mangosteen_N	0.456650	0.962650	1.000000							
	0.2554	0.0001	-----							
PA_Rambutan_N	0.478143	0.952236	0.977573	1.000000						
	0.2308	0.0003	0.0000	-----						
PA_Rice_N	0.592065	0.755076	0.754532	0.681763	1.000000					
	0.1220	0.0303	0.0305	0.0626	-----					
PA_Rubber_N	0.914603	0.825469	0.685726	0.673832	0.771530	1.000000				
	0.0015	0.0116	0.0605	0.0669	0.0249	-----				
PA_Soybean_N	-0.537951	-0.662834	-0.700416	-0.664541	-0.804202	-0.555926	1.000000			
	0.1690	0.0732	0.0530	0.0722	0.0161	0.1525	-----			
PA_Sugarcabe_N	0.572250	0.927714	0.942222	0.950267	0.776820	0.757501	-0.663700	1.000000		
	0.1383	0.0009	0.0005	0.0003	0.0233	0.0295	0.0727	-----		
PA_Palm_N	0.796118	0.896821	0.834656	0.838452	0.878111	0.932124	-0.696369	0.908808	1.000000	
	0.0181	0.0025	0.0099	0.0093	0.0041	0.0007	0.0550	0.0018	-----	
Abandoned_N	0.576166	0.090048	NA	NA	0.892900	0.461595	-0.844418	0.499076	0.714307	1.000000
	0.2314	0.8653	NA	NA	0.0166	0.3568	0.0344	0.3135	0.1108	-----

Covariance Analysis: Ordinary

Date: 01/20/14 Time: 12:45

Sample (adjusted): 2005 2012

Included observations: 8 after adjustments

Pairwise samples (pairwise missing deletion)

Correlation Probability	PA_Cassava_NE	PA_Coffee_NE	PA_Mangosteen_NE	PA_Rambutan_NE	PA_Rice_NE	PA_Rubber_NE	PA_Soybean_NE	PA_Sugarcane_NE	PA_Palm_NE	AB_NE
PA_Cassava_NE	1.000000									

PA_Coffee_NE	NA	NA								
	NA	-----								
PA_Mangosteen_NE	NA	NA	NA							
	NA	NA	-----							
PA_Rambutan_NE	-0.495510	NA	NA	1.000000						
	0.2118	NA	NA	-----						
PA_Rice_NE	-0.030720	NA	NA	0.098059	1.000000					
	0.9424	NA	NA	0.8173	-----					
PA_Rubber_NE	0.570817	NA	NA	-0.014724	0.751328	1.000000				
	0.1395	NA	NA	0.9724	0.0316	-----				
PA_Soybean_NE	0.137153	NA	NA	-0.049798	-0.419833	-0.136893	1.000000			
	0.7460	NA	NA	0.9068	0.3004	0.7465	-----			
PA_Sugarcane_NE	-0.185289	NA	NA	0.748655	0.622968	0.559338	-0.113519	1.000000		
	0.6605	NA	NA	0.0326	0.0990	0.1495	0.7890	-----		
PA_Palm_NE	0.364825	NA	NA	0.094921	0.872610	0.960022	-0.248316	0.693552	1.000000	
	0.3742	NA	NA	0.8231	0.0047	0.0002	0.5532	0.0564	-----	
Abandoned_NE	-0.564165	NA	NA	-0.266787	0.647716	-0.159066	-0.650840	-0.119556	0.084729	1.000000
	0.2435	NA	NA	0.6093	0.1643	0.7634	0.1616	0.8215	0.8732	-----

Covariance Analysis: Ordinary

Date: 01/20/14 Time: 12:45

Sample (adjusted): 2005 2012

Included observations: 8 after adjustments

Pairwise samples (pairwise missing deletion)

Correlation Probability	PA_CASSAVA_S	PA_COFFEE_S	PA_MANGOSTEEN_S	PA_RAMBUTAN_S	PA_RICE_S	PA_RUBBER_S	PA_SOYBEAN_S	PA_SUGARCANE_S	PA_PALM_S	AB_S
PA_CASSAVA_S	NA									

PA_COFFEE_S	NA	1.000000								
	NA	-----								
PA_MANGOSTEEN_S	NA	0.729149	1.000000							
	NA	0.0401	-----							
PA_RAMBUTAN_S	NA	0.739618	0.856968	1.000000						
	NA	0.0360	0.0066	-----						
PA_RICE_S	NA	0.842588	0.796159	0.856633	1.000000					
	NA	0.0086	0.0181	0.0066	-----					
PA_RUBBER_S	NA	-0.909684	-0.789949	-0.910341	-0.951982	1.000000				
	NA	0.0017	0.0197	0.0017	0.0003	-----				
PA_SOYBEAN_S	NA	NA	NA	NA	NA	NA	NA			
	NA	NA	NA	NA	NA	NA	-----			
PA_SUGARCANE_S	NA	NA	NA	NA	NA	NA	NA	NA		
	NA	NA	NA	NA	NA	NA	NA	-----		
PA_PALM_S	NA	-0.813166	-0.588366	-0.863552	-0.859066	0.947703	NA	NA	1.000000	
	NA	0.0141	0.1250	0.0057	0.0063	0.0003	NA	NA	-----	
AB_S	NA	0.034107	-0.594080	-0.426097	-0.655685	0.431158	NA	NA	0.249353	1.000000
	NA	0.9489	0.2137	0.3995	0.1574	0.3933	NA	NA	0.6337	-----