CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusions

The dissertation assesses the sustainability of biofuels for transport in Thailand by focusing on the four key issues related to their production and use i.e. environmental consequences, full cost performance, long-term security of feedstocks supply and socio-economic impacts. A variety of environmental and economic assessment tools and indicators including net energy balance (NEB), life cycle assessment (LCA), life cycle costing (LCC), externalities assessment based on benefits transfer approach, net feedstock balances, Shannon index, net life cycle greenhouse gas (GHG) emissions and economic input-output (IO) analysis are applied in the study to evaluate the existing biofuels production systems in Thailand i.e. cassava ethanol, sugarcane molasses ethanol and palm biodiesel. The conclusions and recommendations of this dissertation are presented below.

5.1.1 Environmental sustainability of biofuel systems in Thailand

The study evaluates the energy efficiency and identifies the environmental hotspots of 'cradle to gate' biofuels production in Thailand. NEB and LCA show that there are significant differences in energy and environmental performance between the existing production systems even for the same feedstock. The differences are dependent on many factors such as farming practices, feedstock transportation, fuel used in biofuels plants, operation practices and technology of biofuels conversion and waste management practices. For example, the comparison of NER and Renewability show that molasses ethanol plants (MoE plant-1 and MoE plant-2) and cassava ethanol (Plant CE-1 (designed)) are effective in fossil energy saving as both the NER and Renewability are greater than 1. However, the actual plant CE-1 which uses coal as fuel for steam production and has an inefficient boiler as well as the MoE plant-3 that lacks good energy conservation practices can also bring about the net fossil energy loss.

The environmental 'hotspots' of cassava and molasses ethanol are revealed by the LCA study. The LCIA results show three major factors that directly affect GWP of cassava and molasses ethanol, i.e. types of fuel used in ethanol plant, trash burning during harvesting of sugarcane and credits from surplus electricity from bagasse at the sugar mill. Another effect of sugarcane trash burning is the creation of incomplete combustion air pollutants such as CO and CH_4 which contribute to photo-oxidant formation. Thus, utilizing cane trash as fuel in sugar milling is an important proposed measure not only to avoid impact from burning of cane trash in field but also to get benefit from energy credits. The results show that per 1000 L of molasses ethanol, the GWP can be decreased from 686 to -288 kg CO_2 eq. and the POCP can be decreased from 5.79 to 0.48 kg C_2H_4-eq. as well as the renewability and NER of molasses ethanol will be improved. Air emissions of NO_x, SO_2, and particulates from steam production in the ethanol conversion stage are the major causes of acidification and human toxicity impacts for both cassava and molasses ethanol.

For the case of palm biodiesel production systems, the NEB results indicate the energy gain of PME and its co-products as compared to fossil energy inputs. However, LCA reveals a wide range of results of the environmental impact potentials such as GWP, AP, EP, POCP and HTP. The variation depends upon the production factors inside the system boundary such as methods to treat the by-products and wastes generated in the palm oil milling stage. For instance, methane generated from the treatment of POME in open ponds is the largest source of GWP contributing almost 100% of the GWP in the milling stage or about 43% of the total GWP of PME. The GWP value of about 1,233 kg CO_2eq per 1000 L PME would be decreased by around 48-57% in case that POME is treated to produce biogas, co-composting with EFB and returning the produced compost to the plantation.

In addition, the assessment reveals that land-use change is an important factor in the GHG performance of first generation biofuels production in Thailand as the GHG emissions can possibly increase from 1 to 10 times when comparing to the cases where LUC is excluded. Therefore, biofuels will contribute to the country's strategic plan on GHG mitigation in the transportation sector only if the production systems are sustainably managed. Recommendations for improving the overall energy and environmental performance of the biofuel systems are suggested in the study to direct the biofuel industries in Thailand towards environmental sustainability.

5.1.2 Cost performance of biofuels in Thailand

LCC and preliminary assessment of externalities of gasohol and biodiesel blends reveal that in comparison to gasoline at the same performance, the total environmental costs of cassava based ethanol are 6% to 32% lower, depending on the blending level of ethanol into gasoline i.e. E10, E20 and E85. However, the environmental benefits of various blends of gasohol, i.e. E10, E20 and E85, cannot compensate for their higher production costs as compared to gasoline. The total environmental costs from palm biodiesel are lower than that of diesel by about 3% for B5 and 76% for B100. For the case of biodiesel blends i.e. B5 and B10, the total costs are lower than that of diesel. However, B100 is still not economically attractive and also faces constraints of feedstock availability. Therefore, several measures to improve the environmental performance and enhance the cost-competitiveness of cassava ethanol and palm biodiesel are required by focusing on maximizing utilization of wastes and by-products generated from the biofuel production systems.

5.1.3 Availabilities of feedstock supply for future biofuels production in Thailand

An increased feedstocks demand for biofuels production in Thailand is likely to continue to grow rapidly as per the government policy targets which lead to increasing concerns about availability of feedstocks supply in the long-run. This part of the study assesses the availability of feedstocks supply to satisfy the increased demand of biofuels based on the recent 15 years bio-ethanol development plan and target (year 2008-2022). For the case of bio-ethanol production, the results show that only the case of high yields improvement scenario can result in a reliable and sufficient supply of molasses, cassava and sugarcane to satisfy the long-term demands for bio-ethanol and other related industries. Cassava is identified as the critical feedstock for meeting the future ethanol targets and a reduction in cassava export is necessary. In contrast to cassava and molasses, sugarcane would play an important role as feedstock for the medium and long-term bio-ethanol production in Thailand because of its surplus availability and its comparatively high net feedstock balance results.

Meanwhile, both increase in fresh fruit bunch (FFB) yields and expansion of new oil palm plantation need urgently to be promoted by the government to avoid the shortage of crude palm oil supply. Therefore, the study concludes that to enhance long-term security of feedstocks supply for sustainable biofuels production in Thailand, increasing use of sugarcane juice as feedstock, improved yields of existing feedstocks, expansion of oil palm plantation and promoting production of biofuels derived from other feedstocks such as using agricultural residues for bio-ethanol production and utilization of Jatropha for biodiesel production are the important measures that need to be urgently implemented by the policy makers.

5.1.4 Employment and socio-economic impacts of biofuels in Thailand

In terms of socio-economic development, the results obtained from a combination of analytical approach and IO analysis show that producing bio-ethanol and biodiesel requires respectively about 17-20 times and 10 times more workers than gasoline and diesel as per unit energy. Direct employment in agriculture contributes to more than 90% of total employment. Nevertheless, there are significant differences in the characteristics of employment between persons employed in agriculture and biofuel processing sectors in Thailand. The overall impacts of bio-ethanol production in Thailand in the year 2022 are the generation of employment around 238,700-382,400 persons-year, 55.5 billion THB additional Gross Domestic Product, imported goods worth 58 billion THB but 93 billion THB of reduced petroleum imports.

5.1.5 Recommendations towards sustainable biofuels production in Thailand

The study concludes that Thailand has a large potential to produce and use biofuels for substituting petroleum fuels for domestic consumption and for trade in the global market. Biofuels have the potential to address climate-change mitigation, energy security and socio-economic development especially for the agricultural sector in rural areas. However, these advantages will only be achieved if the appropriate policy measures are adopted to direct the biofuels production in Thailand towards the sustainable biofuels production. The findings obtained from the study and recommendations for improving environmental and cost performance of biofuel production are summarized as **Table 5.1**.

Table 5.1 Recommendations for improving environmental and cost performance, economic and socio-economic performance of biofuel production in Thailand

Recommendations	Relevant aspects			
	Env.	Econ.	Feedstock avail.	Socio-econ.
Agriculture				
(1) To increase productivity of sugarcane, cassava and oil palm	×	×	×	×
1.1 Promoting good agricultural practice (GAP) for cassava, sugarcane and oil palm as suggested by the Department of Agriculture to farmers i.e. since land preparation, selection of good and appropriate varieties, regular treatment, until selecting	×	×	×	×

Recommendations	Relevant aspects			
	Env.	Econ.	Feedstock avail.	Socio-econ.
the good period of harvesting.				
1.2 Improving soil quality by using organic fertilizers or animal waste (or co-compost between EFB and POME for oil palm plantation) to substitute chemical fertilizers	×	×		
(2) Specifying the lands suitable for future oil palm plantation expansion to avoid those with high carbon stock e.g. set-aside land.	×		×	
(3) Avoding sugarcane trash burning during harvesting to reduce CH_4, CO and NO_x emissions which contribute to global warming, photo-oxidant formation, acidification, etc	×			
Feedstock processing				
(1) To maximize the use of by-products and wastes generated from the oil mills	×	×		
1.1 Recovery of biogas and nutrients from POME	×	×		
1.2 Utilization of shell and EFB as fuel for power generation	×	×		
1.3 Utilization of shell as fuel for cement and brick factories	×	×		
1.4 Using EFB as substrate for cultivating straw mushroom	×	×		
1.5 Mixing EFB with POME to make co-compost	×	×		
1.6 Using shells to produce activated carbon	×	×		
(2) To maximize use of by-products and wastes generated from the sugar mills				
2.1 Recovery of biogas from wastewater	×	×		
2.2 Utilization of surplus bagasse as fuel for power generation	×	×		
2.3 Using filter cake as organic fertilizer	×	×		
Biofuel conversion				
(1) To enhance waste management efficiency of ethanol production process				
1.1 Adding the Upflow Anaerobic Sludge Blanket (UASB) system for biogas recovery from spent wash of ethanol process	×	×		

Recommendations	Relevant aspects			
	Env.	Econ.	Feedstock avail.	Socio-econ.
1.2 Mixing spent wash with filter cake from sugar milling to produce organic fertilizers	×	×		
1.3 Producing Dry Distillers Grains (DDG) or Dry Distillers Grains with Solubles (DDGS) from spent wash to use as animal feed	×	×		
(2) To promote utilization of renewable fuel in ethanol plant to replace imported coal	×			
(3) To improve energy efficiency in ethanol plant through good practices for energy conservation e.g. regular monitoring of combustion efficiency, insulation of steam equipment and pipeline, condensate recovery, controlling the quality of feedwater entering to boiler and preventive maintenance of equipment.	×	×		
(4) To increase use of sugarcane juice as feedstock for bio-ethanol production			×	
(5) To encourage the utilization of other feedstocks especially Jatropha for future commercial biodiesel production.			×	×
(6) To develop the utilization of other feedstocks such as sugarcane trash, rice straw and bagasse for second generation bio-ethanol production			×	×
Others				
(1) To help small scale farmers for fair trading conditions with the industry				×
(2) To develop the standards of labour rights and working conditions for labours in the biofuel production chain e.g. Occupational Health and Safety (OH&S) standard and traning				×

Remarks: Env.: Environmental; Econ.: Economic; Feedstock Avai.: Feedstock Availability; and Socio-econ.: Socio-economics

5.1.6 Sustainability assessment and indicators to support sustainable biofuels production in Thailand

5.1.6.1 Sustainability assessment methodologies

The global consensus on sustainable development has set it as a target for continual improvement of technologies. 'Sustainability' is the result of the development with a concern for three main aspects: (1) sustained economic stability; (2) ecological balance (including quality of natural ecosystem, depleting resources, etc); and (3) social development and equity [194]. As well as the sustainable development of global biofuels production and use, the key environmental and socio-economic issues have been addressed in a variety of initiatives as principles and criteria for sustainable biofuels production (as shown **Table 1.1**). Nevertheless, in the real situation, it is impractical to try to develop a methodology and an indicator that would be universally applicable for all the issues of interest. Therefore, in this study, the assessment method is designed for specific issues or specific aspects of interest i.e. environmental impacts, cost performance, feedstock security and socio-economic impacts of biofuels production in Thailand. The results obtained from the assessments show that the detailed energy, environmental and economic assessment through the full biofuel systems are useful for supporting sustainable biofuels production in the future. This is because the key sustainability issues of biofuels e.g. greenhouse gas balance, net energy balance, environmental impacts, cost competitiveness compared to petroleum fuel were identified as well as the tailor-made measures to deal with those issues would be suitably designed for each specific biofuel system.

The study concludes that key principles for conducting sustainability assessment of biofuel systems are as follows: 1) setting up goal and scope of study with clarity; 2) defining it through life cycle perspective; 3) selecting methods related to the objectives; and 4) applying appropriate indicators to interpret results. The goals have been formulated from the questions to biofuels such as how does biofuel support reducing fossil fuel dependency, how does it affect the reduction of GHGs emissions or what would be the environmental consequences of production and use of biofuel in substituting conventional oil. As well as the basis that generally used for assessing, five types of units that usually defined are: (1) based on an energy performance of biofuels such as MJ of biofuels; (2) based on an amount of biofuels such as a liter of biofuels; (3) based on the feedstocks that are used to produce biofuels such as a ton of cassava; (4) based on the function of biofuel such as using biofuels for car driving kilometers; and (5) based on the total amount in a focused area and the certain time such as analysis the impacts due to the bio-ethanol production in Thailand for a year. After that, select the suitable method consistent to the objectives of the study such as using the NEB or LCA analysis when the study aims to analyze the energy efficiency or environmental impacts.

Findings from the methodology used in the study, a combination of Renewability and NER indicators obtained from NEB is useful for evaluating energy performance and effectiveness of using renewable energy to replace fossil energy. Limitation of NEB is in case that the objectives of the study focus beyond the energy issue. LCA is a useful environmental sustainability assessment tool to identify and quantify health and environmental impacts relevant to biofuel systems. However, the diverse results can be obtained due to the different approaches used to address methodological issues in LCA such as the treatment of multifunctional processes, the determination of system boundaries e.g. include or exclude LUCs or accounting for direct- and indirect-impacts, and the handling of biogenic carbon balances [195-198]. Life cycle costing analysis along with the internalization of environmental costs, i.e. externalities, can provide useful information regarding the cost-performance of biofuels as compared to petroleum fuels. However, due to the lack of information and the difficulties for tracing back to the actual extraction cost of all raw materials used in production process; therefore, prices of raw materials are generally used in the life cycle cost calculation instead of tracing back to those raw materials' extraction and production costs. Economic tool such as Input-Output analysis can be applied to assess the socio-economic impacts such as employment, GDP and trade balance of biofuels production to the economy. The advantage of using Input-Output analysis is that all direct and indirect effects of the economy from an economic sector will be estimated in a rather complete picture. Moreover, combining IO analysis which is macro level with the process analysis approach which is micro level or namely "hybrid method" would be a better strategy to investigate the employment effect of biofuels production in Thailand as the direct employment for the main production stages of biofuels system will be estimated accurately through process analysis. However, it should be remembered that the obtained results are highly sensitive to the assumptions used in the IO analysis and there are many remaining data gaps in labour force statistics and IO Tables; the statistical reporting categories should be improved in order to help capture the relevant employment for the newly-emerging biofuel sector or even for the other newly-emerging renewable energy sectors in the future.

5.1.6.2 Sustainability indicators

The sustainability indicator is a tool for simplifying, quantifying and communicating information according to the goal of assessment and group of target audience. For assessing sustainability of biofuel systems, effective indicators are needed in order to help in quantification of impacts, evaluation of the performance of biofuel systems and direction those biofuel systems to comply with the standards and criteria for sustainable biofuels production which have been set in the many initiatives or certification schemes so far, or will be set by the Thai government in the future. Based on the assessment results of the three biofuel systems in Thailand i.e. cassava ethanol, molasses ethanol and palm biodiesel and the reviewed relevant literature, **Table 5.2** shows a summary of possible indicators that can be used for assessing sustainability of biofuels in Thailand. The proposed indicators include both quantitative (i.e. indicating the sustainability performance in each aspect) and qualitative ones (i.e. indicating the processes or actions that should be adopted).

Table 5.2 Proposed key sustainability indicators to support sustainable biofuels production in Thailand

Sustainability issues	**Indicators**	**Units**	**Related pressures to the indicators**	**Level of application**	**Possible standards/ criteria/ benchmark**
1.Environmental					
1.1Greenhouse gas emissions	GHG emissions per energy output of biofuels	kg CO_2 eq/GJ	-System boundary e.g. include/exclude LUCs - Allocation method	- Site base - National base	Net emission reduction ≥50% in 2011 (based on EU) as compared to petroleum fuel system
	Substitution of fossil fuel used in biofuel plant e.g. coal by biomass fuel	MJ of fossil fuel inputs/MJ of biofuel output	- Steam and power generation tehcnology	- Site base	Minize fossil energy inputs per MJ of biofuel output
1.2 Energy balance	NEB: [Net energy output / Net energy input]	Dimensionless	-System boundary e.g. include or exclude construction of machinery - Allocation method	- Site base - National base	> 1 : net energy gain < 1 : net energy loss
	Renewability: [Energy yield output / Fossil energy input]	Dimensionless		- Site base - National base	> 1 : system approaches renewability ∞ : ideal renewability system
1.3 Other environmental issues	Abiotic resource depletion (ADP)	kg Sb eq./GJ	- Modelling used to evaluate the environmental impacts (the study has referred to the CML method)	- Site base - National base	These impacts should be minimized or at least lower than the impacts from life cycle of petroleum systems
	Acidification potential (AP)	kg SO_2 eq./GJ			
	Stratopheric ozone depletion potential (ODP)	kg CFC-11 eq./GJ			
	Human toxicity potential (HTP)	kg 1,4-DB eq./GJ			

Sustainability issues	Indicators	Units	Related pressures to the indicators	Level of application	Possible standards/ criteria/ benchmark
	Photochemical oxidants creation potential (POCP)	kg ethylene eq./GJ			
1.4 Productive capacity of land	Land use (LU)	m^2.yr/GJ	- Crop yields	- National base	Minimize land-use per biofuel output
	Land use policy to specify the suitable lands e.g. degraded land for cultivating biofuel feedstocks e.g. oil palm	None	-	- National base	The existence of the mandatory land use policy
1.5 Crop management and agrochemical use	Fertilizers or Agrochemical inputs/cultivation areas	kg chemical fertilizers or active ingredients (A.I.)/rai	- Insect Pests and diseases	- Site base	Good Agricultural Practices set by suggested by Department of Agriculture
	Substitution ratio of chemical fertilizers by organic fertilizers (from animal waste or co-compost from EFB&POME or Filter cake of sugar mills and spent wash from ethanol plant	kg chemical fertilizers substituted/ rai	- Nutrients in POME and Spent wash	- Site base	Chemicals used in cultivation of biofuel feedstocks should be minimized.
1.6 Good management practices and continuous improvement	Avoid sugarcane trash burning	% burnt cane supplied to the sugar mills	-None	- Site base - National base	% burnt cane supplied to the sugar mills (least than the current percentage which is around 50%)
	Training and dissemination of the Good Agricultural Practices to local farmers	Numbers of trained farmers	-None	- National base	
	Implementation of energy conservation program in biofuel plant	MJ energy inputs/MJ biofuel output	-Biofuel conversion technology	- Site base	Minimizing energy inputs
1.7 By-products or waste management	The amounts of waste or by-products recycled or recovered	% waste or by-product is recycled	-Waste/by-products utilization system	- Site base	Maximize use of waste or by-products generated in biofuel production system
2. Economic					
2.1 Full cost performance	Net Cost/Benefits of biofuels compared to petroleum fuel	THB/GJ	-Uncertainty of feedstock cost and crude oil price -Modelling and assumptions used to monetize the externalities	- National base	Maximize the Net Benefits of biofuels
3. Socio-economic					
3.1Employment	Total employment generated from biofuel system compared to petroleum fuel system	Number of people employed	-Approach and assumption used to quantify the employment -The scope of the analysis (i.e. direct, indirect, induced)	- National base	The generated employment should be more than investment in petroleum fuel sector
	Wage and labour conditions respect to all applicable laws	None	-None	- Site base - National base	To comply the national laws and regulations or the ILO Labour conventions
3.2 Human health and safety	Implementation of the OH&S standard for agricultural workers and workers in biofuel industry	None	-None	- Site base	To comply the OH&S standard for agriculture and industry in Thailand
4. Food security					
Food availability	Net feedstock balance: [the amount of feedstock surplus (after accounting for	ton of feedstock per year	-Modelling to project crop production -Modelling to estimate demand for	- National base	≥ 0 : Availability of feedstock to satisfy the demand for food and

Sustainability issues	Indicators	Units	Related pressures to the indicators	Level of application	Possible standards/ criteria/ benchmark
	the demand for food and others existing industries) – the amount of feedstock required for biofuel production]		food and other industries		biofuel < 0 : Lack of feedstock to supply for both food and biofuel demand (i.e. reduction of food export or increased production is required/ import of feedstock is necessary)
5. Technology					
Research and development for continual improvement	The development of second generation biofuels	% share of second generation biofuel in the total biofuel production	-Government policy -Cost performances as compared to petroleum fuels and first generation biofuels	- National base	The existence of second generation biofuel in the commercial scale in Thailand
	R&D on the management of the residues, wastes and by-products from biofuel production	Number of research and new technologies for waste management in biofuel system	-Government policy	- National base	Increase in the numbers of R&D and available technologies for waste management in biofuel systems

5.2 Future Works

Based on the findings of this study, the anticipated growing demand for biofuels and the development of biofuels in the foreseeable years, future research areas especially regarding biofuels and land-use change can be summarized as follows:

(1) Determining more accurate GHG balances for biofuel systems in Thailand: Even though land-use change is the essential factor for the GHG performances of biofuel systems; however, it has not been possible to calculate this accurately so far due to the lack of reliable information on the carbon stocks and the GHG emissions associated with different forms of soil, different types of land prior to conversion to cropland for biofuels and the different cultivation practices (e.g. tillage and non-tillage). These need further investigation as well as the indirect effects or namely "indirect land-use change" should be accounted into the system boundary of biofuels production Although a lot of uncertainties are related to the determination of indirect LUC emissions, but several studies have noted their importance [55, 199-203] especially an increasing number of governments are considering direct and indirect land use change emissions in the elaboration of policies concerning biofuels e.g. United States through California Low-Carbon Fuel Standard and EPA Renewable Fuel Standard, United Kingdom through UK Renewable Transport Fuel Obligation, European Union through Renewable Energy Sources Directive and EU Low Carbon Fuel Standard. Therefore, the indirect land-use changes modeling for biofuels or even food production in Thailand would be an interesting research in the future.

(2) Clarifying the links between food security and biofuels in Thailand: The complex relationship between food security and biofuels in Thailand should be explored in order to get clearer picture of policy decision makers in promotion of biofuels such as whether biofuels should be subsidized or which kind of measures needs to be adopted to avoid the food security problems. Therefore, food security needs to be defined in the Thai context as well as the food security indicators to measure the implications of biofuels production in Thailand on the four key dimensions of food security as defined by FAO [204] i.e. availability of food, access to food, stability of food and utilization of food should be explored and developed. In addition, the future work can also be extended to the analysis of the role of the demand for biofuels in the rises in food prices in Thailand or in the world as Thailand is known as one of the world's leading exporters of agricultural products.

(3) Determining the cost and environmental performances of different pathways for utilizing by-products and residues generated over the entire life cycle of biofuels production: As there is a continual improvement of biofuel conversion technology and also the technologies for making benefits from the by-products, wastes and agricultural residues generated during the biofuels production (e.g. utilizing of EFB for energy generation or for other purposes); therefore, the comparative assessment for those future options should be investigated for identifying the most appropriate way to maximize economic and environmental benefits of biofuel production system.