

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Environmental sustainability of bio-ethanol production in Thailand

This section shows the results of net energy balance (NEB) and life cycle assessment (LCA) of the existing bio-ethanol production systems in Thailand. The analysed results focus on (1) the evaluation of energy efficiency and renewability of the bio-ethanol system, (2) the identification of current significant environmental risks and (3) recommendations in order to improve the environmental performance of ethanol production in Thailand. The NEB and LCA for the entire cassava and molasses ethanol production system in Thailand are assessed. Detailed information according to goal and scope definitions, systems boundary and data sources are described in **Chapter 3**.

4.1.1 Cassava based ethanol

In Thailand, there was only one commercial cassava-ethanol plant with a capacity of 130,000 L/day operating in 2007. Although the government had approved twelve cassava-ethanol plants with a total daily capacity of 3.4 ML which were expected to be operational in 2008, only one new ethanol plant which could use cassava as feedstock started operating in January 2009. The study refers to the production data from the existing cassava ethanol as mentioned earlier which details were shown in **Chapter 3**.

4.1.1.1 Energy analysis

This study divided energy analysis into two scenarios, viz., Scenario I: Current operation of the existing cassava ethanol plant and Scenario II: Designed operation of the existing cassava ethanol plant. These two scenarios are considered because cassava ethanol production is a new industry for Thailand being promoted by the government; therefore, there is a potential that current production will have lower efficiency than the design due to lack of adequate experience to control the plants. The results are shown in **Table 4.1**.

The net energy ratio (NER) of about 0.82 of the current operation scenario indicates that producing cassava ethanol by the existing plant leads to a net energy loss. This result differs significantly from designed operation scenario where the plant should have NER = 1.19 and also has a significant difference when compared to a recent study of cassava ethanol assessment in Thailand which showed the NER = 1.93 [19]. However, the previous

study used the estimated information from a pilot-scale study and scaled-up calculation. One of the reasons that NER in the previous study is higher than the existing cassava plant is the use of Simultaneous Saccharification and Fermentation (SSF) which can save more energy and time when compared to the traditional fermentation which is currently in use [107]. The energy analysis results show that the current operation consumes 17,287 MJ/1000 L of ethanol for steam production which is 1.75 times the designed value. A key factor resulting in the high energy consumption is an inefficient steam production system [84]. The detailed energy analysis of the existing plant showed an average boiler efficiency (η), defined as energy in produced steam divided by total energy input, of only 62 % efficiency while the designed efficiency ranges between 85-90%. A major cause of this inefficiency is the high hardness level of feed water resulting in problems with the boiler tubes. However, this problem is very site specific and should not occur if this and other new cassava ethanol plants have good practices for steam production.

Table 4.1 Energy balance (MJ) for production of 1000 L cassava ethanol^a

Items	Unit	Scenario I: Current operation		Scenario II: Designed operation	
		Total energy	Fossil energy	Total energy	Fossil energy
1) Cassava farming/processing					
<i>Ia. Cassava farming</i>					
NPK fertilizers	MJ	1,790	1,703	1,779	1,693
Herbicide	MJ	649	617	645	612
Diesel (farm machinery)	MJ	317	317	315	315
Labour	MJ	377		375	
<i>Ib. Cassava processing</i>					
Diesel (chip processing)	MJ	-	-	761	761
2) Transport					
Fresh cassava	MJ	885	885	880	880
3) Ethanol conversion					
Coal (Steam production)	MJ	16,495	16,495	8,104	8,104
Energy recovered from biogas used for steam production)	MJ	792	-	1,760	-
Electricity	MJ	4,430	4,297	3,130	3,036
Net energy inputs	MJ	25,735	24,314	17,749	15,401
NEV^b	MJ	(-4,535)		3,827	
NRnEV^c	MJ		(-3,114)		5,799
Net Energy Ratio (NER)^d			0.82		1.19
Renewability^e			0.87		1.38

^aEnergy content of ethanol = 21,200 MJ/1000 L ethanol.

^bNet Energy Value (NEV) = Energy content of ethanol – Net energy inputs.

^cNRnEV = Energy content of ethanol – Fossil energy inputs.

^dNet Energy Ratio (NER) = Net energy outputs/Net energy inputs.

^eRenewability = Net energy outputs/Net fossil energy inputs.

4.1.1.2 Environmental impacts

The life cycle impact assessment results from the production of 1000 litres of cassava based ethanol are shown in **Table 4.2**. The ethanol conversion stage contributes the heaviest environmental burdens in the system; emissions of CO₂, SO_x, NO_x, CO and particulates from the steam boiler using sub-bituminous coal in the ethanol plant contribute about 52%, 48%, 51 % and 43% to global warming, photochemical oxidation, acidification and human toxicity impacts, respectively. In addition, indirect emissions due to grid electricity production and coal extraction are also added in this stage making it the crucial source of environmental problems. The eutrophication potential, however, mainly stems from two major sources i.e. fertilizers use in cassava cultivation and the wastewater discharged from the UASB system and collected in wastewater ponds inside the plant.

Table 4.2 Potential environmental impacts of 1000 L cassava ethanol production

Environmental Impact	Unit	Life cycle stages							
		Cassava cultivation		Transport		Ethanol conversion		Total	
		I ^a	II ^b	I	II	I	II	I	II
Land use	rai ^c .yr	2.32	2.30	-	-	-	-	2.32	2.30
	(ha.yr)	0.371	0.368					0.371	0.368
Global warming	kg CO ₂ eq.	433	430	69	68	2,379	1,424	2,881	1,922
Photo-oxidation	kg C ₂ H ₄ eq.	0.13	0.12	0.02	0.02	1.12	0.65	1.27	0.80
Acidification	kg SO ₂ eq.	2.41	2.40	0.39	0.38	23.44	13.22	26.24	16.00
Human toxicity	kg 1,4 DB eq	4.23	4.20	0.88	0.86	22.63	13.47	27.73	18.53
Eutrophication	kg PO ₄ ³⁻ eq.	1.08	1.07	0.09	0.08	2.44	1.64	3.60	2.80

^aI : Scenario I (current operation) ; ^b II : Scenario II (designed operation) ; ^c1 rai = 0.16 hectare

4.1.2 Molasses based ethanol

Of the seven commercial ethanol plants operating in 2007, six were molasses based with a total capacity of 825,000 L/day [153]. Nevertheless, three more sugar juice and/or molasses ethanol plants with a combined capacity of 420,000 L/day have been approved and started operating in year 2008 [154]. The study refers to the production data from three ethanol producers and the product is 99.5% purity ethanol for using in gasohol and details of each plant are shown in **Table 4.3**.

Table 4.3 Comparison of the key characteristics of the three studied molasses ethanol plants

System Characters	MoE Plant-1	MoE Plant-2	MoE Plant-3
Type of ethanol plant	Sugar milling & ethanol production	Individual ethanol plant	Individual ethanol plant
Fuel used for steam production	Buying from sugar mills	Rice husk & recovered biogas	Corn cob
Type of electricity source	Buying from sugar mills	In-house production	Buying from grid-mix
Type of wastewater treatment	Organic fertilizers production	Biogas production	End of pipe treatment
Transportation of molasses	Pipeline (Electricity)	Truck (Diesel)	Truck (Diesel)

4.1.2.1 Energy analysis

The energy analysis is presented based on different characteristics of the three existing molasses ethanol plants in Thailand. Unlike the case for cassava, design values do not need to be considered in the molasses ethanol production because molasses based ethanol has been produced in Thailand for many years. Therefore, technologies and knowledge in this case are already quite mature. The net energy ratio (NER) and renewability of those three plants were calculated by using the same methodology and assumptions as for the case of cassava ethanol. The results are shown in **Table 4.4**.

Table 4.4 Energy balance (MJ) for production of 1000 L molasses based ethanol (MoE)

Items	MoE Plant-1		MoE Plant-2		MoE Plant-3	
	Total energy	Fossil energy	Total energy	Fossil energy	Total energy	Fossil energy
1) Sugarcane farming						
NPK fertilizers	3,228	3,069	3,089	2,937	2,932	2,788
Herbicide	662	626	634	599	601	569
Diesel (farm machinery)	3,968	3,968	3,798	3,798	3,604	3,604
Labour	429		418		397	
2) Sugar Milling						
Surplus electricity during normal operation (to grid)	(-2,608)		(-2,496)		(-2,369)	
Surplus bagasse (converted to electricity to grid)	(-7,047)		(-6,745)		(-6,401)	
3) Ethanol conversion						
Steam & Electricity	17,378		16,412		23,491	2,173
4) Transport						
Sugarcane	1,955	1,955	1,871	1,871	1,775	1,775
Molasses	238		869	869	1,155	1,155
Net energy inputs	27,858	9,618	27,091	10,074	33,955	12,064
Net energy outputs (Ethanol & surplus electricity)	30,855		30,441		29,970	
NEV	2,997		3,350		(-3,985)	
NRnEV		21,237		20,367		17,906
Net Energy Ratio (NER)	1.11		1.12		0.88	
Renewability	3.21		3.02		2.48	

The net energy output from molasses ethanol includes energy content of ethanol and surplus electricity from sugar milling. Two of the molasses ethanol plants (MoE plant-1 and plant-2) have an NER slightly higher than 1 while the third one (MoE plant-3) loses energy. The poor performance of the third one is due to inadequate energy conservation practices especially for the steam production and utilization system e.g. less amount of condensate recovery, no biogas recovery and low efficiency of boiler due to lack of preventive maintenance. The result also shows that among all subsystems in the molasses ethanol cycle, ethanol conversion is the most energy-consuming stage, contributing two-thirds of the net energy input. Of special interest is the MoE plant-1 where due to the integration of sugar milling and ethanol production, molasses can be transported through pipes to the ethanol conversion plant resulting in reduced fossil energy use. Moreover, the MoE plant-1 also has the highest renewability of about 3.21 indicating that about 69% of the final fuel energy is obtained from renewable resources. It means that fuel ethanol produced from the MoE plant-1 can be considered renewable and the system of MoE plant-1 approaches complete renewability (100%).

4.1.2.2 Environmental impacts

Table 4.5 shows the environmental impact potentials of molasses ethanol in Thailand. It is evident that the MoE plant-3 which has lowest NER and renewability gives the highest global warming potential at 841.29 kg CO₂-eq. The eutrophication potential, which is mainly related to the load of COD, Total-P and Total-N in wastewater, is also the highest in MoE plant-3 at about 31.02 kg PO₄³⁻-eq. The significant difference of eutrophication potential depends upon the amount of wastewater or spent wash from ethanol conversion process and treatment technique of each ethanol plant. The MoE plant-1 which uses spent wash from ethanol plant to mix with the filter cake (a by-product from sugar milling) in order to produce organic fertilizers gives the lowest eutrophication potential value. The MoE plant-2 has anaerobic treatment and biogas recovery system thus also yielding lower eutrophication impact than the MoE plant-3 which has only ponds to collect and treat wastewater. The other impacts including photochemical oxidation, acidification and human toxicity are not significantly different for these three MoE plants.

Figure 4.1 presents the average impacts over the “cradle to gate” of molasses ethanol. The average values are obtained by using the weighting factor (WF) based on production capacity of each plant. The results show that sugarcane cultivation has the most

contribution to all the environmental impact categories considered. It differs from cassava ethanol where the ethanol conversion stage has the most significant contribution because of the credits from electricity produced from surplus bagasse at sugar milling which are partly allocated to molasses. The environmental credits from using bagasse such as reduction of global warming, acidification and human toxicity impact during the sugar milling stage are shown in **Figure 4.1**.

Table 4.5 Environmental impacts potential of 1000 L molasses ethanol production

Environmental Impact	Unit	Molasses based Ethanol Plants			
		MoE Plant-1	MoE Plant-2	MoE Plant-3	Average
		WF ^a = 0.40	WF = 0.53	WF = 0.07	
Land use	rai.yr (ha.yr)	2.53 0.40	2.42 0.39	2.30 0.37	2.46 0.39
Global warming	kg CO ₂ eq.	653.81	689.72	841.29	685.46
Photo-oxidation	kg C ₂ H ₄ eq.	5.88	5.78	5.42	5.80
Acidification	kg SO ₂ eq.	11.28	13.55	11.55	12.51
Human toxicity	kg 1,4 DB eq	16.51	21.02	19.29	19.10
Eutrophication	kg PO ₄ ³⁻ eq.	14.66	21.78	31.02	19.55

^aWeighting Factor (WF) derived from the production capacity of each plant

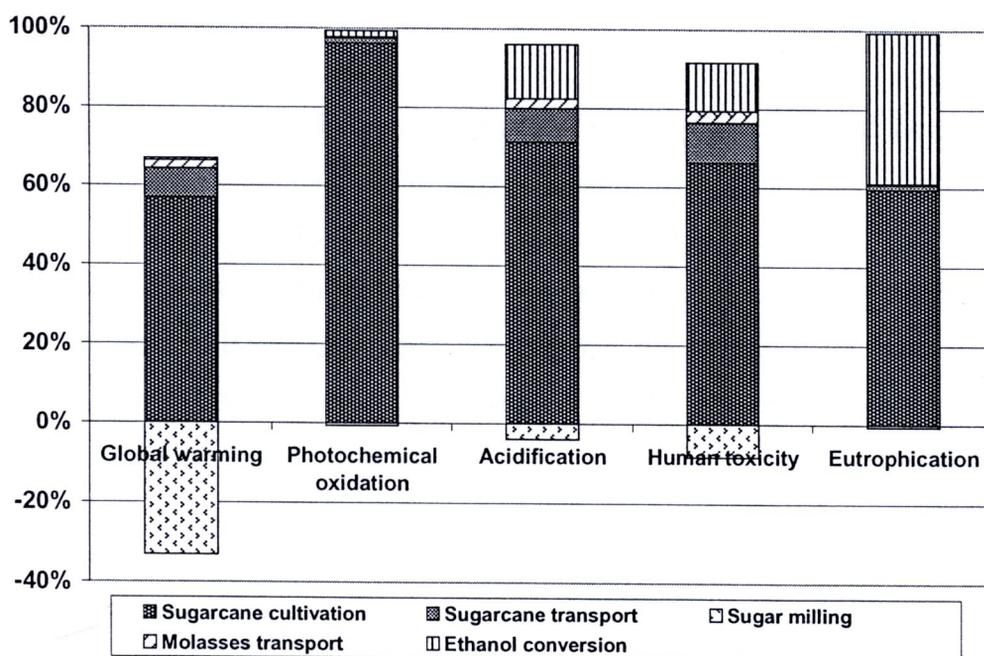


Figure 4.1 Average impacts contribution from "cradle to gate" of 1000 L molasses ethanol.

4.1.3 Comparison of environmental performance

Based on the five sets of LCIA results from Plant CE-1, Plant CE-1 (designed), MoE plant-1, MoE plant-2 and MoE plant-3, an average environmental impacts comparison between cassava and molasses ethanol is done as presented below.

(1) Global warming

The average global warming potential (GWP) of cassava and molasses ethanol are 1922 and 685 kg CO₂ eq./1000L ethanol, respectively (**Figure 4.2**). The significant difference between cassava and molasses ethanol stems from types of fuel used at the ethanol conversion stage. The current molasses ethanol production facilities in Thailand mainly use biomass such as corn cob, bagasse and rice husk for steam production and electricity generation. On the other hand, the existing cassava ethanol plant consumes coal as fuel to produce steam and electricity from grid system mainly produced from natural gas [155]. This is also reflected in the renewability of existing molasses ethanol plants which are higher than the cassava ethanol plant. Another contrast is the GWP at feedstock processing stage where molasses can reduce 673 kg CO₂ eq./1000L ethanol due to the credits of surplus bagasse in sugar milling. Nevertheless, trash burning during harvesting of sugarcane is a major source of CO and CH₄ emissions which leads to high value of GWP in feedstock production stage. One of various measures to mitigate global warming impact is cane trash utilization for energy purposes [83]. Cane trash can be considered a renewable fuel supply competitive to other conventional energy sources with a heating value of approximately 15.48 MJ/kg [84]. In a reasonable assumption 50% of cane trash should be left in fields to secure soil quality and the other 50% are possible to use as a fuel in sugar milling [83]. If this assumption were applied, the cane trash burned in fields about 125 kg dry matter (DM)/ton sugarcane (based on 250 kg DM of trash produced/ton cane and 50% in Thailand that cane trash burned in the fields) would also be avoided. Calculations show that by avoiding cane trash burning, the GWP of molasses ethanol during feedstock production could be decreased from 1,157 to 669 kg CO₂ eq. This along with credits from electricity production from cane trash utilization lead an overall GWP of about -288 kg CO₂ eq./1000 L molasses ethanol. It must be noted that the emissions from cane trash harvesting, transportation and combustion for power production are included in the calculations.

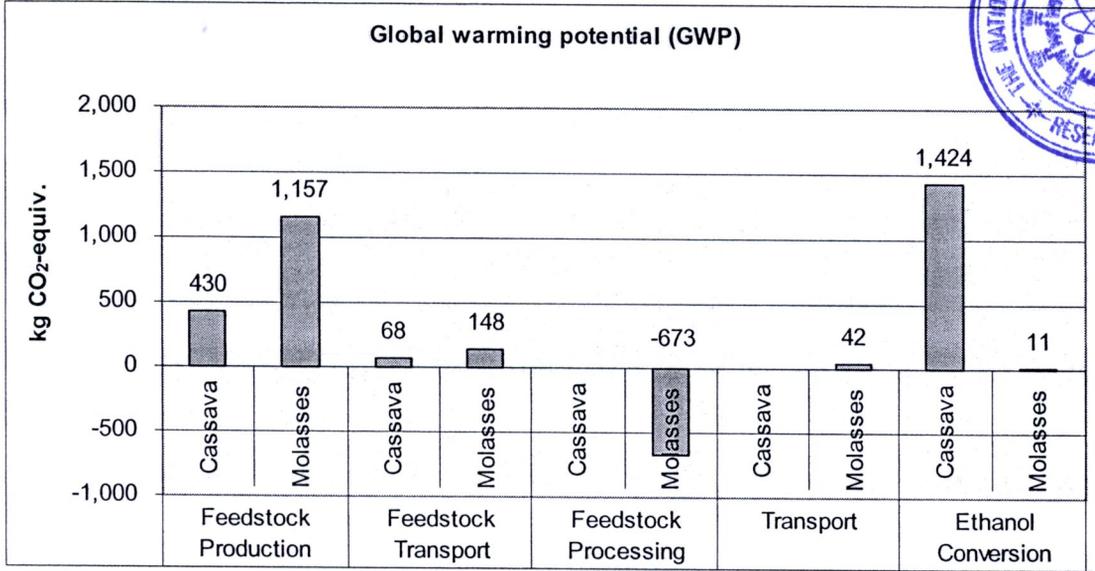
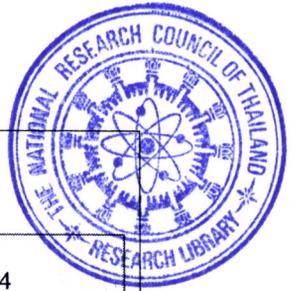


Figure 4.2 Comparison of GWP from 1000 L of cassava and molasses ethanol

(2) Photochemical oxidation

In this study, photochemical oxidation potential (POCP) is associated with the emissions of NO_x, SO₂, CH₄ and CO. **Figure 4.3** shows that sugarcane growing and harvesting is a major stage that results in higher POCP of molasses ethanol when compared to cassava. The major contribution in this stage comes from the burning of sugarcane leaves to speed up harvesting which contribute to 93% of total POCP. Once again, the POCP of molasses ethanol during feedstock production could also be reduced from 5.65 to be 0.35 kg C₂H₄-eq from avoided burning on the field. Avoided burning and utilization for electricity would lead to an overall POCP of only 0.48 kg C₂H₄-eq./1000 L of molasses ethanol.

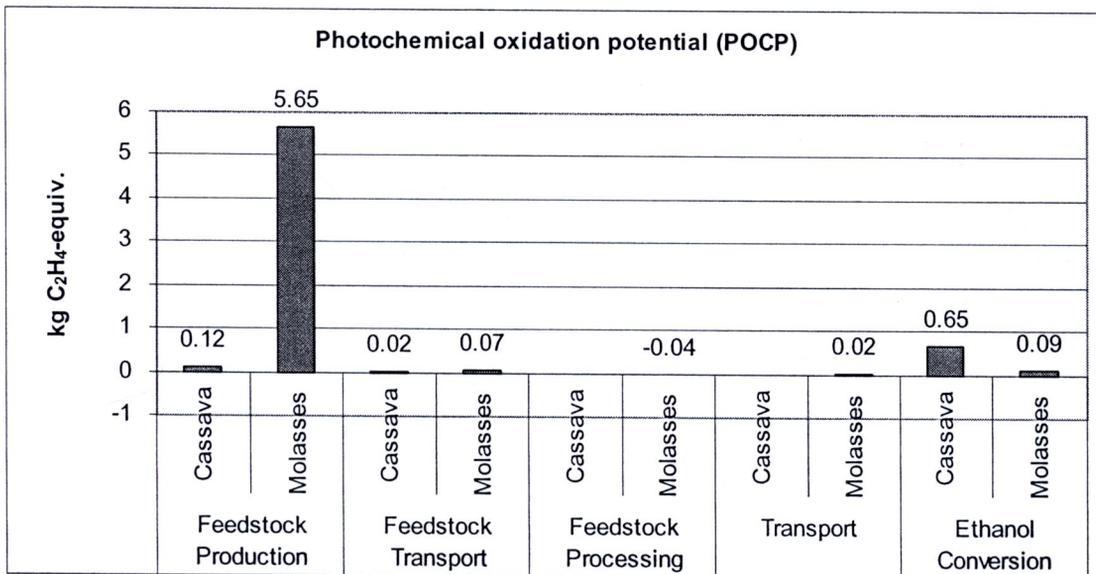


Figure 4.3 Comparison of POCP from 1000 L cassava and molasses ethanol

(3) Acidification

Acidification potential (AP) results stem from the emissions of SO₂ and NO_x. **Figure 4.4** indicates that using sub-bituminous coal for steam production in cassava ethanol production results in a high amount of acidifying substances. The acidification potential for molasses ethanol is mainly contributed by the feedstock production, diesel combustion and cane trash burning being the two major sources of problem contributing 44% and 41% of AP, respectively. Avoiding cane trash burning could reduce the AP of molasses ethanol during feedstock production from 9.68 to be 5.73 kg SO₂-eq. This along with utilization of the cane trash for electricity would reduce the total AP from 12.5 to 8.15 kg SO₂-eq./1000L molasses ethanol

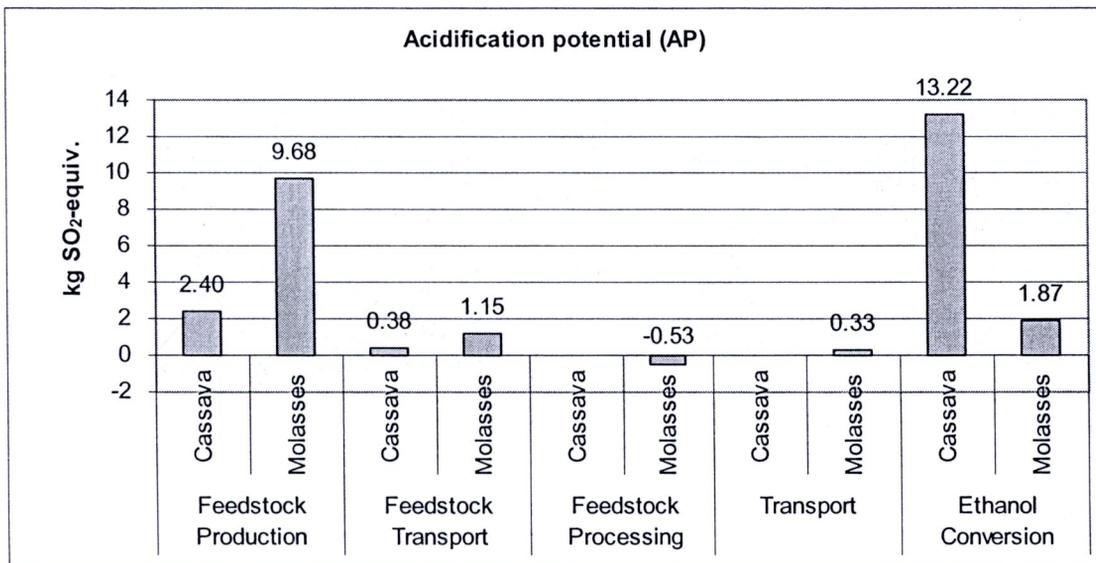


Figure 4.4 Comparison of AP from 1000 L of cassava and molasses ethanol

(4) Human toxicity

Human toxicity potential (HTP) originates from emissions of NO_x, SO₂ and particulates. As the substances causing HTP are mostly the same as the acidifying substances, the stages contributing mainly to the two impact categories are also similar. Like AP, HTP is also contributed mainly by the cassava ethanol conversion stage and sugarcane cultivation and harvesting stages as seen in **Figure 4.5**.

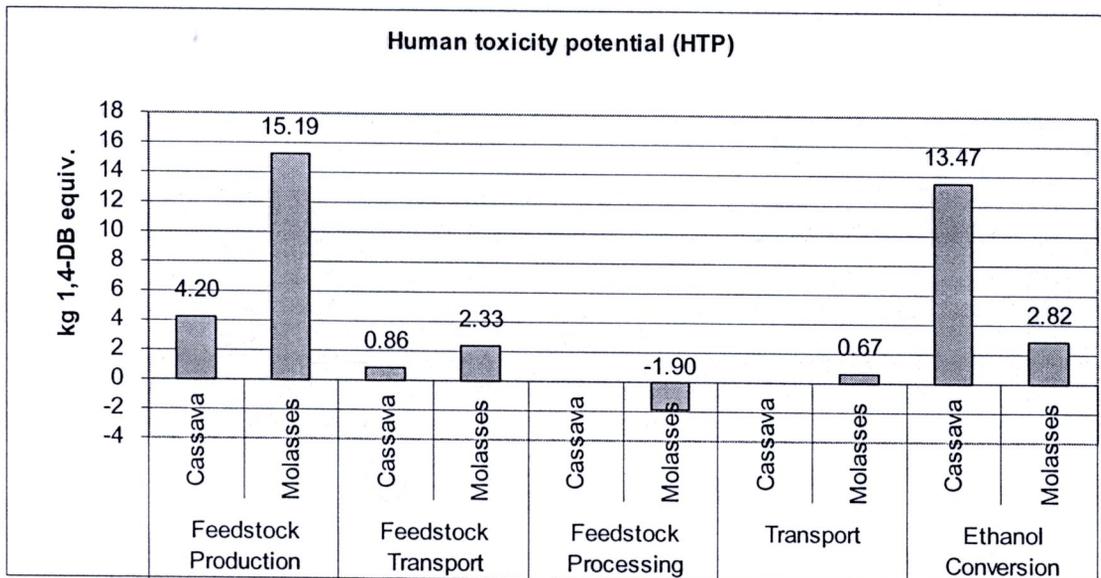


Figure 4.5 Comparison of HTP from 1000 L of cassava and molasses ethanol

(5) Eutrophication

The Eutrophication Potential (EP) is set at 1 for phosphate. Emission of NO_x to air and COD, Total-P and Total-N emissions to water contribute to eutrophication. **Figure 4.6** shows that ethanol conversion stage and feedstock production stage are the two large contributors of the eutrophication impact. The EP value during molasses ethanol conversion is significantly higher than cassava ethanol because the spent wash from molasses ethanol process has COD ranging between 100,000-150,000 mg/L while COD of spent wash from cassava ethanol is only 40,000-60,000 mg/L. Furthermore, it is obvious that the existing cassava ethanol plant which used the Upflow Anaerobic Sludge Blanket system (UASB) for treating wastewater and recovering biogas is more effective than the wastewater treatment system of the molasses ethanol plants which are mainly using pond systems [21]. In addition, fertilizers use in feedstocks production stage is also a major source of eutrophication. Effective use of fertilizers and chemicals in agriculture could potentially reduce this impact.

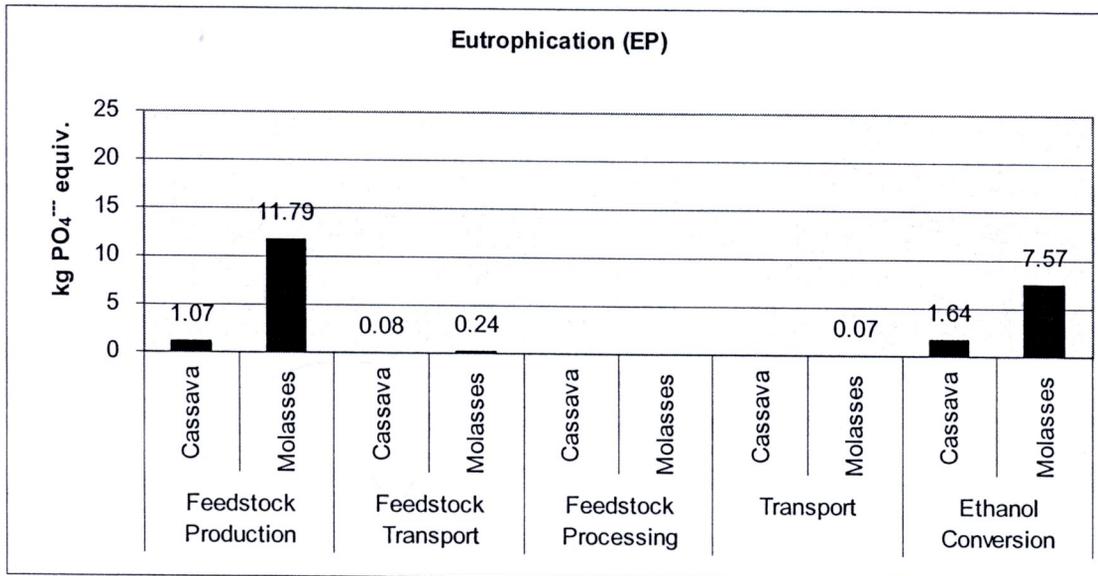


Figure 4.6 Comparison of EP from 1000 L of cassava and molasses ethanol

4.1.4 Recommendations for improving environmental performance

According to environmental hotspots of existing cassava and molasses ethanol production as obtained by the net energy analysis and life cycle assessment results, the following recommendations are made towards improving the energy and environmental performance of bioethanol production in Thailand:

(1) Reduction of air emissions from agricultural activities, especially, preventing the sugarcane trash burning during harvesting could help decreasing CH₄, CO and NO_x emissions which contribute to global warming, photochemical oxidation, acidification, etc.

(2) Enhancing waste management efficiency of ethanol producers and creating value-added or credit to the environment by promoting waste recycling such as biogas recovery, organic fertilizer production and Dry Distillers Grains (DDG) or Dry Distillers Grains with Solubles (DDGS) production. The investigation results show that currently Thai ethanol producers lack by-product management. For example, a research team of the Kasetsart Agricultural and Agro-industrial Product Improvement Institute (KAPI), Kasetsart University estimated that 0.23 kg of DDGS will be produced per L of cassava ethanol and 1.08 kg organic fertilizer per L of molasses ethanol will be obtained. To determine environmental benefits from these by-products, economic allocation technique is used assuming that the prices of ethanol, DDGS (12% protein) and organic fertilizer (spent wash of ethanol process mixed with filter cake from sugar milling) are 0.76 \$US/L, 152

\$US/Ton [107], 85 \$US/Ton [84] respectively (exchange rate: 1 \$US = 33 THB). The estimated results show that the environmental burdens of cassava ethanol and molasses ethanol would decrease about 4.5% and 10.8% respectively if the DDGS were produced as by-product of cassava based ethanol plant and the organic fertilizers were produced as by-product of molasses based ethanol plant. Besides, the ethanol producers also gain the economic benefits from selling these by-products.

(3) Promoting utilization of renewable fuel in ethanol conversion stage could help reducing of GHG emissions as well as increasing renewability. Ethanol conversion stage is the heaviest energy consumer over the life cycle. The results show that the plant CE-1 which uses coal as fuel for steam production gives lowest renewability and has the highest value of GWP/L of ethanol.

(4) Improving energy efficiency in ethanol production is also an important measure because the investigated and analysed results indicate that there are some ethanol plants having very low energy performance. One of the areas that should be encouraged is energy conservation and good practices of steam production including regular monitoring of combustion efficiency, insulation of steam equipment and pipeline, condensate recovery, controlling the quality of feedwater entered to boiler and preventive maintenance of steam equipment. Technical knowledge about cassava ethanol production such the SSF and water-wastewater management needs to be encouraged for industrial application.

4.2 Environmental sustainability of palm biodiesel in Thailand

This section shows the results of net energy balance and life cycle assessment of palm biodiesel systems in Thailand. The assessments focus on (1) evaluation of energy efficiency and identification of current environmental risks of the production system, (2) estimation of the availability of CPO supply for future palm biodiesel production in Thailand; and (3) recommendations to improve the environmental performance of palm biodiesel production in Thailand. Detailed information about goal and scope definitions, systems boundary and data sources are described in **Chapter 3**.

4.2.1 Energy analysis

The energy analysis of palm biodiesel system is divided into two scenarios i.e. with and without consideration of the by-products. The results are shown in **Table 4.6**.

Table 4.6 Energy balance (MJ) for production of 1000 L palm biodiesel^a

Items	Base case (PME)		PME & its co-products	
	Total energy	Fossil energy	Total energy	Fossil energy
1) Oil palm plantation				
Seeds	76	76	76	76
NPK fertilizers	5,537	5,265	5,537	5,265
Herbicide	925	874	925	874
Diesel (farm machinery)	88	88	88	88
2) FFB transport				
Diesel	1,224	1,224	1,224	1,224
3) CPO production				
Diesel	339	339	339	339
Kernel (sold)			(-5,703)	
Surplus shell (sold as biomass energy)			(-1,233)	
EFB (sold as biomass energy)			(-23,964)	
Biogas recovered from POME (used for steam production)			(-1,468)	
4) CPO transport				
Diesel	474	474	474	474
5) Palm biodiesel conversion				
Electricity	966	937	966	937
Methanol	6,381	6,381	6,381	6,381
NaOH	160	160	160	160
Glycerol			(-3,644)	
Net energy inputs	16,171	15,819	16,171	15,819
NEV^b	17,247		53,259	
NRnEV^c		17,599		53,611
Net Energy Ratio (NER)^d		2.07		4.29
Renewability^e		2.11		4.39

^aDensity of PME is 0.8778 kg/L and Energy content of PME is 38.07 MJ/kg or equivalent to 33,418 MJ/1000 L PME.

^bNet Energy Value (NEV) = Energy content of PME (and its co-products) – Net energy inputs.

^cNRnEV = Energy content of PME (and its co-products) – Fossil energy inputs.

^dNet Energy Ratio (NER) = Net energy outputs/Net energy inputs.

^eRenewability = Net energy outputs/Net fossil energy inputs.

The energy performance of palm biodiesel has been examined by the renewability and NER. NER > 1 indicates the palm biodiesel system has net energy gain, on the other hand, Renewability > 1 on the other hand is a minimum requirement to indicate that the

biodiesel system can help reduce dependency on fossil energy. The NER and renewability of PME (individual) are 2.07 and 2.11; while, the NER and renewability of PME (with its co-products) are 4.58 and 4.68. This indicates that producing PME significantly lead to a net energy gain and using PME can help reduce dependency on fossil energy. The obtained results close to the NER of PME alone and PME with co-products which studied by Pleanjai and Gheewala (2009) i.e. are 3.58 and 2.42, respectively [97]. The greater value of NER of PME with co-products is due to the EFB, which is currently is being dumped in the plantation or in the mill, were used as biomass fuel. With this assumption, around 23,964 MJ/1000 L PME could be saved and this would result in a higher NER and Renewability of PME. Today, there are opportunities for more efficient utilization of the co-products including fiber, shell, EFB and POME which can help improve the overall energy performance of palm biodiesel system. For example, an adaptation of the upflow anaerobic sludge blanket (UASB) reactor and the upflow anaerobic sludge fixed-film (UASFF) reactor which have more efficiency in COD removal from POME, less hydraulic retention time and high methane composition in the generated biogas as compared to the current anaerobic pond could help increase performance of wastewater treatment and increase efficiency of biogas recovery for use as fuel at the mills [109].

4.2.2 Environmental impacts

The life cycle impact assessment results from the production of 1000 litres of palm biodiesel are shown in **Table 4.7**. Land-use changes (LUCs) have not yet been included in this base case scenario as the assumption that FFB used currently originate from the old palm plantation. However, the possible LUCs for future oil palm plantation and their consequential impacts on the environmental performance of palm biodiesel will be discussed later.

4.2.2.1 Global warming

The GWP of palm biodiesel is 1,233 kg CO₂ eq./1000L for the base case scenario. Oil palm plantation and palm oil milling are the two major contributors to global warming. **Figure 4.7** shows that N-fertilizer application and its consequential impact on N₂O emissions is the main source of the agricultural stage. At the milling stage, methane generated from the treatment of POME in open ponds is the biggest source of GWP (**Figure 4.8**). It contributes almost 100% of GWP in the milling stage and contributes about 43% of the total GWP of PME. However, biogas production from POME has gained

recognition in Thailand due to the economic benefits from CDM opportunities. Thus a great opportunity exists to improve GHG performance of PME by installing the anaerobic treatment and biogas recovery system. Then, the emitted methane would be avoided and the credits for the energy from biogas could be accounted to the GHG performance of PME.

4.2.2.2 Photochemical oxidation

In this study, photochemical oxidation potential (POCP) is associated with the emissions of NO_x , CH_4 and CO . **Table 4.7** shows that palm oil milling is the major stage that results in high POCP of palm biodiesel and the major contributor in this stage is the methane emission from POME in open ponds (**Figure 4.8**).

4.2.2.3 Acidification

The acidification potential (AP) results in this study are mainly obtained from the emissions of SO_2 and NO_x . **Table 4.7** indicates that oil palm plantation is the main contributor to AP and this originates from the SO_2 and NO_x generated during production of N-P-K fertilizers (**Figure 4.7**). The substitution of chemical fertilizer used at the plantation by compost from the co-composting of EFB and POME would be an opportunity to mitigate the environmental burdens of CPO and also PME [156].

4.2.2.4 Human toxicity

In the results, human toxicity potential (HTP) is scoped only from emissions of NO_x , SO_2 and particulates. As the substances causing HTP are mostly the same as the acidifying substances, the stages contributing mainly to the two impact categories are also similar. Like AP, HTP is also contributed mainly by the N-P-K fertilizer application at the oil palm plantation as seen in **Table 4.7** and **Figure 4.7**.

4.2.2.5 Eutrophication

In this study, emission of NO_x to air and COD, Total-P and Total-N emissions to water contribute to eutrophication. Even though, the POME from palm oil milling has high organic content, this is removed by the wastewater treatment system before direct discharge to the environmental following pollution regulations. Therefore, only fertilizers and agrochemical use in oil palm plantation stage is the major source of eutrophication as shown in **Table 4.6**. Effective use of fertilizers and chemicals in agriculture could potentially reduce this impact.

Table 4.7 Potential environmental impacts of 1000 L palm biodiesel production

Environmental impacts	Unit	Life cycle stage of palm biodiesel production					Total
		Oil palm plantation	Transport (FFB)	Palm oil milling	Transport (CPO)	Biodiesel conversion	
Land use	rai.yr (ha.yr)	1.48 (0.24)					
Global warming	kg CO ₂ eq.	544	56	531	27	75	1,233
Photochemical oxidation	kg C ₂ H ₄ eq.	0.05	0.02	0.14	0.02	0.02	0.25
Acidification	kg SO ₂ eq.	1.00	0.31	0.05	0.33	0.30	1.99
Human toxicity	kg 1,4 DB eq.	1.16	0.71	0.11	0.67	0.38	3.03
Eutrophication	kg PO ₄ ³⁻ eq.	0.11	0.07	0.02	0.07	0.04	0.32

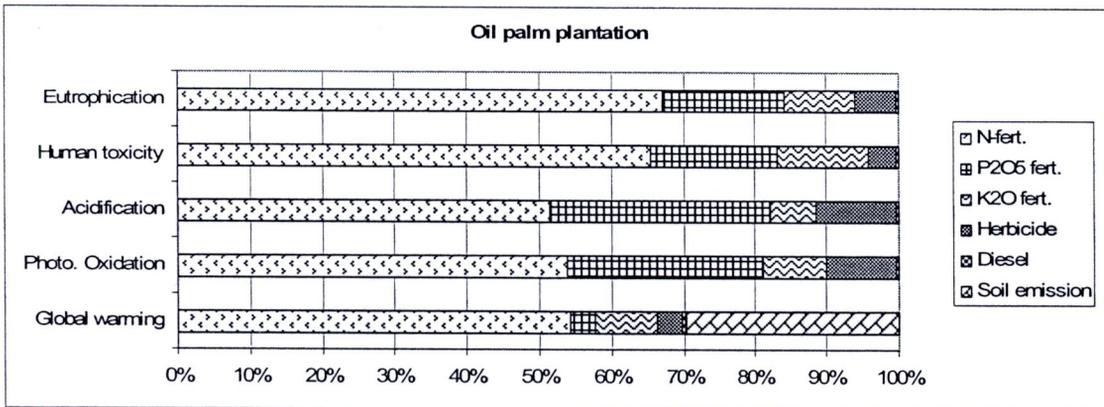


Figure 4.7 Environmental impacts of oil palm plantation (based on 1000L PME)

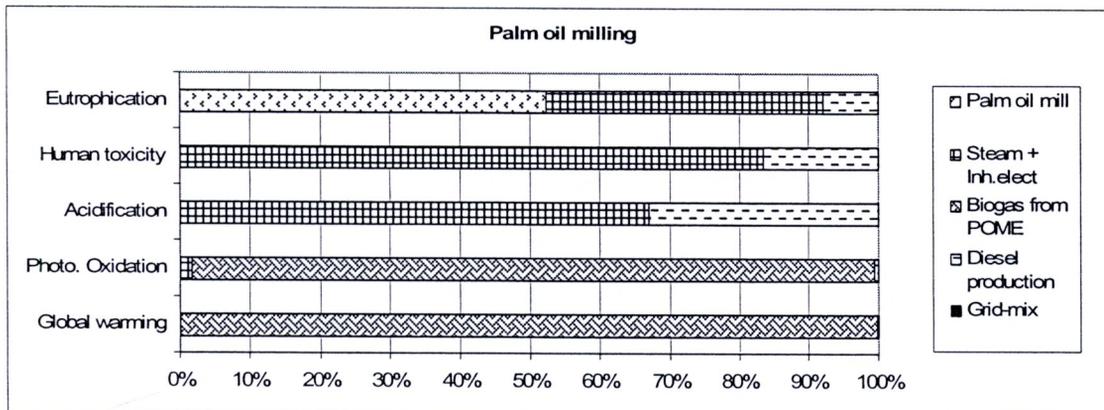


Figure 4.8 Environmental impacts of palm oil milling (based on 1000L PME)

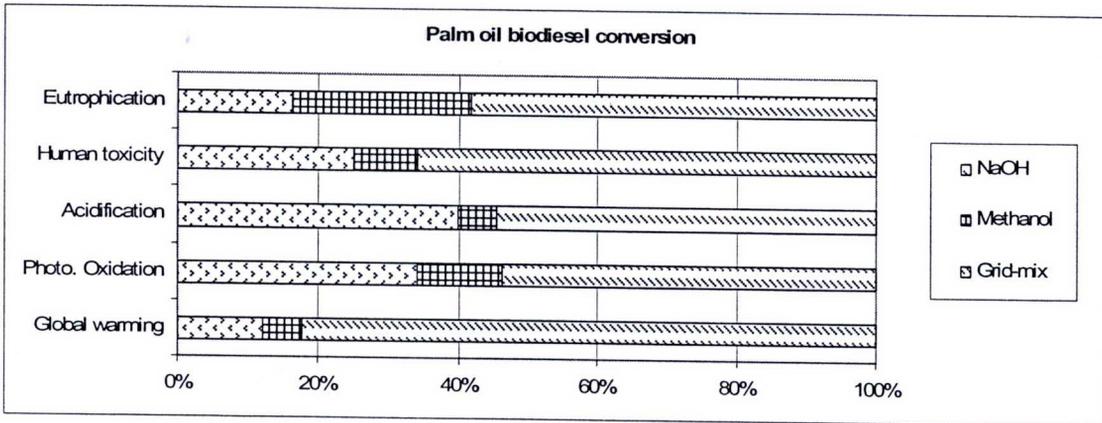


Figure 4.9 Environmental impacts of biodiesel conversion (based on 1000L PME)

4.2.3 Comparison of environmental performance of PME from the different treatment options for palm oil production waste

In the entire life cycle of palm biodiesel production, palm oil milling is the most complex stage associated with various by-products and wastes e.g. EFB, shell, fiber, POME, decanter cake and fly ash. Nowadays, many options are proposed to treat those oil palm by-products and wastes; the different practices resulting in the different environmental performance of palm biodiesel. In this study, several measures to handle the EFB and POME which currently have no actual use are investigated. A base case and other four other scenarios of EFB and POME management at the mills are modeled as shown in **Table 4.8** The LCIA results of producing 1000 L of PME by using the different modeled scenarios are estimated and shown in **Table 4.9**. The results reveal that utilization of EFB and POME in all scenarios could help improve the environmental performance of palm biodiesel in all impact categories. For example, the GWP values per 1000 L PME would decrease around 48-57% as compared to base case scenario which lack of treatment of EFB and POME. In addition, the other environmental impact potential such as AP, POCP, HTP and EP of palm biodiesel would also be decreased. The scenario 3 in which POME is treated to produce biogas before co-composting with EFB and returning the produced compost to the plantation is the most environmental friendly system as compared to the other scenarios. The three environmental benefits obtained from scenario 3 are the avoidance of CH₄ emissions as compared to the conventional POME treatment system, the environmental credits from biogas which is used to substitute diesel as starting fuel in the power plant, and the environmental credits from N-P-K fertilizers reduction.

Table 4.8 Comparison of the various possible scenarios for treatment of EFB and POME at the oil mills

	EFB	POME
Base case	EFB is dumped in the plantation.	Open ponds with CH ₄ leakage
Scenario 1	EFB is dumped in the plantation.	Biogas recovery
Scenario 2	Co-composting with POME	Open ponds with CH ₄ leakage
Scenario 3	Co-composting with POME	Biogas recovery
Scenario 4	EFB is sold as fuel or other purposes at a price of about 600 THB/ton EFB*	Biogas recovery

* Chavalparit et al., 2006 [100]

Table 4.9 Potential environmental impacts of 1000 L palm oil biodiesel production in different systems

Environmental impacts		Base case	Sce-1	Sce-2	Sce-3	Sce-4
Global warming	kg CO ₂ eq.	1,233	600	639	535	582
Photochemical oxidation	kg C ₂ H ₄ eq.	0.25	0.11	0.11	0.10	0.11
Acidification	kg SO ₂ eq.	1.99	1.89	1.88	1.77	1.85
Human toxicity	kg 1,4 DB eq	3.03	2.91	2.85	2.73	2.86
Eutrophication	kg PO ₄ ³⁻ eq.	0.32	0.30	0.30	0.29	0.30

4.2.4 Land-use changes and its implications to GHG emissions of palm biodiesel

Impacts of land use and land-use change (LUC) can be divided into two categories i.e. (1) use of land with impacts on the resource aspect and (2) use of land with impacts on biodiversity, ecosystem services and carbon stocks in biomass and soil. The study investigates the impacts of palm biodiesel production on the loss of arable land as a resource in the sense of being temporarily unavailable and the GHG emissions resulting from LUC.

4.2.4.1 Land use as resource

The assessment results show that to produce 1000L of palm biodiesel, about 1.48 rai.yr (0.24 ha.yr) of land is required for oil palm cultivation. This occupied land is lower than the land required to produce 1000L of the other biofuels such as cassava and molasses ethanol which require about 2.30 rai.yr (0.37 ha.yr) and 2.46 rai.yr (0.39 ha.yr), respectively [132]. Furthermore, the comparison in terms of per TJ of biofuels produced in

Thailand shows that palm biodiesel has highest the efficiency of land use per energy output i.e. 39 rai.yr/TJ followed by cassava ethanol and molasses ethanol at 108 and 116 rai.yr/MJ, respectively. However, this efficient use of land of palm biodiesel might not be enough to imply the environmental superiority of palm biodiesel due to the impacts of LUC on ecosystems such as carbon stock change (i.e. above and below ground biomass, stored carbon in soil) which might bring about substantial release of CO₂ released to into the atmosphere which must be investigated.

4.2.4.2 Land-use change and GHG consequences

According to the Palm Oil Industry and Oil palm development plan (year 2008-2012), the government has selected three suitable land types to encourage new oil palm plantations; (1) around 0.5 M.rai perennial crop land (e.g. durian and rambutan) in the eastern and southern regions; (2) around 0.5 M.rai rubber plantations in the south of Thailand; and (3) around 1.5 M.rai old rice field and the other lands in the eastern, north-eastern and southern regions [157]. However, the findings based on the agricultural statistics during 1982-2008 [99] and the on-site surveys [158-159] reveal that there have also been other types of lands had also been displaced by oil palm. For example, the agricultural statistics indicated that the trend of oil palm and rubber trees in the south region, which is the highest oil palm planted region in Thailand, are raised; while, the major rice is decreased. Nevertheless, there has been a question regarding the unbalances between the decreasing of major rice planted area and the increasing of oil palm and rubber trees. Subsequent field visits verified by the field visits that there was the conversion of other lands such as fruit trees, set-aside land and secondary forests to oil palm and rubber trees [159]. However, there is no real evidence of the change from tropical rainforest to oil palm in Thailand. For the eastern region, although oil palm is not the major crop but the trend of oil palm plantations in the provinces such Chonburi has increased from the conversion of land for sugarcane, cassava and pineapple. For the northeastern region which is the largest region for major rice plantation in Thailand, growing oil palm was initiated just in 2008 by displacing on the paddy field and crop field such as cassava. Therefore, the possible changes of land or cropping system to oil palm can be summarized into five scenarios as shown in **Table 4.9**.

The study calculates GHG emissions caused by direct land-use change (dLUC) based on the IPCC guidelines [96]. The scope of GHG emission sources includes the

change in biomass carbon stocks (ΔC_B), the change in dead organic matter (ΔC_{DOM}), the change in soil carbon stocks (ΔC_{SO}) and the GHG emissions from clearance of land prior to establishment of oil palm and the non-CO₂ emissions i.e. CH₄ and N₂O from biomass burning as part of clearance of historic land prior to establishment of a new plantation. The key assumptions used are as follows: (1) GHG balance of LUC is calculated based on 25 years life-span of oil palm (T); (2) The stock-difference method is used for calculating by referring to the available information of carbon stock information in both biomass and soil from Thai literature sources. The general formula of the stock-difference method is $\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)}$ where ΔC is the annual carbon stock change in the pool (tons C.yr⁻¹), C_{t_1} and C_{t_2} are the carbon stocks in the pool at the times t_1 and time t_2 (tons C), respectively; (3) The calculations for soil carbon are based on IPCC factors considering the farming practices and soil/climate conditions on site. Only the annual carbon stock change in mineral soils ($\Delta C_{\text{mineral}}$) is considered in the study as the organic soil is rare in Thailand and the information to estimate the change in inorganic soil is not enough. Whereas, $\Delta C_{\text{mineral}} = \frac{(SOC_{\text{(current)}} - SOC_{\text{(prior)}})}{T}$ and $SOC_{\text{(prior)}} =$ soil carbon stock at the beginning of the inventory time period (ton C); $SOC_{\text{(current)}} =$ soil carbon stock in the last year of an inventory time period (ton C). Soil carbon stock (SOC) can be estimated from the equation i.e. $SOC = SOC_{\text{Ref}} \times F_{LU} \times F_{MG} \times F_I$; where, SOC_{Ref} is the reference SOC which is obtained from recently cleared plantations and is set to be the value of $SOC_{\text{(prior)}}$ in this study. SOC_{Ref} can be obtained from IPCC's default value or from the literature; and (4) Mass carbon is converted to mass CO₂ with the multiplication of 3.664.

Table 4.10 shows the GHG emissions per litre biodiesel for various scenarios, the results indicate that there is a large variation in the GHG performance of palm biodiesel when direct LUC is included in the system boundary. The conversion of rubber and tropical forest land to oil palm increases the released GHG of palm biodiesel production around 2.75 times (for base case scenario) and around 5.2 times (for scenario 3) as compared to the case where LUC is excluded. This increased GHG emission originates from the loss of biomass carbon stock (ΔC_B). On the contrary, conversion of field crops such as cassava and sugarcane, paddy fields and set-aside land to oil palm would bring about GHG benefits i.e. the gain of biomass carbon stock and the increase in soil organic carbon stock. Therefore, the policy to control the expansion of oil palm cultivation by

promoting only the suitable land is important for the future palm biodiesel production. Otherwise, palm biodiesel may not be a preferable alternative to replace fossil fuels. In addition, the trade of palm biodiesel as commodities might have a problem because nowadays the GHG performance of biofuel is being considered as one of the criteria of sustainable biofuels production. To avoid socio-economic consequences as competition with food, the use of set-aside land for new oil palm plantations seems to be more sustainable as compared to the conversion of field crops or paddy. However, this might not be true in case that the farmers change their old paddy fields or other crop fields which have low yields and low income to grow oil palm. This more income to farmers would help encourage the well-being of farmers as well. Nevertheless, it must be noted that there are a number of variables in real agricultural practices that can affect GHG emissions e.g. the effects of different tillage methods and other crops management measures such growing cover crops to improve soil organic carbon or no-tillage cultivation and these variables need further investigation [160]. Moreover, indirect land-use change (iLUC) is not yet included in the analysis.

Table 4.10 GHG performances of various palm biodiesel system after accounting for LUC

Land-use change scenarios	GHG emission factors for LUC (ton CO ₂ -eq/ha/yr)	GHG emissions of palm biodiesel (kg CO ₂ eq/L biodiesel)				
		Base case	Sce-1	Sce-2	Sce-3	Sce-4
Excluding LUC	-	1.2	0.6	0.6	0.5	0.6
Including LUC						
Rubber to oil palm	8.72	3.3	2.7	2.7	2.6	2.7
Field crop to oil palm	-17.55	-3.0	-3.6	-3.6	-3.7	-3.6
Paddy field to oil palm	-17.70	-3.0	-3.6	-3.6	-3.7	-3.7
Set-aside land to oil palm	-18.88	-3.3	-3.9	-3.9	-4.0	-3.9
Forest land to oil palm	8.51	3.3	2.6	2.7	2.6	2.6

4.2.5 Recommendations for improving environmental performance

The following recommendations are made to improve the energy and environmental performance of palm biodiesel system in Thailand:

- (1) To maximize use of by-products and wastes generated from the oil mills. Recovery of biogas and nutrients from POME should be encouraged to the mills by using

the CDM opportunities. Surplus shells from in-house boilers and EFB could possibly be used for other purposes than for fueling boilers. For example, shells could be used to produce activated carbon or as a source of fuel for cement and brick factories [100]. EFB can be used as substrate for straw mushroom cultivation or mixing with POME to make co-compost due to its high N-P-K content [161]. The credits of substituted materials from waste recovery such as diesel for operating power generator replaced by biogas, chemical fertilizers replaced by co-compost of POME and EFB, fossil fuels for grid-power generation replaced by biomass fuels such as shells and EFB of the Small Power Providers (SPP) would induce the externality savings and help improve the economic and environmental performance of palm oil and palm biodiesel industries in Thailand.

(2) To increase FFB yield by promoting the good agricultural practice (GAP) for oil palm as suggested by the Department of Agriculture to farmers [162]. The good practices include land preparation, selection of good and appropriate oil palm varieties, determining fertilizers demand of oil palm by observing or scientific measurement and regular treatment and selecting the good-period of harvesting. The suitable time-period of harvest would result in high content and good quality of oil in FFB. In addition, using co-compost derived from EFB and POME which contain nutrients as organic fertilizers would be another measure to improve soil quality and to reduce chemical fertilizers consumption. These good practices could help increase FFB yield from 2.8 to 3.5 tons/rai or even to reach the genetic potential of oil palm varieties i.e. 5 tons/rai [157].

(3) To maintain the availability of crude palm oil supply for future biodiesel production, both increase in palm cultivating areas and productivity are required. Uncontrolled expansion of palm plantation would result in low FFB productivity and consequently adverse impacts on the environment e.g. increase in GHG emissions. The assessment results show that conversion of set-aside land to oil palm would be the best way for environmental sustainability of future palm oil and palm biodiesel industry as compared to the conversion of the other lands.

(4) To encourage the utilization of other feedstocks such as used cooking oil, *Jatropha* (*Jatropha curcas Linnaeus*), coconut and soybean for future commercial biodiesel production. Except the used cooking oil which is presently used as feedstock for commercial biodiesel production. *Jatropha* seems to be the most suitable prospective feedstock for biodiesel in terms of availability and socio-economic concern about the

competition with food as the other oil plants are almost all used for food. *Jatropha* is interesting because of the possibility to cultivate it on dry and marginal land. In addition, the energy balance of *Jatropha* Methyl Ester (JME) had been done and the results show the net energy gain from JME and its co-products [163]. However, the cost of investment and the other environmental impacts of JME need further investigation.

4.3 Life cycle cost and externalities analyses of cassava ethanol in Thailand

This section analyses the cost performance of cassava ethanol comparing to gasoline when the environmental externalities are determined and internalized into the total production cost of bioethanol and gasoline. Not only the environmental benefits of bioethanol are considered but also the environmental damages resulting from fossil fuel use during the life cycle of cassava ethanol production and land used for cassava cultivation. Detailed information regarding goal and scope definitions, systems boundary of the analysis, methodology and assumptions used are described in **Chapter 3 (Section 3.2)**. The analysed results and the recommendations to improve the cost-competitiveness of cassava ethanol are discussed as follows:

4.3.1 Estimation of life cycle cost

The costs of main-processes can be categorized into five groups i.e. cassava planting costs, dry chips processing costs, ethanol conversion costs, gasohol production costs and all transportation costs which take place in the system.

4.3.1.1 Cassava farming costs

The statistics of cassava farming costs in Thailand over the period 2006-2008 were collected from the Office of Agricultural Economics (OAE) and are reported in **Table 4.11** [164-165]. Fixed costs are the costs associated with land rental, depreciation and tax. Variable costs involve all operating costs i.e. labour costs, material costs and miscellaneous costs e.g. reparation and interest. Based on production data and costs in 2007, cassava farming costs can be classified into five categories i.e. (1) land preparation, including costs of fuel, and hiring tractors and drivers; (2) hand planting including the cost of planting materials (cassava stems); (3) chemicals (fertilizers and herbicides); (4) harvesting; and (5) transportation of chemicals, stem cuttings and harvesting, which contribute to 11%, 15%, 35%, 18% and 21% of the total farming costs, respectively [61].

Table 4.11 Cassava farming costs [164-165]

		2006	2007	2008
Yield	kg.rai ⁻¹ *	3375	3668	3456
Production costs	THB.(ton roots) ⁻¹	843	824	880
Fixed costs	THB.(ton roots) ⁻¹	99	91	92
Variable costs	THB.(ton roots) ⁻¹	744	733	788
Sale prices	THB.(ton roots) ⁻¹	1290	1180	1730
Farmer incomes	THB.(ton roots) ⁻¹	447	356	850
	THB.ra ⁻¹	1,509	1,306	2,938

*[1 rai = 0.16 ha]

4.3.1.2 Chips processing costs

Ethanol producers generally have their own facilities to produce dried chips. Dried chips processing is referred to as a process step taking place at the ethanol production plant. Production costs of dried chips processing consist of raw material cost (fresh cassava roots), fuel used in the tractor to transfer roots into the hopper of the chopping machine and transfer of chopped roots on a large floor for drying by sunlight. Another cost is from the electricity used in the chopping machine. Today, the cassava chips market has expanded substantially as cassava chips can be used as feedstock to produce various chemicals [166]. Ethanol producers directly buy roots from farmers or suppliers. Only chips processing costs are considered in this study. Based on data from 2007 [61], chips processing cost amounted to 152 THB.ton dry chips⁻¹ (calculated from diesel cost and labour cost).

4.3.1.3 Ethanol conversion costs

The ex-refinery price of ethanol is a summation of ethanol conversion costs, profit margin of ethanol producer and transportation costs for delivery of ethanol to petroleum refinery for blending. Details are shown in Appendix B (Table B.1). The ethanol conversion costs include costs of raw material (cassava dry chips), utilities (e.g. energy and water), chemicals, repair, and maintenance, wages and salary, depreciation, fiscal charges, selling expenses and miscellaneous and profit margin. This information is available based on data produced by Nguyen et al. (2008) [61]. However, to estimate the ethanol ex-refinery price, truck 15-20 tons capacity with the distance 100 km and truck 10-12 tons-capacity with distance 150 km are assumed to determine transportation costs of cassava roots and ethanol respectively. The obtained results reveal that raw material cost (cassava

chips) represents 55% of the ethanol ex-refinery price (based on data from 2007). The other contributors in conversion costs are shown in **Figure 4.10**.

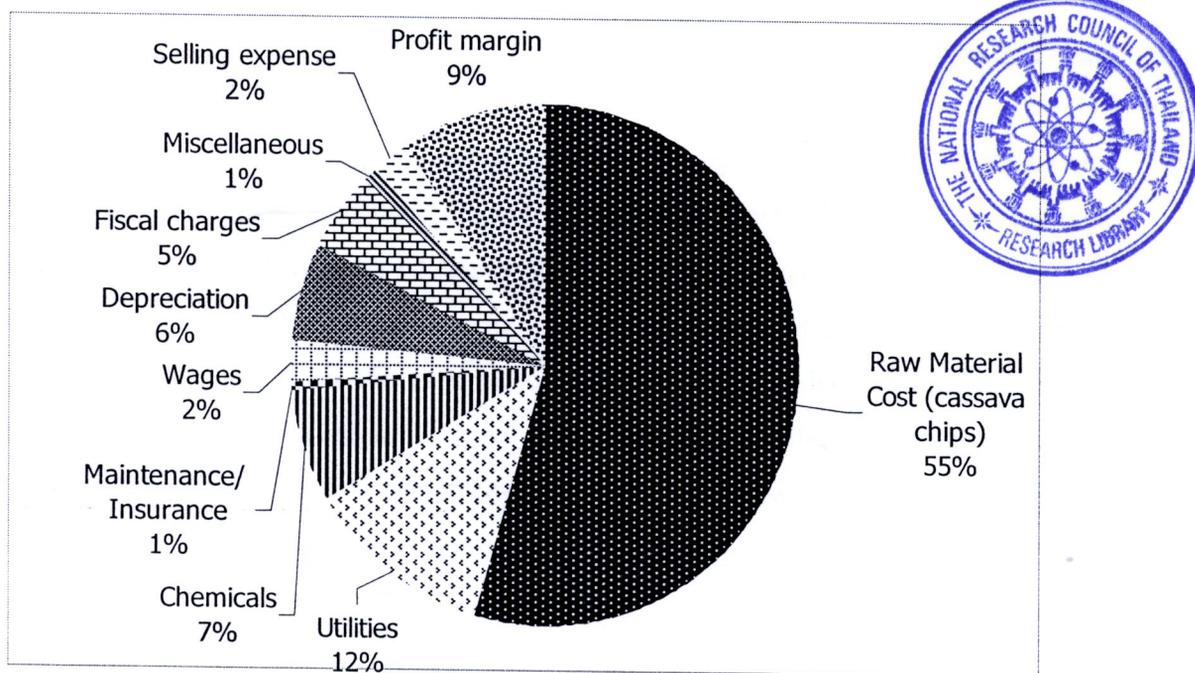


Figure 4.10 Ethanol conversion cost breakdown (year 2007)

4.3.2 Cost performance comparison between gasoline and ethanol (without externalities)

The cost performance of ethanol and gasoline has been compared in terms of ex-refinery price (excluding all taxes) per litre of gasoline equivalent as shown in **Figure 4.11**. The results show that the production costs of cassava based ethanol are much higher than that of gasoline in particular for high percentages of gasohol blends. As a result, for E10, the most popular gasohol available on the Thai market, it is observed that the production cost of cassava ethanol has almost always been more expensive than that of gasoline except in cases when the crude oil price has exceeded 110 US\$ per barrel. Feedstock (cassava root) is the major contributor to overall ethanol conversion cost followed by the cost of utilities, i.e. fuel, electricity and water.

From the above, it is clear that the price of crude oil is a key factor in the success of any policy relating to the promotion of bioethanol in the transport sector. If the crude oil price rises up to a certain benchmark (133 USD/barrel) as seen in **Figure 4.11**, it would contribute easing the introduction of the bioethanol program in Thailand as lesser subsidies would be needed to enhance the competitiveness of bioethanol as compared to

conventional gasoline. However, if the crude oil price drops below that benchmark and falls below 84 USD/barrel the competitiveness of bioethanol would be hindered as compared to gasoline even for the lowest cassava price (1.18 THB/kg roots).

4.3.3 Influence of externalities on the cost performance of cassava ethanol and gasoline

The externalities of various gasohol blends including E10, E20 and E85 have been evaluated and internalized into their respective production costs. As shown in Figure 4, based on total costs per kilometer of achieved driven distance, environmental externalities are essential pieces of information for policy makers as they contribute about 16-33% of the total costs depending on the ratio of cassava ethanol blended with gasoline. The environment costs are observed to decrease with the increase in the percentage of ethanol blended into gasoline. The two major benefits of cassava ethanol are the avoidance of fossil fuel resources depletion and the mitigation of carbon dioxide emissions.

Higher blends of gasohol although being more competitive in terms of environmental costs, are characterized by higher production costs than conventional gasoline. For an average price of cassava feedstock and crude oil during 2006-2008, only E10 is about to be able to compete with gasoline once the environmental costs have been internalized into the overall production costs. However, based on the prices of crude oil and cassava feedstock observed in 2008, it is noticed that E10, E20 and even E85 could possibly compete with gasoline (based on total cost) as seen in **Figure 4.12**. For example, the maximum total cost of gasoline is 2.91 THB.km⁻¹ which relates to a crude oil price of around 133 US\$.barrel⁻¹. This total cost is higher than the average total costs of E10, E20 and E85 (based on a cassava feedstock price of 1.4 THB.(kg root)⁻¹).

Once external costs have been internalized into the production costs, the results reveal that per kilometer of achieved driven distance, E10 and E20 are quite attractive and competitive as compared to gasoline. Their total costs are similar to that of gasoline but the country gains more on other social benefits attached to those biofuels such as stabilization of farmer's income and employment generation, as well as reduction of the country's dependence on oil imports leading to improved energy security and lesser economic dependence on third oil exporting countries. On the other hand, E85 is still not economically competitive in Thailand as the savings resulting from its environmental benefits cannot compensate for its substantially higher production costs as compared to

gasoline. Therefore, to achieve the policy target set by the government with regards to the production of cassava based ethanol, production costs need to be reduced to enhance cost performance.

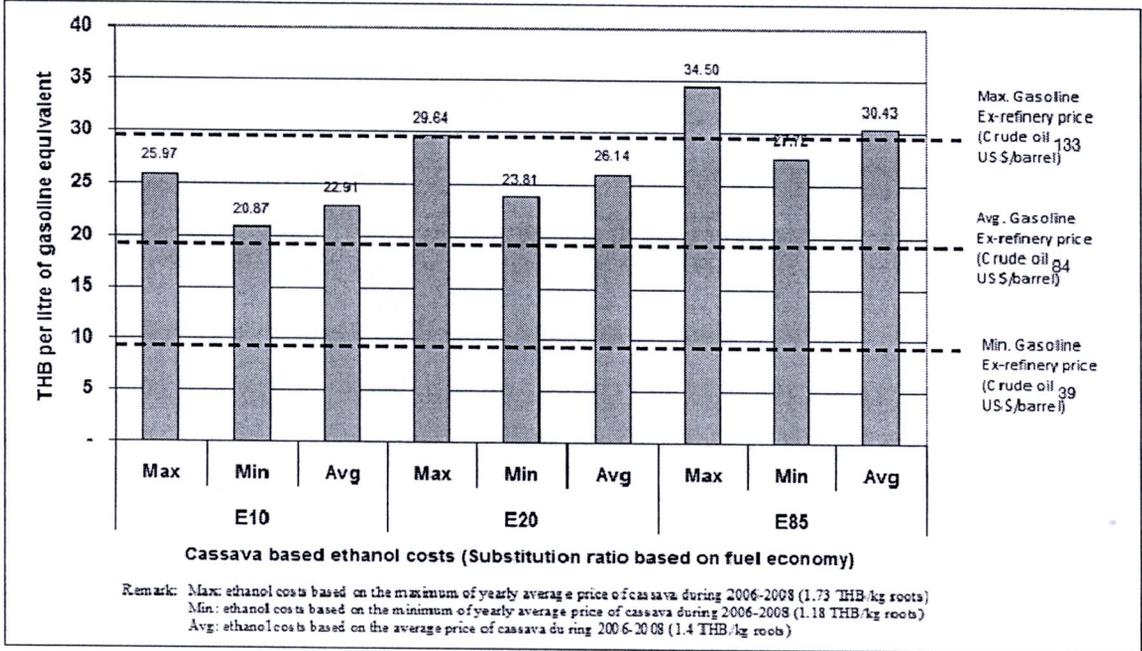
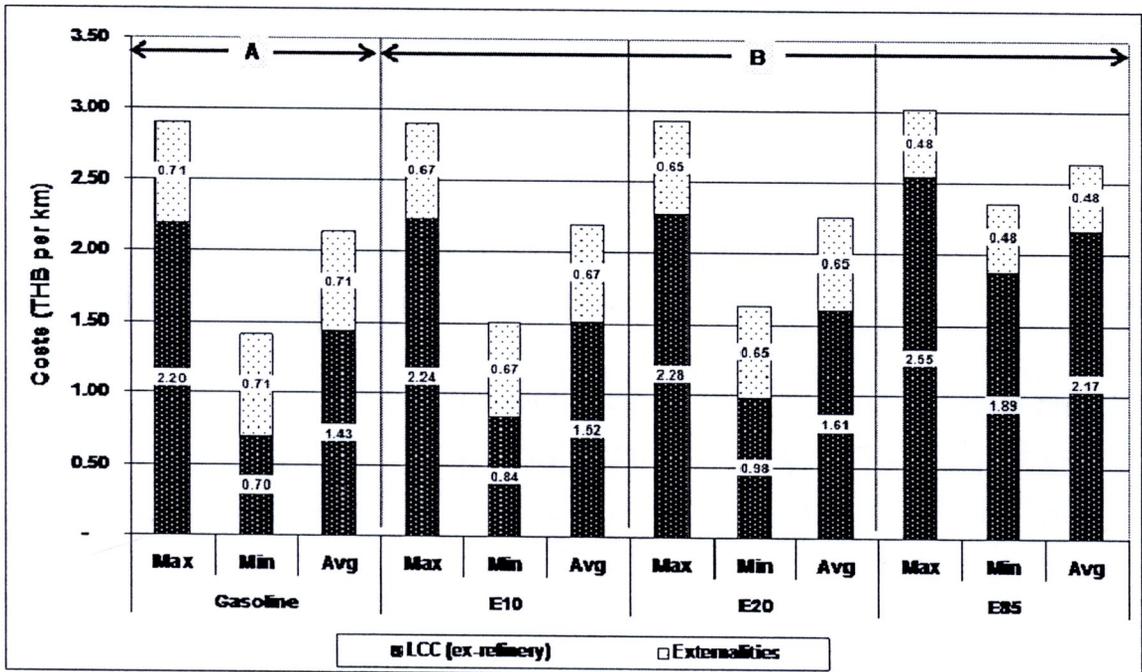


Figure 4.11 Comparison between ex-refinery price of cassava ethanol and gasoline 95 in terms of per litre of gasoline equivalent (using substitution ratios based on fuel economy of gasohol and gasoline)



Remark:

A : Gasoline costs vary by crude oil prices i.e. Max: Ex-refinery price of gasoline 95 = 29.61 THB/L; Min: Ex-refinery price of gasoline 95 = 9.47 THB/L; and Avg: Ex-refinery price of gasoline 95 = 19.313 THB/L
 B : Gasohol costs vary by crude oil prices and cassava root prices i.e. Max: Ex-refinery price of gasoline 95 = 29.61 THB/L and Cassava price = 1.73 THB/kg; Min: Ex-refinery price of gasoline 95 = 9.47 THB/L and Cassava price = 1.18 THB/kg; and Avg: Ex-refinery price of gasoline 95 = 19.313 THB/L and Cassava price = 1.40 THB/kg.

Figure 4.12 Ranges of total costs per km between gasoline (based on prices of crude during 2006-2008) and gasohol (based on prices of cassava roots during 2006-2008)

4.3.4 Recommendations to enhance the cost-performance of cassava ethanol in Thailand

In this study, there are three approaches suggested for enhancing the cost-performance of cassava ethanol production in Thailand including (1) improvement of conversion efficiency; (2) improvement of waste recycling and co-products utilization such as biogas recovery, DDGS or CO₂; and (3) improvement of cassava yield at the plantation stage. The estimation of cost-saving results are shown in **Table 4.12**.

The comparison of cassava production costs after implementation those improvement options shows that the ethanol production costs will be 24.43 THB per litre of gasoline equivalent for a target market price of cassava root at 1.5 THB.kg⁻¹ (based on government policy target). Even though, this price still does not quite compete with gasoline for an average ex-refinery price of 19.31 THB per litre of gasoline, it enables, however, to narrow down the price gap between ethanol and gasoline. This should help the government in their effort to promoting and subsidizing biofuels especially for higher blends of gasohol such as E85.

Table 4.12 Ethanol production costs after implementing the improvement measures

	Cassava price		
	Average (2006-2008)	Policy target [166]	Ranges (2006-2008)
Cassava root price (THB.kg ⁻¹)	1.4	1.5	1.12 - 2.23
Ethanol production costs (THB.litre ⁻¹)	20.45	21.20	18.14 - 26.47
Ethanol production costs saving & co-products credits from proposed options (THB.litre⁻¹)			
Improving conversion efficiency from 7.5 to 6 kg roots per litre ethanol	2.1	2.5	1.7 - 3.34
Biogas production	0.3-0.5	0.3-0.5	0.3-0.5



	Cassava price		
	Average (2006-2008)	Policy target [166]	Ranges (2006-2008)
Dry Distillers Grains with Soluble (DDGS) production	0.24	0.24	0.24
CO ₂ recovery	0.3-0.65	0.3-0.65	0.3-0.65
Improvement of cassava yield by promoting good agricultural practices from farmers¹			
Increase cassava yield from 3.5 to 5 tons/rai (based on government policy target)	<ul style="list-style-type: none"> - Reduction in cassava production cost 0.28 THB/kg - Ethanol conversion cost would decrease 1.68 THB/L ethanol (@ efficiency 6 kg roots/L ethanol) 		
	1.68	1.68	1.68
Ethanol production costs after implementing all the measures (THB.litre ⁻¹)	15.53	15.88	13.62 - 20.31
Ethanol production costs after implementing the measures (THB per litre gasoline equivalent) ²	23.89	24.43	20.95 - 31.25
Ranges of gasoline 95 Ex-refinery price during 2006-2008 (THB/Litres)	Max: 29.608; Avg: 19.313; Min: 9.427		

Remarks:

¹ Several good practices for increasing yield i.e. development of new varieties, selection of appropriate varieties, good plantation period, improving soil quality by using organic fertilizers, good practices in land preparation, plantation and harvesting, and weed control.

² Ethanol is assumed to contain 0.65 the energy of a litre of gasoline

The implementation of the recommended measures reported above as a mean to improve the cost-performance of cassava based ethanol are necessary, particularly for E10 and E20 (E10 provides a positive net societal benefits). E10 and E20 are therefore in a favorable position to compete with gasoline while E85 is still economically un-attractive due to its substantially higher production costs. At present, with externalities internalized into the total production costs of E85, the biofuel is about 0.511 THB.km⁻¹ more expensive than gasoline. An equivalent subsidy of about 4.86 THB.litre⁻¹ would be needed to make E85 competitive as compared to gasoline. If all the recommended measures to improve the cost-performance of cassava ethanol were adopted, it would narrow down the price gap between E85 and gasoline to 0.033 THB.km⁻¹ or 3.138 THB.litre⁻¹ (**Table 4.13**).

Table 4.13 Total costs breakdown of gasoline and gasohol after implementing all five recommended measures to improve the cost-performance of cassava ethanol (based on cassava roots price of 1.5 THB/kg)

	Unit	Gasoline	E10	E20	E85
LCC (ex-refinery)	THB.km ⁻¹	1.44	1.47	1.50	1.70
Environmental Externalities	THB.km ⁻¹	0.71	0.67	0.65	0.48
<i>Land use</i>	THB.km ⁻¹	-	0.005	0.01	0.06
<i>Fossil energy depletion</i>	THB.km ⁻¹	0.39	0.36	0.35	0.21
<i>Air emissions</i>	THB.km ⁻¹	0.32	0.30	0.29	0.21
Total costs	THB.km ⁻¹	2.14	2.14	2.15	2.18
Net environmental benefits (as compared to gasoline)	THB.km ⁻¹		+0.04	+0.06	+0.23
Net societal benefits (as compared to gasoline)	THB.km ⁻¹		+0.006	-0.007	-0.033

Remark: (+) means benefits over the gasoline; (-) means costs over the gasoline.

4.4 Life cycle costing and externalities of palm biodiesel in Thailand

This section analyses the cost performance of palm biodiesel comparing to conventional diesel when the environmental externalities are determined and internalized into the total production cost of biodiesel and diesel. Detailed information about goal and scope of the analysis, methodology and assumptions used are described in **Chapter 3 (Section 3.2)**. The analysed results and the recommendations to improve the cost-competitiveness of palm biodiesel are discussed as follows:

4.4.1 Estimation of life cycle cost

The life cycle cost of biodiesel involves all the costs arising in the palm oil based biodiesel production system as shown in **Figure 3.4**, i.e. oil palm cultivation, palm oil milling, PME production and all transport activities. The production costs in each stage are detailed below.

4.4.1.1 Oil palm cultivation costs

Details of the costs related to oil palm cultivation in Thailand are shown in **Table 4.14**. Fixed costs are those related to land rental, depreciation and tax. Variable costs refer to all the operating costs such as labour costs, material and agrochemical costs and miscellaneous costs (reparation and interest). Regarding the production data of 2007 which has been used as base case in this analysis, the variable costs contribute to 84% of the total production costs. The main costs stem from the use of fertilizers, labour costs for

harvesting and labour costs for farming activities which contribute to 46%, 22% and 16% of the total variable costs, respectively.

Table 4.14 Oil palm farming costs

		2006	2007	2008
Yield	kg FFB.rai ⁻¹	2,828	2,399	3,147
Total Production costs	THB.(ton FFB) ⁻¹	1,530	1,836	2,176
Fixed costs	THB.(ton FFB) ⁻¹	248	292	301
Variable costs	THB.(ton FFB) ⁻¹	1,282	1,544	1,875
Sale prices of the FFB	THB.(ton FFB) ⁻¹	2,390	4,070	4,230
Farmer income	THB.(ton FFB) ⁻¹	860	2,234	2,054

Source: OAE, 2008 * [1 rai = 0.16 ha]

4.4.1.2 CPO production costs

CPO production costs are classified into three main categories i.e. raw material costs, processing costs and transportation costs of CPO products to the biodiesel production factory. Regarding the production data of palm oil mills, the conversion efficiency used in the analysis is 5.95 ton FFB/ton CPO (ranges 5.56 – 6.13 ton FFB/ton CPO) [97, 100, 167]. The processing and administrative costs are 2 THB/kg CPO (range: 1.25 - 2 THB/kg CPO) [168]. The transportation cost of CPO products is around 0.9 THB/kg CPO (calculated from distance). According to the average price of FFB (years 2006-2008) of 3,563 THB/ton FFB [99], the analyzed results reveal that the cost of the raw material (fresh palm fruits) contributes 88% of the total production costs. Processing and transportation contribute 8% and 4 % of the total production costs, respectively.

4.4.1.3 Biodiesel production costs

The ex-refinery price of biodiesel is a summation of all costs associated with CPO production, biodiesel conversion, profit margin (biodiesel producer) and transportation for delivery of PME to petroleum refinery for blending. Details are shown in Appendix B (Table B.3). The obtained results (**Figure 4.13**) reveal that the raw material cost (CPO) contributes 69% of the biodiesel ex-refinery price, while the cost of methanol is the second contributor sharing 11% of the total production costs [169].

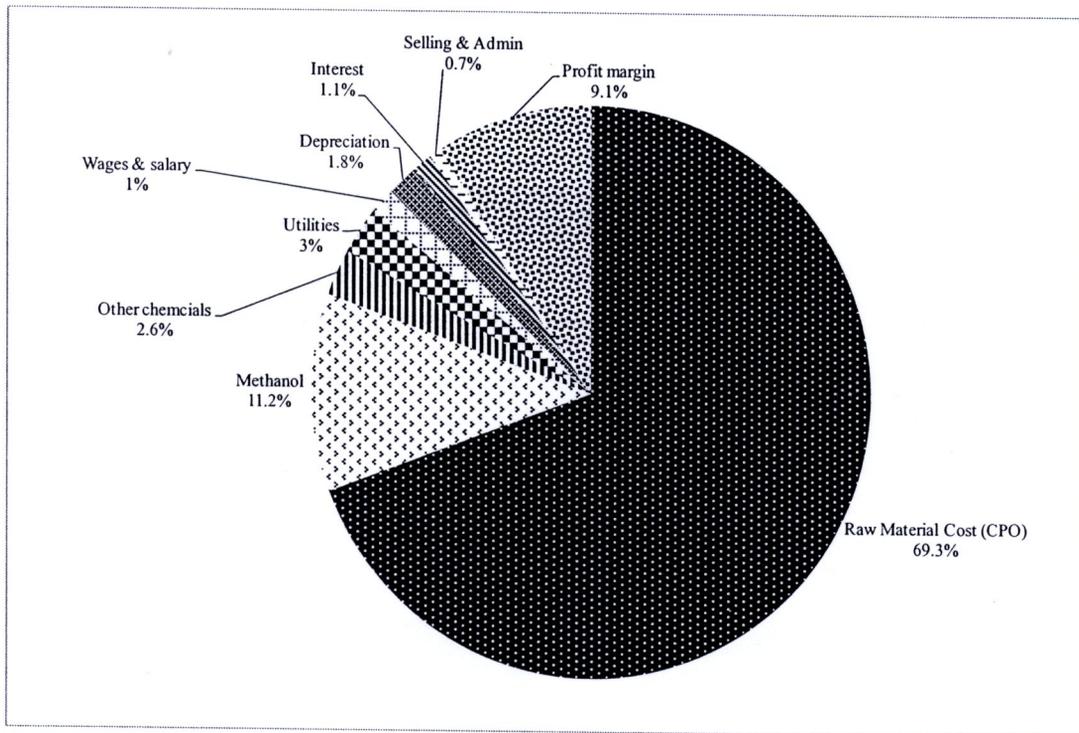


Figure 4.13 Ex-refinery price breakdown of biodiesel (average data during 2006-2008)

4.4.2 Cost performance comparison between diesel and biodiesel (without externalities)

The ex-refinery price per liter of petroleum diesel equivalent was used for comparing the cost performance of biodiesel and diesel. **Figure 4.14** reveals the possible minimum, maximum and average costs of biodiesel and diesel over a three years period. Based on the average cost of biodiesel, the former is not able to compete with diesel if no subsidies are provided by the government to boost its cost competitiveness. Biodiesel's competitiveness is influenced by two major factors that are the cost of the feedstock, which directly affects the ex-refinery price of biodiesel, and the price of crude oil, which influences the ex-refinery price of diesel.

Based on the results shown in **Figure 4.14**, it is clear that the price of crude oil is a key factor in the success of any policy relating to the promotion of biodiesel in the transport sector. For an average price of CPO (23 THB/ton CPO or 3.56 THB/kg FFB), when the crude oil price rises up to 133 US\$/barrel, it contributes to easing the introduction of the biodiesel program in Thailand as lesser subsidies are needed to enhance the competitiveness of the biodiesel as compared to conventional diesel. However, if the crude oil price drops below that benchmark and falls below 100 USD/barrel the competitiveness

of biodiesel would be hindered as compared to diesel and therefore even for the lowest price of fresh palm fruit (2.4 THB/kg FFB or 15.77 THB/kg of CPO).

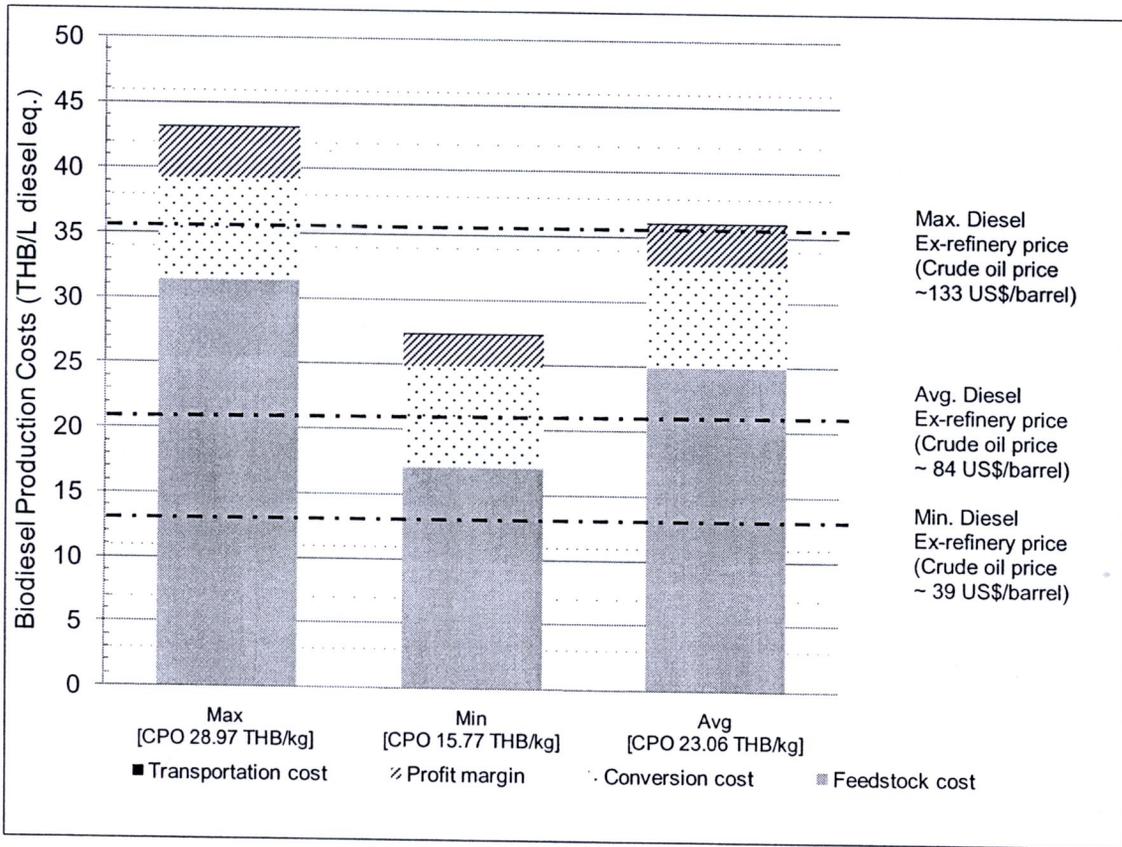


Figure 4.14 Ex-refinery prices of PME (B100) and diesel in terms of per litre of diesel equivalent (based on data during 2006-2008)

4.4.3 Influence of externalities on the cost performance of diesel and biodiesel

The environmental burdens listed in **Table 2** were assessed and their costs internalized into the production costs of fuels. The monetized results are shown in **Figure 4.15** for conventional diesel and various blends of biodiesel i.e. B5, B10 and B100. The environmental costs show that biodiesel blends give more environmental benefits than petroleum diesel. From the full costs analysis (production cost combined with environmental externalities), it is observed that higher percentages of biodiesel blends result in lesser environmental costs but higher production costs. However, the results reveal that B5 and B10 are able to compete with diesel once the environmental costs have been internalized into the production costs. The external costs of diesel and biodiesel blends classified for each environmental burden are presented in **Figure 4.16**. The results

show that the highest environmental cost stems from the depletion of fossil energy resources followed by CO₂ emissions. An increase in the percentage of biodiesel blend can significantly help reducing both fossil resources depletion and CO₂ emissions. The environmental costs arising from the increase of NO_x and N₂O emissions as well as land use expansion for energy crop cultivation are lower than the total environmental benefits arising from the production and use of the biodiesel blends covered in this study.

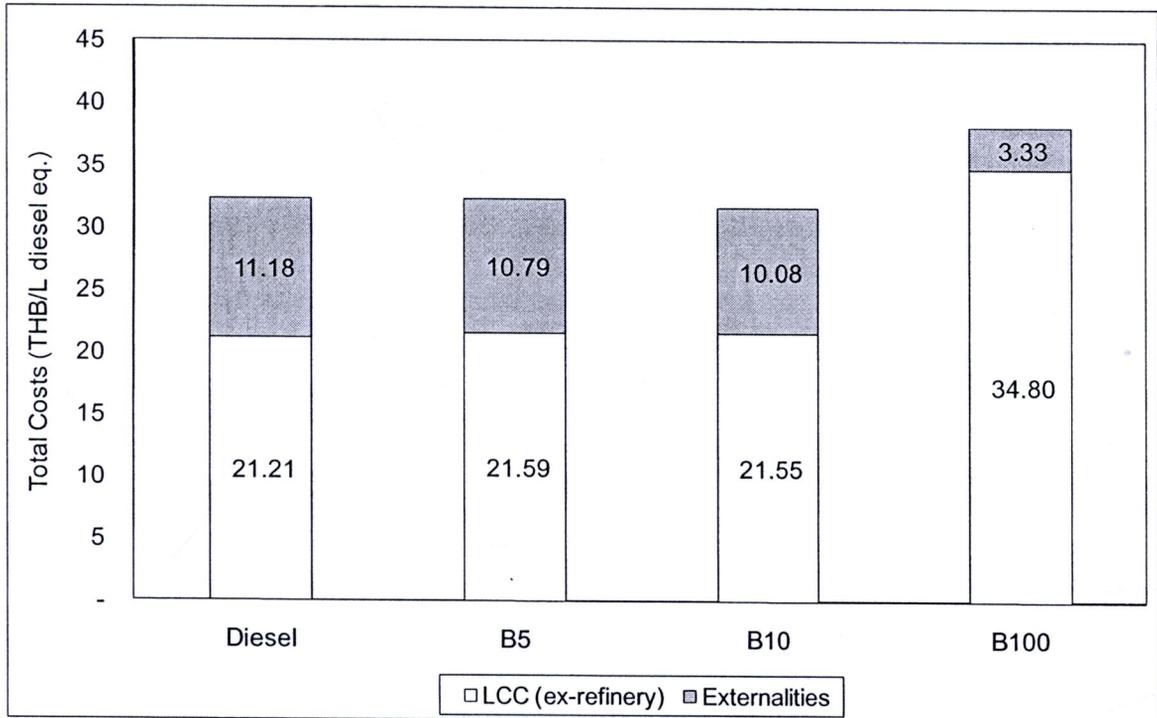


Figure 4.15 Comparison of total costs per litre of diesel equivalent for petroleum diesel and various blends of biodiesel (based on the average price during 2006-2008 of diesel = 21.21 THB/L and of CPO = 23.06 THB/kg)

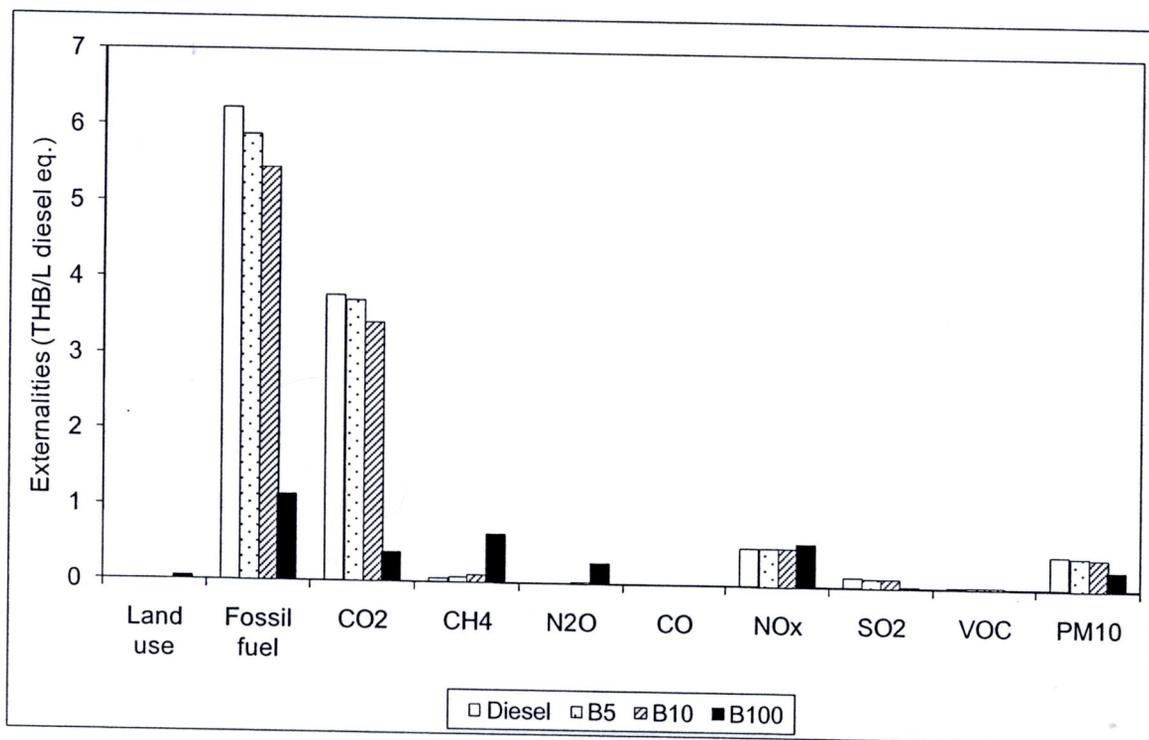


Figure 4.16 Externalities per liter of diesel equivalent for conventional diesel and biodiesel blends (based on PME from CPO)

4.4.4 Recommendations to enhance the cost-performance of palm biodiesel in Thailand

Based on the above results, it is observed that palm oil based biodiesel in Thailand is characterized by production costs which are higher than that of diesel, in either pure or blended form. This is mainly due to the high cost of the biodiesel feedstock. Based on the LCC analysis, it is observed that the production cost of biodiesel is dominated by the cost of crude palm oil. It accounts for 69% of the total production cost of biodiesel which is directly related to the market price of fresh palm fruits.

However, as the life cycle assessment results show, an increase in the use of biodiesel can help reduce both the depletion of fossil energy resources as well as the emissions of CO₂ as compared to conventional diesel. However, there are also several adverse environmental burdens associated to the production of biodiesel particularly with regards to increased surface of land occupied for planting and growing oil palm, N₂O emissions from N-fertilizer applications at the nursery stage and in the field, and increased tailpipe emissions of certain pollutants, particularly NO_x. Those externalities have been assessed and internalized to determine their impacts on the cost performance of biodiesel as compared to conventional diesel. The assessment results reveal that these environmental

costs contribute about 34% of the total costs (production costs + environmental costs) of petroleum diesel. When compared on the basis of per liter diesel equivalent, using diesel and biodiesel blends, the results show that an increase in the percentage blend of biodiesel is accompanied with a decrease in environmental costs but increase in fuel production costs, (**Figure 4.15**). However, in terms of total costs (including externalities), the results indicate that the promotion of biodiesel (B5 and B10) to replace diesel is economically feasible. The assessment shows that B5 and B10 could save welfare losses in Thailand at about 0.01 and 0.76 THB.L⁻¹ diesel equivalent, respectively (**Table 4.14**).

Currently, B100 is less economically attractive than conventional diesel. Its environmental benefits cannot totally compensate for the increase in its production costs. Reducing the production costs of biodiesel is necessary for the achievement of the policy aiming at promoting biodiesel in Thailand. Particularly, the influence of the feedstock and methanol on the ex-refinery price of biodiesel needs to be considered since they contribute 80% of its cost. In the future, the price of FFB and crude palm oil is expected to increase due to the increasing trade and demand of these products by both the food and fuel industries. If the selling price of both products were fixed, an increase in the price of feedstock would improve profitability for farmers but shrink profitability for biodiesel producers. Balancing benefits among stakeholders in the supply chain of biodiesel production is therefore an important issue to consider.

To achieve the biofuels policy targets set by the Thai government, minimizing the production cost of biodiesel and optimizing the use of all by-products generated along the chain of its production is imperative. One of the key approaches to increase the competitiveness of biodiesel along with the sustainability of the palm oil industry in Thailand is to improve the environmental performance of crude palm oil mills. Crude palm oil mills generate many by-products and large quantities of wastewater, which may have significant environmental impacts if they are not managed adequately. However, if those by-products and wastes are well-managed based on the concept of reuse, recycling, and maximization of waste utilization along with appropriate energy management measures, the production costs of CPO could decrease benefiting further the palm oil industry [33, 100, 109, 156, 170]. Thus for instance, based on 1 ton processed FFB, 140 kg of fibres and 30 kg of shells are required as fuels in the cogeneration system of Thai palm oil mills to produce steam and electricity for supplying the production process [100]. Therefore, the

surplus of 30 kg shells and 240 kg EFB per 1 ton processed FFB could possibly be used for other purposes than for fueling boilers. For examples, shells could be used to produce activated carbon or as a source of fuel for cement and brick factories [100]. One ton of shells costs about 2300 THB on the market. Selling such material would enable production cost savings of about 0.3 THB per liter of biodiesel. With regards to EFB, this material can be used as substrate for straw mushroom cultivation. The market price of EFB is about 600 THB/ton [100] and would enable production cost savings of about 0.62 THB per liter of biodiesel. However, since EFB is characterized by high N-P-K content, it is more valuable to be used as organic fertilizer [161]. Concerning POME, the treatment of 1m³ of such wastewater via anaerobic digestion can approximately generate about 20m³ of biogas (with 60% methane content) [110, 171]. This could be used as fuel in boilers or for power generation via CDM project. The production cost savings that would result from implementing biogas recovery would amount to 0.28 THB per liter of biodiesel (based on the assumption that 1m³ of biogas is equivalent to 1 kWh electricity and the price of electricity amounts to 3.5 THB.kWh⁻¹). Thus, overall biodiesel production cost savings via implementation of the above mentioned options would amount to 1.2 THB per liter of biodiesel. These, in addition to enhanced externality savings, would help contributing sustaining the palm oil industry and biodiesel production for use in the transport sector. **Table 4.15** also shows the total cost breakdown of diesel and various blends of biodiesel by comparing between baseline scenarios and improved scenarios (after implementing all the three waste utilizations measures as mentioned). The results show that both production cost and externality would be saved from maximizing utilizations of by-products and waste obtained from the mills such as EFB, shells and POME.

Table 4.15 Total cost breakdown of diesel and various blends of biodiesel (based on average price of CPO during 2006-2008 = 23.06 THB/kg) (Unit: THB/L diesel equivalent)

	Diesel	B5		B10		B100	
		Baseline	Improved*	Baseline	Improved*	Baseline	Improved*
LCC (ex-refinery)	21.21	21.59	21.53	21.55	21.44	34.80	33.62
Environmental Externalities	11.18	10.79	10.76	10.08	10.00	3.33	2.69
• <i>Land use (species extinction)</i>	-	0.002	0.002	0.004	0.004	0.044	0.042
• <i>Fossil energy depletion</i>	6.23	5.89	5.89	5.46	5.45	1.14	1.13

	Diesel	B5		B10		B100	
		Baseline	Improved*	Baseline	Improved*	Baseline	Improved*
• <i>Air emissions</i>	4.95	4.90	4.87	4.62	4.55	2.15	1.52
Total cost	32.39	32.38	32.29	31.63	31.44	38.13	36.31
Net external benefit (as compared to diesel)		0.39	0.42	1.10	1.18	7.85	8.49
Net societal (LCC + externality) benefit (as compared to diesel)		0.01	0.10	0.76	0.95	-5.74	-3.92

Remark: (+) means benefits over the gasoline; (-) means costs over the gasoline.

*Refer to the total cost breakdown of the various blends of biodiesel after improving by-products utilizations in palm oil mills i.e. (1) selling of EFB for straw mushroom cultivation; (2) selling of excess shells to produce activated carbon or used as fuel; and (3) biogas recovery.

Sensitivity analysis has been done to analyse the uncertainty of the results when the allocation factors of co-products were determined based on energy content. This is useful in case that the co-products obtained entire the life cycle of palm oil biodiesel production such as shells, EFB, Kernels and POME are utilized for energy purposes. The results show that there are no significant different in the total cost results between using economic and energy allocations as the obtained energy allocation factors for CPO:kernels and PME:glycerin are 0.87:0.13 and 0.92:0.08, respectively (based on the calorific values of CPO = 39.2 MJ/kg, kernels = 17 MJ/kg, PME 38.1 MJ/kg and glycerin = 19 MJ/kg. While, the economic allocation factors for CPO:kernels and PME:glycerin are 0.82:0.18 and 0.92:0.08, respectively. Using energy allocation method to credit the utilizations of waste or co-products of the palm oil mill would result in slightly more incentive in promoting utilization of shells, EFB and POME i.e. the net societal benefits as compared to diesel of B5, B10 and B100 would be 0.1, 0.95 and -3.92 THB/Liter of diesel equivalent, respectively.

4.5 Security of feedstocks supply for future bio-ethanol production in Thailand

This section shows the availability and diversity of feedstock supply for future bio-ethanol production in Thailand according to the policy goals of the recent 15 years biofuels development plan year (2008-2022). The multi-dimension comparisons are conducted in to evaluate the security of feedstocks supply and the sustainability of long-term bio-ethanol production in Thailand. Modeling of long-term supply-demand for feedstocks i.e. cassava, molasses and sugarcane and the analysed results are discussed below.

4.5.1 Modeling of long-term supply-demand for feedstocks in Thailand

4.5.1.1 Feedstock requirements for projected bio-ethanol production

To evaluate the security of feedstocks supply for the long-term bio-ethanol production in Thailand, the assessments are made for three distinct periods: 2008-2011, 2012-2016 and 2017-2022. The future bio-ethanol production system in Thailand has been modeled based on the policy targets set by the government i.e. 3.0, 6.2 and 9.0 M.litres.day⁻¹ by the years 2011, 2016 and 2022, respectively complemented with the assumption that the development in the targets of bio-ethanol production in each period is linear. Feedstock requirements for future bio-ethanol production are investigated by assuming that all 47 ethanol plants licensed by the government can start operation in accordance with the proposed schedule (as updated in September 2009) and are fully operational by year 2016. The total 47 ethanol plants consist of four categories classified by feedstocks used including (1) 5 molasses ethanol (MoE) plants (with a total capacity of 0.675 M.litre/day); (2) 10 molasses/sugarcane ethanol (MoE/SCE) plants (2.01 M.litre/day); (3) 8 molasses/cassava/sugarcane ethanol (MoE/CE/SCE) plants (1.22 M.litre/day) and (4) 24 cassava ethanol (CE) plants (8.39 M.litre/day). Considering these approved plants, only three major feedstocks including molasses, cassava and sugarcane juice are considered in the study. The proportion of feedstocks used to satisfy the policy target demands in each year is estimated based on the production capacity ratio of each type of ethanol plants that will operate in that particular year. For the multi-feedstock bio-ethanol plants, the ratios of feedstocks used for those plants are assumed to be equal i.e. the feedstocks used for the 8 MoE/CE/SCE-plants will be molasses (50%) and cassava (50%). Also, the feedstocks used for the 11 MoE/SCE-plants will be molasses (50%) and sugarcane (50%). The estimated feedstock requirements for future bio-ethanol production are shown in **Table 4.16**. The Thai bio-ethanol system in 2022 will be comprised of 19% from molasses, 72% from cassava and 9% from sugarcane and this requires the supply of 2.51 M.ton molasses, 13.15 ton cassava and 4.15 M.ton sugarcane. The modeling shows that in 2008 almost 92% of ethanol produced in Thailand was derived from cane molasses and only 8% from cassava. However, this proportion would shift over time in favor of cassava if the remaining 35 approved ethanol plants were operated in the future. Cassava would surpass molasses as the major feedstock for ethanol production in Thailand from 2010 onwards and cassava ethanol would share about 67% of the total ethanol produced in

2022 according to the base case scenario. Ethanol derived from sugarcane juice would be around 6% of the total production.

Table 4.16 Feedstocks required for bio-ethanol production

	2008	2009	2010	2011	2016	2022
Bio-ethanol production targets						
(M.litres/day)	0.88	1.34	2.11	3.00	6.20	9.00
Projected bio-ethanol production classified by feedstock types						
Molasses ethanol (M.litre/day)	0.81	0.66	0.64	0.72	1.19	1.72
Cassava ethanol (M.litre/day)	0.07	0.38	1.17	1.95	4.47	6.48
Sugarcane ethanol (M.litre/day)		0.31	0.30	0.33	0.55	0.80
Estimated. feedstocks required						
Molasses (M.ton/year)	1.18	0.96	0.93	1.05	1.73	2.51
Cassava (M.ton/year)	0.15	0.76	2.38	3.95	9.06	13.15
Sugarcane (M.ton/year)		1.60	1.55	1.74	2.86	4.15

4.5.1.2 Feedstock requirements for related industries (domestic use and export)

Demand of feedstocks to produce food and other products (both domestic use and export) in the existing related industries correspond to the projections by the related organizations in Thailand such as the Office of the Cane and Sugar Board (OCSB), the Ministry of Commerce and the Thai Tapioca Starch Association (TTSA). The study refers the demands of cassava and sugarcane in 2008 from the actual data recorded by the OAE [99]. The demands of cassava and sugarcane for domestic use and export during year 2009- 2011 are projected by DEDE and the Ministry of Commerce [172]. However, for the medium- and long-term period (2012 – 2022), the study makes projections by using assumptions as follows:

(1) Domestic demands for cassava to produce flour/starch, chips and pellets are projected by using linear regressing of data of 2008-2011. The National Roadmap on Bio-plastic production in Thailand proposed by the National Innovation Agency (NIA) of Thailand and approved by the Cabinet has cassava as one of the suitable crops for bio-plastics industrial production [173]. However, based on the projected production of bio-plastic (polylactic acid or PLA) in this roadmap, the amount of cassava required is not significant as compared to other uses and is neglected from this study.

(2) Export demands for cassava flour/starch and cassava dried chips are projected by using linear regression of the data of year 2000-2011. However, as the export demand for pellets has been continuously decreasing, so the study refers to the projected demand of year 2011 as maximum demand for exporting pellets during 2012-2022;

(3) Molasses demand for distillery is presumed constant at 1 M.ton per year as per the government's social policy, while, demand for food & feed industries is projected using linear regression of the data during 2007-2011;

(4) Molasses demand for export is supposed to be constant at 0.5 M.ton/yr as per the projection of DEDE in order to keep the market;

(5) Domestic sugar consumption is projected by regressing historic data of domestic sugar demand for household and industries;

(6) The potential amount of sugar for export actually depends on the sugarcane production and demand for domestic consumption in each year, the surplus will be exported. In this study, the demand for sugar export is projected by linear regression of the data of years 1998-2009. The projected feedstock demands for both domestic uses and export for base scenario are shown in **Table 4.17**.

Table 4.17 Feedstock requirements for other related industries (Unit: M.ton feedstock)

Feedstocks used		2008	2009	2010	2011	2016	2022
Cassava	Domestic uses	<i>7.76</i>	<i>8.18</i>	<i>8.42</i>	<i>8.68</i>	<i>10.21</i>	<i>12.00</i>
	Chips/ pellets	2.31	2.52	2.63	2.73	3.44	4.26
	Flour/starch	5.45	5.66	5.78	5.94	6.76	7.74
	Exports	14.16	19.63	21.38	22.01	29.54	37.33
	Cassava chips	2.53	8.45	7.35	7.77	11.41	15.07
	Cassava pellets	3.29	0.70	3.36	3.15	3.15	3.15
	Cassava flour/starch	8.35	10.49	10.67	11.09	14.98	19.11
Sugarcane	Domestic uses	19.23	19.42	20.00	20.00	22.43	24.43
	Exports						
	Raw sugar	28.82	22.67	22.75	23.16	25.18	27.62
	Refined sugar	19.38	25.91	23.14	24.08	28.78	34.42
Molasses	Domestic uses						
	Animal feed & MSG	0.36	0.4	0.4	0.4	0.50	0.61
	Distillery	1.00	1.00	1.00	1.00	1.00	1.00
	Exports	0.71	0.5	0.5	0.5	0.5	0.5

4.5.1.3 Feedstock supply potentials

Feedstock supply potentials are analyzed based on three scenarios which are varied by the possibilities of yields improvement. An expansion of cultivation area for growing

cassava and sugarcane is not considered due to the government policy aimed at maintaining the plantation areas of cassava and sugarcane as of year 2008 i.e. 7.75 M.rai for cassava and 6.59 M.rai for sugarcane [1 rai = 0.16 hectare]. The descriptions of the three scenarios are as follows:

Scenario 1: Low yields improvement: Crop yields are projected to continue growing as usual as if there is no policy on biofuels development. The linear regressions of yields data of cassava and sugarcane during 2000-2008 are used. However the data of year 2005 is excluded in the analysis because of the abnormal situation (i.e. drought) that significantly affected the yields obtained. The annual growth rates of cassava and sugarcane yields are about 3% and 2%, respectively. This scenario is named “low yields improvement scenario” because the yields improving rates would be lower than the rates anticipated in Thailand’s 15 years renewable development plan (2008-2022) for which one of the measures is to boost productivity in the agricultural sector.

Scenario 2: Moderate yields improvement: Crop yields are anticipated to be improved as per the government’s short-term policy targets in Thailand’s 15 years renewable development plan i.e. increase yield of cassava from 3.46 (in 2008) to 5.4 ton roots/rai by 2013 and increase yield of sugarcane from 11.15 to 15 ton cane/rai by 2012. Linear growth rates in the crop yield are assumed.

Scenario 3: High yields improvement: Crop yields are projected to increase to reach the genetic potential of the cassava and sugarcane varieties. Based on genetic potentials of the current varieties of cassava and sugarcane, their yields could possibly reach 8 ton/rai and 20 ton/rai, respectively if they were cultivated in appropriate soil with good agricultural practices [157].

4.5.2 Availability of feedstocks supply

Feedstock surpluses calculated by subtracting demand (domestic + export) from the project yields are shown in **Table 4.18**. The availability of surpluses is varied by three scenarios of yields improvement. The total capacity of bio-ethanol production in Thailand in year 2022 can vary from 3.6 to 17.6 M.litre ethanol/day depending on the potential to improve crop yields. However, the projections reveal that surplus cassava is going to run out since 2012 for the low yields improvement scenario and 2018 for the moderate yields improvement scenario. Only the high yield scenario could ensure that the country has

enough cassava for catering to the export market and still have surplus feedstock for bio-ethanol production. However, to determine whether the surpluses presented in **Table 4.18** are sufficient to satisfy the demand for bio-ethanol in the future, the Net feedstock balances are estimated by subtracting the projected feedstock requirements in **Table 4.16** from the estimated available feedstock resources. The balance figures are shown in **Table 4.19** and the analyses for each specific feedstock are as follows.

Cane molasses is a major feedstock for bio-ethanol production in Thailand as in 2008, 92% of ethanol produced was derived from molasses and only 8% from cassava. The high dependency on molasses resulted in a very small amount of surplus remaining in 2008 as compared to both cassava and sugarcane. However, as there will be only a few number of new molasses ethanol plants that are planning to operate and incorporate the potentials to improve sugarcane yield in the future; therefore, the balances reveal that molasses is still enough to supply in the short- and medium-term. Nevertheless, for the long-term (year 2022), there will be a deficit of about 0.17 M.ton molasses in case of low sugarcane yield improvement. Therefore, increase of sugarcane yield to 15 ton/rai as per the current policy on biofuels development would help the country attain security of molasses supply. Otherwise, decreased export of molasses of around 16% would be required in 2022 to satisfy the bio-ethanol demand.

Cassava is significantly different from molasses in terms of supply availability. Due to its high surplus availability in 2008 i.e. 3.65 M.ton cassava, and only a small amount being used for bio-ethanol, the balance shows that there was about 3.5 M.ton of surplus cassava remaining which made cassava the most interesting feedstock for bio-ethanol production. However, due to the continuously increased demand for dried chips and starch especially for exporting to other countries such as China and incorporating the rapidly growing domestic demand for cassava when many of the 24 cassava ethanol plants are fully operational by year 2016, the balances reveal that cassava is going to run short since year 2010, 2014 and 2016 for the low-, moderate- and high-yields improvement scenarios, respectively. Even though the deficits of cassava supply for bio-ethanol production in the future could possibly be fulfilled by decreasing the export of cassava products, export reduction is an indicator of supply insecurity. It will affect not only the existing dried chips and starch industry in the country but also the lack of supply to the global market bringing about the consequential impacts to global cropping systems and land-use change because

Thailand is the world's leading cassava exporter. For example, in case of moderate yield improvement, the deficit of cassava at about 6.95 and 20.63 M.ton in 2016 and 2022 (Table 4.19) could be compensated by decrease in the projected cassava export by about 24% and 55%, respectively. Therefore, the most appropriate approach is that cassava yields should be improved to at least 6.3 ton/rai by 2016 and 8.1 ton/rai by 2022.

On the other hand, sugarcane juice would play an important role as feedstock for the medium and long-term bio-ethanol production in Thailand because of its surplus availability and high net balances as compared to cassava and molasses. In addition, 19 of the total 48 licensed ethanol producers (totally installed capacity of 3.43 M.litre ethanol/day) have multi-production process i.e. they can switch input feedstocks from molasses and/or cassava to sugarcane. This could also help producers have more security of feedstocks supply by increasing the use of sugarcane when molasses or cassava runs short. In addition, using sugarcane to make bio-ethanol could increase opportunity for the country in having more choices to make benefit from sugarcane instead of producing sugar only. This would also increase income stability for farmers when sugar price in the market falls. However, this advantage would also be considered as the risk of feedstock supply insecurity. The feedstocks might be shocked if country highly depends on using sugarcane for ethanol and the sugar price increases until it is less attractive to produce biofuels as the lesson learned from Brazil [174]. Nevertheless, increased diversion of sugarcane juice to ethanol in the simultaneous sugar-ethanol producers in the future would directly decrease the potentiality to export sugar in the future. Thus, policy makers need consideration on proper management in balancing the use of sugarcane for producing both sugar and ethanol. Regularly monitoring is also required because feedstock prices can rapidly change by forcing of many factors in the market mechanism.

Table 4.18 Feedstock resource estimates for long-term bio-ethanol production

Surplus feedstocks		2008	2009	2010	2011	2016	2022
Scenario 1: Low yields improvement	Molasses (M.ton/year)	1.31	1.50	1.58	1.66	1.96	2.34
	Cassava (M.ton/year)	3.65	1.30	0.27	0.34	-3.94	-7.80
	Sugarcane (M.ton/year)	6.08	5.93	9.81	10.23	9.89	10.39
	Estimated molasses ethanol (M.litre/day)	0.90	1.03	1.08	1.14	1.35	1.61
	Estimated cassava ethanol (M.litre/day)	1.80	0.64	0.14	0.17		
	Estimated sugarcane ethanol (M.litres/day)	1.17	1.14	1.88	1.96	1.90	1.99
	Total potential ethanol production (M.litres/day)	3.87	2.81	3.10	3.27	3.24	3.60

Surplus feedstocks		2008	2009	2010	2011	2016	2022
Scenario 2: Moderate yields improvement	Molasses (M.ton/year)	1.31	1.77	2.06	2.36	2.54	2.44
	Cassava (M.ton/year)	3.65	1.99	3.02	5.14	2.11	-7.48
	Sugarcane (M.ton/year)	6.08	11.84	20.30	25.30	22.46	12.38
	Estimated molasses ethanol (M.litre/day)	0.90	1.21	1.41	1.61	1.74	1.67
	Estimated cassava ethanol (M.litre/day)	1.80	0.98	1.49	2.54	1.04	
	Estimated sugarcane ethanol (M.litre/day)	1.17	2.27	3.89	4.85	4.31	2.37
	Total potential ethanol production (M.litre/day)	3.87	4.47	6.80	9.00	7.09	4.04
Scenario 3: High yields improvement	Molasses (M.ton/year)	1.31	1.77	2.06	2.36	3.15	3.95
	Cassava (M.ton/year)	3.65	1.99	3.02	5.14	8.83	12.67
	Sugarcane (M.ton/year)	6.08	11.84	20.30	25.30	35.65	45.33
	Estimated molasses ethanol (M.litre/day)	0.90	1.21	1.41	1.61	2.16	2.71
	Estimated cassava ethanol (M.litre/day)	1.80	0.98	1.49	2.54	4.35	6.25
	Estimated sugarcane ethanol (M.litre/day)	1.17	2.27	3.89	4.85	6.84	8.69
	Total potential ethanol production (M.litre/day)	3.87	4.47	6.80	9.00	13.35	17.65

Table 4.19 The Net feedstock balances (after accounting for the projected bio-ethanol demand)

Net balances (M.ton feedstocks/year)		2008	2009	2010	2011	2016	2022
Scenario 1: Low yields improvement	Molasses	0.13	0.54	0.65	0.62	0.23	-0.17
	Cassava	3.50	0.54	-2.11	-3.61	-13.00	-20.95
	Sugarcane		4.33	8.26	8.49	7.03	6.24
Scenario 2: Moderate yields improvement	Molasses	0.13	0.81	1.13	1.31	0.81	-0.08
	Cassava	3.50	1.23	0.64	1.19	-6.95	-20.63
	Sugarcane		10.24	18.75	23.55	19.60	8.23
Scenario 3: High yields improvement	Molasses	0.13	0.81	1.13	1.31	1.42	1.44
	Cassava	3.50	1.23	0.64	1.19	-0.23	-0.48
	Sugarcane		10.24	18.75	23.55	32.79	41.18

4.5.3 Diversity of feedstocks supply

To measure the security of feedstock supply for the future Thai bio-ethanol production system, the study refers the Scenario 2: Moderate yield improvement as base line because it is modeled based on the recent government policy target on yield improvement. Shannon index is applied to measure the diversity in utilizing feedstocks for bio-ethanol production in Thailand. Regarding the equation to estimate the Shannon index as shown in section 3.1.2, the feedstock source index (i) would represent the potential feedstock supply for the future Thai bio-ethanol production i.e. cassava, molasses and sugar cane. The shares of those feedstocks supply in the future bio-ethanol system (p_i) are estimated based on the projected bio-ethanol production classified by feedstock types as

shown **Table 4.16**. For the problem about lack of cassava and molasses supply in medium- and/or long-term which were identified in the availability of feedstocks supply section, the calculation supposes that it would be solved by reducing export of cassava and molasses. Then, the year-by-year Shannon indexes can be estimated as shown in **Table 4.20**.

For year 2008 where the bio-ethanol system consists only molasses and cassava as feedstock sources, the results show that Shannon index obtained is just about 0.28 and this is the lowest value as compared to the other years where it ranges between 0.74 – 1.01 because sugarcane is started to use as an additional source of feedstock since 2009. Therefore, the feedstock sources index (i) is changed from $i = 2$ in year 2008 to $i = 3$ in the latter years which results in a shift of the Shannon index. However, the obtained values are still lower than the possible maximum Shannon index which could reach 0.693 and 1.099 for feedstock source index (i) = 2 and 3, respectively. Moreover, the trend of Shannon index would decrease in the long-run when the other approved ethanol plants were fully operated following schedule. During the years 2009 – 2022, Shannon index will reduce from 1.016 in 2009 to 0.740 in 2022. These results express that there is an increased imbalance in utilizing feedstock across categories in the long-run. This is because according to the government's plan, if all 48 licensed ethanol plants operate at full capacity, the country will be highly dependent on cassava. This insecurity of supply in terms of imbalance across utilizing feedstocks, nevertheless, could be remedied by increasing the utilization of sugarcane juice (i.e. more than 50% of the total feedstock inputs which is the basis for estimating the scenario) in the multi-feedstocks ethanol plants.

Table 4.20 Projected Shannon index of bioethanol production system in Thailand

	2008	2009	2010	2011	2016	2022
Shannon index	0.285	1.016	0.946	0.842	0.740	0.740

4.5.4 Recommendations for enhancing long-term security of feedstocks supply

To enhance long-term security of feedstocks supply for bio-ethanol production in Thailand, several recommendations are identified as follows:

4.5.4.1 Increasing use of sugarcane juice as feedstock

Sugarcane juice should be the most crucial feedstock for the medium and long-term bio-ethanol production system in Thailand. Its advantages are not only the surplus availability but also producing ethanol from sugarcane juice in the simultaneous sugar-

ethanol factory is more efficient [175-176]. Low production cost and high efficiency of sugarcane juice ethanol stems from several reasons i.e. (1) all low-quality sugar-containing streams such as secondary juice (from 2nd to the last mill), filter juice and others can be sent to the distiller with no losses; (2) facilities such as steam and electricity generation, water-wastewater treatment, etc. can be shared with sugar mills [175]. In addition, its performance in GHG emissions is better than cassava and molasses ethanol. Increased share of using sugarcane juice in biofuels production system, therefore, would help improve the security of supply indicators. For instance, reduction in molasses and cassava required when more sugarcane juice was introduced more would increase the net balances of molasses and cassava. In addition, this would also result in the increase of Shannon index of the Thai bio-ethanol production system in the long-term because the balance in utilizing molasses, cassava and sugarcane as feedstock would be improved. For example, **Table 4.21** shows the comparison of indicators between the former high yield improvement scenario (scenario 3) and its modification. In the modification, it is assumed that sugarcane use will be increased to replace cassava which is likely to face shortage in the long run. The easiest way is to presume that the 8 MoE/CE/SCE ethanol plants will switch their feedstocks used from 50% molasses and 50% cassava to be 50% molasses and 50% sugarcane. The results show that yield improvement and increased use of sugarcane could help the Thai bio-ethanol production system in year 2022 to have more security of feedstock supply in all the dimensions i.e. availability, diversity and environmental performance.

Table 4.21 Indicators of comparisons for the Thai bio-ethanol system in year 2022

	Feedstock balances	Diversity of supply (Shannon index)	Net GHG reduction based on 9 M.litre ethanol/day (M.ton CO ₂ -eq./year)
High yields improvement scenario	Decrease exporting cassava 1%	0.74	3.4
High yields + Increased use of sugarcane as feedstock by replacing cassava in 8 Molasses/Cassava/Sugarcane ethanol plants	No need to decrease cassava export	0.82	3.6

Nevertheless, there still are some practical problems and concerns when promoting the increased utilization of sugarcane juice as feedstock:

(1) How to deal with the existing revenue-sharing system which has been adopted under the Sugar Act of 1984 [177-178] and is a practical barrier of the simultaneous sugar-ethanol producers today. Under this existing system, cane growers receive a 70 percent share of revenue from sugar and molasses sales in both the domestic and export markets after deducting all costs and taxes, and mills earn the remaining 30 percent. Therefore, if the sugar mills utilize sugarcane juice to produce ethanol, this revenue-sharing system may need to be adjusted. This question is still a controversial issue among various stakeholders. The basic calculation can be done by converting the amount of sugarcane juice used for producing ethanol into sugar equivalent and bring this obtained amount of sugar equivalent into the revenue-sharing system of 70:30. However, the results obtained must be verified and revised again after trial implementation by OCSB and other parties such as Ministry of Energy and Ministry of Agriculture and Cooperatives in order to make the appropriate methodology that can give reasonable benefits to both millers and farmers.

(2) Uncertainty of sugarcane juice supply due to rising market price of sugar would be another barrier when promoting its utilization to produce ethanol. This lack of supply, however, is not in terms of surplus unavailability but in terms of uncertainty in market prices of sugar and ethanol. A good example is the experience of Brazil which used to confront the “alcohol crisis” during the late '80s due to the vast national market because of the sugar price increase [174]. A good balance in utilizing sugarcane for both sugar and ethanol products needs to be controlled by the government in order to avoid risks of food/fuel competition. Policy instruments such as subsidies may be required to provide incentive to millers and farmers when sugar prices rise. It, however, must be a temporary measure and should be carefully adopted by considering the costs-benefits for the country.

(3) Utilization of sugarcane juice in the simultaneous sugar-ethanol plants will be limited only for a period i.e. December – March because sugarcane is a seasonal crop that has a fixed time period for growing and harvesting. Therefore, good ethanol stock management is required from the ethanol producers and also from the policy makers. This is because huge amounts of ethanol could be produced and come out in a very short period of time. In addition, encouragement of a multi-processing structure where the ethanol producer can switch easily between feedstocks such as molasses/sugarcane/cassava should be sustainable for long-term production.

4.5.4.2 Improved yields with existing feedstocks

Yield improvement would be another vital measure to enhance security of feedstocks supply with less environmental and social impacts as compared to expansion of cultivation areas. Expansion of cultivation areas for energy crops brings about the concern of land-use change (LUC) and its consequential impacts on carbon stock change, biodiversity and ecosystem services loss and soil erosion, for which first generation biofuels are now being blamed [13, 55]. According to the assessment results, sufficient and reliable feedstock supply of cassava and molasses for bio-ethanol program in the long-run without reducing exports will occur only if cassava and sugarcane yields were improved as per the high yield scenario (scenario 3) i.e. 8 and 20 ton/rai by 2022, respectively, which seem difficult to achieve if compared to the historical growth rate of yields improvement in scenario 1. However, due to the continual development of genetic technology, there are various high yield varieties of cassava and sugarcane nowadays that could possibly reach those yield targets when they were grown on appropriate soil with good agricultural practices such as improved soil quality by using organic fertilizers, good practices in land preparation, plantation, harvesting and regularly weed control [179-181]. For example, the current varieties of cassava (e.g. Kasetsart 50, Rayong 5, Rayong 72 and Rayong 9) and sugarcane (e.g. K 84-200, U thong 3 and K 90-54) being recommended to Thai farmers have the potential to yield about 5-8 ton/rai for cassava and 15-18 ton/rai for sugarcane. Intensification of fertilizers could be another way to quickly improve yields but it needs careful control because it may create adverse impacts on ecosystems and GHG emissions [182-183].

4.5.4.3 Promoting production of bioethanol derived from agricultural residues

Bio-ethanol derived from agricultural residues or second generation bio-ethanol would be an attractive option for Thailand in the long term. There is a variety of reasons why agricultural residues should be promoted as feedstock for biofuels. Thailand is an agro-industrial based country which nowadays has abundant agricultural residues left in the field. The use of agricultural waste/residues offers a way of creating value added to society. No additional land is required for its production and it does not compete with food. In addition, enhancing production of bio-ethanol from agricultural residues could improve diversification of feedstocks supply for bio-ethanol production system in Thailand. Therefore, one of the measures in the Thai biofuel development policy is to encourage research and development on second generation biofuels and it is expected that at least one

commercial plant could start operation by 2022. Based on crop production in 2008 [99], crop-to-residue factor [184] and factors of non-utilization [185], the calculations reveal that oil palm fronds, sugarcane trash (including tops and leaves) and rice straw are the three major unused residues in terms of available quantity. Their available unused residues are 28.2, 21.9 and 9.6 M.ton/year, respectively. Oil palm fronds are principally left rotting between the rows of palm trees. Some amount of cane trash and rice straw are also left in the fields or used as raw materials for other industries such as fibre production or animal feed. However, one of the facts is that huge quantities of rice straw and cane trash are also, currently, burnt in the fields and create other consequential impacts such as air pollution problems and soil degradation [186-187]. Therefore, utilization of sugarcane trash and rice straw as feedstocks for bio-ethanol production in Thailand would be a good opportunity for socio-economic development.

Nevertheless, it does not mean that all the calculated surplus amounts can be removed from field and used to produce biofuels. This is because there are long-term economic and environmental concerns associated with the removal of huge quantities of residues from cropland. Removing any residue from some soils could reduce soil quality, promote erosion and lead to a loss of soil carbon stock, which, in turn, lowers crop productivity and profitability. Therefore, further research on sustainable levels of crop residue removal for different crops and soil conditions are required. This aims to ensure that removal of residues for bio-ethanol production in the future will be done in a sustainable manner. Bagasse could also be another choice to consider for biofuels. It is not the reason of surplus availability because almost all bagasse is already being used as fuel for producing utilities such as steam and power. But the advantage is that bagasse is already collected in the sugar mills and many millers have licenses as ethanol producers. Therefore, the transport cost will be cheaper than other feedstocks if the bagasse-ethanol production process is installed in the sugar mills. Increased bio-ethanol derived from agricultural residues in the long-run would help the country's bio-ethanol system to have more diversity of supply sources which would improve the Shannon index of the system compared to the current scenario.

4.6 Security of feedstocks supply for future palm biodiesel production in Thailand

To meet the ambitious goals of biodiesel production in Thailand leads to the challenges on how to maintain the availability of CPO supply to satisfy the increased

future demand of the food, cosmetics and biodiesel industries. This section, therefore, intends to assess the availability of CPO supply for future biodiesel production in Thailand and the consequential impacts of future CPO demand on LUC.

4.6.1 Feedstock requirements for projected biodiesel production

To evaluate the security of feedstock supply for future biodiesel production in Thailand, the assessments are made for three distinct periods: 2008-2011, 2012-2016 and 2017-2022 as short-, medium-, and long-termed period, respectively. The future biodiesel production system has been modeled based on the policy targets set by the government i.e. 3.0, 3.6 and 4.5 M.litre.day⁻¹ by year 2011, 2016 and 2022, respectively complemented with the assumption that the development in the targets of biodiesel production in each period is linear. As commercial biodiesel in Thailand today is mainly produced from palm derivatives especially CPO; therefore, the study can estimate the maximum CPO and FFB requirements for future biodiesel production in Thailand (as shown in **Table 4.22**) by assuming that total biodiesel production would be derived only from CPO.

4.6.2 Feedstock requirements for related industries (domestic use, stock and export)

To estimate the CPO demand of food and the other related industries (both domestic use and export), the study refers to the assumption of DEDE and Ministry of Commerce that the demand for CPO would be increased at 5% annually over the years 2009-2022 [188]. The stock of CPO has been set around 10% of the total CPO demands (food, biodiesel and others). Then, the demand for CPO and FFB of food, other industries and stocks can be projected as shown in **Table 4.22**.

4.6.3 Feedstock supply potentials

Oil palm plantations in Thailand have doubled from 1.6 to 3.2 M.raï during years 2000-2007 with increased harvested areas from 1.4 to 2.9 M.raï. Nevertheless, the FFB yield has been variable and has not increased as much as the oil palm cultivated areas. This is because of many uncontrollable factors e.g. drought, flood, disease and insects. Just a slight improvement of FFB yield has been observed from the statistics; the current average yield being 2.8 ton.raï⁻¹.yr⁻¹ [99, 189-190]. To satisfy the future anticipated CPO demand for biodiesel, the road map of the oil palm and palm oil industries development plan (2008-2012) calls for the oil palm productivity improvement as well as the expansion of palm plantation [190]. The targeted FFB yield is set to 3.2 tons.raï⁻¹.yr⁻¹ by 2012; meanwhile,

about 2.5 million rai additional land is expected for new oil palm plantation by 2012. This amount of promoted areas will almost double the current harvested area. In this study, the CPO supply potentials are calculated based on the policy targets on oil palm development and the conversion factors of 5.95 kg FFB/kg CPO.

4.6.4 Net feedstock balances

The net feedstock balances have been evaluated to determine the availability of CPO supply for long-term palm biodiesel production in Thailand. The assumptions are as follows:

- (1) FFB yields are anticipated to be improved as per the short-term government's policy targets as mentioned above i.e. increase FFB yields from 2.8 (in 2007) to 3.5 tons.rai by 2012. Linear growth rate in the yield is assumed;
- (2) Cultivation areas for oil palm are anticipated to be increased as per the government's policy targets. The figure of the new oil palm plantation areas is assumed to be expanded by about 0.5 M.rai per year since year 2008 to 2012 to meet the targets of 2.5 M.rai of new cultivated areas.

Table 4.22 shows the net feedstock balances after subtracting the CPO supply potentials with the CPO demands for food, biodiesel and stocks. The balances reveal that expansion of 2.5 M.rai for new oil palm plantation accompanied with an increase of FFB yield to 3.5 ton/rai by year 2012 is enough for the long-term security of CPO supply. However, for the short-term period as year 2010 and 2011, the net balances are 0.03 and (-0.01) million ton CPO, respectively. This means that there is a high possibility to run out of CPO over that period even though the additional palm plantations are encouraged. This is because the new plantations require more than three years before the first harvesting. Thus, the rapid increase in demand for meeting the short-term target might affect to the supply of CPO for food and export or affect to the country stock. Import of CPO might be required to satisfy the deficit.

Actually, the anticipated CPO shortage can possibly be resolved by improving oil palm productivity. However, the existing palm varieties today are difficult to improve as the genetic engineering technology of oil palm in Thailand has just recently begun and it is a time-consuming process [157]. FFB yield of the current palm varieties, although, can possibly reach 5 tons/rai/year; however, this success must be supported by good

agricultural practices of farmers such as selecting the appropriate palm varieties, maintaining of soil quality with organic fertilizers, regular treatment and good irrigation [157]. Therefore, to avoid the risk of CPO shortage especially for the short- and medium-term, new palm plantation areas need to be spurred as fast as possible. Hence, we conclude that policy on biodiesel development in Thailand would result in direct land-use change which has to be included in the assessment which will be discussed later.

Table 4.22 The net CPO balances during 2008-2022

	2008	2009	2010	2011	2016	2022
(1) Feedstock supply potentials						
Planted area (M.raï)	3.63	4.20	4.70	5.20	5.70	5.70
Harvested area (M.raï)	2.87	3.22	3.42	3.67	5.70	5.70
Yield (ton/raï)	3.22	2.98	3.15	3.33	3.50	3.50
FFB production (M.ton FFB)	9.27	9.57	10.78	12.20	19.95	19.95
CPO production (M.ton CPO)	1.68	1.74	1.96	2.22	3.63	3.63
(2) Feedstock requirements for biodiesel						
Biodiesel production targets (M.litre/day)	1.23	1.56	2.28	3.00	3.64	4.50
CPO required (M.ton/year)	0.42	0.54	0.78	1.03	1.25	1.54
FFB required (M.ton FFB/year)	2.32	2.94	4.30	5.66	6.87	8.49
(3) Feedstock requirements for food and others						
CPO required for food and others (incl. domestic & export)	1.08	1.06	1.11	1.17	1.49	2.00
(4) Stocks						
CPO stocks at the beginning of the year	0.08	0.11	0.16	0.19	0.26	0.34
CPO stocks at the end of the year	0.11	0.16	0.19	0.22	0.27	0.35
(5) Net feedstock balances						
Net CPO Balances (M.ton CPO)	0.15	0.09	0.03	(-0.01)	0.88	0.07

4.6.5 Conclusions

Policy on biodiesel development in Thailand will directly affect direct land-use changes as both improving FFB yield and expanding new oil palm plantations are necessary to avoid the shortage of CPO supply for future food and fuel production. The assessments indicate that conversion of rubber and tropical forest land to oil palm increases the released GHG of palm biodiesel production by 2.75 – 5.2 times as compared to the case where LUC is excluded. This is in contrast to the conversion of field crops, paddy and set-aside land to oil palm where can bring about GHG benefits due to the gain of biomass carbon stock and the increase in soil organic carbon stock. Therefore, policy to promote new oil palm

cultivation only on the suitable land such as set-aside land is important for sustainable palm biodiesel production in Thailand.

4.7 Employment and socio-economic impacts of biofuels production in Thailand

4.7.1 Employment effects

According to methodology and data sources as explained in **Section 3.4**, the direct and indirect employment caused by biofuels production in Thailand which are estimated as shown in **Table 4.23**. Per M litre of biofuel, palm biodiesel induces the biggest numbers of employment i.e. 128 employed persons followed by sugarcane ethanol, cassava ethanol and molasses ethanol, respectively. However, if the comparison is done on the basis of energy content of biofuels, say based on 1 TJ of biofuels, producing all bio-ethanol products would generate nearly the same employment i.e. 5-6 persons-year; while, palm biodiesel would generate only around 3 persons-year. Direct employment in agriculture is the most essential employment benefit generated from producing biofuels in less mechanized agriculture like Thailand as it contributes to more than 90% of total employment generation (**Table 4.24**). Employment effects of molasses ethanol to agriculture are revealed by the huge numbers of indirect employment generated during feedstock processing stage of molasses ethanol. The significant employment in agriculture implies that policy to promote production and use biofuels could help spur rural development in Thailand. Nevertheless, two key reasons of the huge numbers of employed persons in agriculture are identified as follows: (1) agriculture is the most labour-intensive sector in the Thai economy as the farmers are generally the small scale and farm operations largely manual; and (2) low productivity due to lack of good agricultural practices.

For comparison with petroleum fuels, the employment effects of gasoline and diesel production in Thailand are also computed based on the average ex-refinery prices of gasoline and diesel during 2006-2008, which is the same baseline time period as in the estimation of biofuels production costs. The average ex-refinery prices of gasoline and high speed diesel in Thailand used in the estimations are 16.28 and 19.44 THB/L; and the energy content of gasoline and diesel are 32.4 and 37.9 MJ/L, respectively. The results show that producing bio-ethanol requires about 17-20 times more workers per joule of energy content produced than gasoline. Meanwhile, biodiesel requires about 10 times employed persons per joule of energy content as compared to diesel. Nevertheless, only underlying the numbers of employment created by biofuels without a closer look at the

characteristics and the role of employment in the biofuels sector would not be enough to interpret the social and socio-economic impacts of biofuels. Therefore, the characteristics and quality of jobs should be clarified and this is discussed further.

Table 4.23 Employed persons (persons-year) of biofuels production in Thailand

	Per Million litre of biofuels			Per Terajoule of biofuels		
	Direct	Indirect	Total	Direct	Indirect	Total
Cassava ethanol	70	47	117	3.3	2.2	5.5
Molasses ethanol	10	102	112	0.5	4.8	5.3
Sugarcane ethanol	85	36	121	4.0	1.7	5.7
Palm biodiesel	74	54	128	2.0	1.5	3.5
Gasoline	0.3	9.1	9.4	0.0	0.3	0.3
Diesel	0.3	10.9	11.2	0.0	0.3	0.3

Table 4.24 Classification of employments in biofuel production (%)

	Cassava ethanol			Molasses ethanol			Sugarcane ethanol			Palm oil biodiesel		
	Dir.	Ind.	Tot.	Dir.	Ind.	Tot.	Dir.	Ind.	Tot.	Dir.	Ind.	Tot.
Agriculture	96%	79%	91%				97%	81%	94%	98%	61%	92%
Feedstock												
processing	0%	8%	3%	51%	92%	88%				1%	20%	4%
Ethanol												
conversion	4%	13%	7%	49%	8%	12%	3%	19%	6%	1%	19%	4%

*Dir.: Direct employment; Ind.: In-direct employment; Tot.: Total employment

4.7.2 Characteristics of employment

Employment in the biofuel sector is better understood when the characteristics of the biofuel-related employment effects in Thailand are investigated and clarified. For biofuels production in Thailand, direct labour/workers involved can be classified into two major groups i.e. holdings in agriculture and workers in the manufacturing sectors for feedstocks processing and biofuel conversion as shown in **Figure 4.17**.

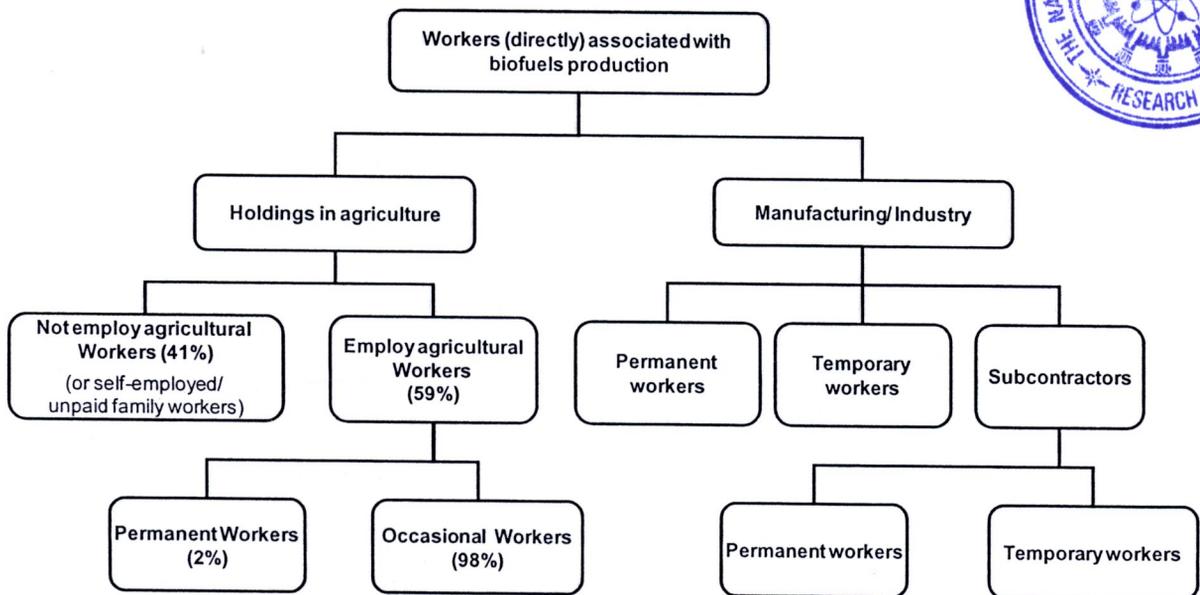


Figure 4.17 Clarification of labour characteristics in biofuels production

There are the obvious differences in the characteristics of employment and quality of jobs between employed persons in agriculture and the biofuels processing sector. Regarding the Agricultural Census [149], the major groups of labourers in agricultural holdings in Thailand are the group of self employed workers (or unpaid family workers) and the group of occasional workers. This means that the key advantage of biofuels on the creation of direct employment in agriculture as quantified earlier is likely to be of a temporary employment nature. This differs from the direct and indirect employment generated in the biofuel industry or the other intermediate production sectors which the surveys found that they are generally employed as the permanent staff. Therefore, labourers in agriculture today are poorly protected by national labour law as compared to employed workers in the industry. For example, there are no national laws or public policies related to working conditions.

In addition, as holdings in agriculture are mainly the small scale farmers, therefore, the collective bargaining is often limited to large commercial farms and plantations. Farmers are generally not able to negotiate with the middle man or industry when selling their crops. Therefore, to ensure sustainable biofuel production in the future, the standards of labour rights and working conditions should be considered by the RTG by focusing on the standards for agricultural sector in order to help those small scale farmers, employed persons or even the unpaid family workers to have more opportunity in labour rights and

decent working conditions. The fair wages and selling prices of crops should be one of the labour rights criteria for sustainable biofuels production.

4.7.3 Employment effects of Thai biofuel targets

Employment generation in the sector of biofuels is a challenge. Effects of biofuel policy to the creation of employment in the future Thai economy depends on several key factors including biofuels production targets, types of feedstocks used and the development of agricultural productivity and biofuels production technologies. For example, if the machinery for harvesting sugarcane were introduced to replace manual harvesting in the large-scale sugarcane plantations in order to increase yields in the future, this would decrease the numbers of direct labour for harvesting sugarcane which currently is the major proportion of employed persons in sugarcane plantation. This section aims to evaluate the total employment effects of the biofuel development in Thailand based on the 15 years alternative energy development plan (2008-2022) in which the ambitious goals of bio-ethanol production have been set at 9.0 M.litre/day in 2022. According to the installed capacity of current and future ethanol plant that licensed by the government, Silalertruksa and Gheewala (2010) estimated that the future bio-ethanol production system in Thailand (year 2022) would consist of producing 1.72 M.litre molasses ethanol/day, 6.48 M.litre cassava ethanol/day and 0.8 M.litre sugarcane ethanol/day [191].

Four scenarios for increasing feedstocks production to satisfy the increased demand for bio-ethanol in the future are assumed and investigated. The description of the scenarios is as follows:

Scenario 1: To expand the cultivation areas for cassava and sugarcane while maintaining the crops yields of cassava and sugarcane at the current levels i.e. 3.5 tons/rai [1 rai = 0.16 hectare] for cassava and 11.2 tons/rai for sugarcane.

Scenario 2: To follow the government policy of keeping the plantation areas of cassava and sugarcane at the same level as year 2008 i.e. 7.8 M.rai for cassava and 6.6 M.rai for sugarcane, the yields of cassava and sugarcane must be improved from 3.5 to 8 tons/rai and 11.2 to 20 tons/rai in 2022, respectively. This is just to help country has enough cassava and sugarcane to satisfy the increased demand of bio-ethanol by without affecting to the requirement for food and feed. The labour requirements during cultivation

and harvesting are assumed to be the same as the current situation since the mechanized system is assumed to be adopted in the future.

Scenario 3: Same as scenario 2, however, the labour requirements for treatment and harvesting during feedstock production are assumed to increase 50% of the rate of increased yields.

Scenario 4: Same as scenario 2, however, the labour requirements for treatment and harvesting as employment for treatment and harvesting are assumed to increase same as the rate of increased yields.

Based on target of producing 9 M.litre of bio-ethanol per day in 2022, the assessment shows that the numbers of persons engaged would be ranged between 238,700 to 382,360 persons (**Table 4.25**). The variations depend upon the policy on the future crop productivity development for large scale biofuel production. Scenario 2, which represents the case that the requirements for workers to treatment and harvest crops will not increase due to mechanization would result in the lowest numbers of employed persons. Even though, the absolute numbers of total employment induced by bio-ethanol policy are large, however, the relative importance of the employment effects is limited. As compared to the total employments in agriculture (year 2009) which is around 14,692,500 people [145], the direct employment effects in agriculture in 2022 would range around 106,100-196,700 persons.

Table 4.25 Projections of employment caused by bio-ethanol target in year 2022

	Employment coefficients for high yields assumption (Persons-year/ML biofuels)			Employment caused by bio-ethanol target in 2022 (Persons-year)			
	Direct	Indirect	Total	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Molasses	10	46	56	70,374	35,209	35,209	35,209
Cassava	36	40	76	276,839	180,421	216,049	251,677
Sugarcane	47	32	79	35,152	23,075	27,388	31,701
Total				382,365	238,705	278,646	318,586

4.7.4 Other contributions of biofuels to socio-economic development

Biofuels development can contribute not only employment impacts but other elements of national development such as economic growth through new biofuels sector investment, economic effects on GDP, trade balance and energy security of the country

[192]. The other important elements of socio-economic development caused by biofuels production in Thailand are investigated as follows:

4.7.4.1 GDP development

The gross domestic product (GDP) of a country is an indicator to measure economic performance and the size of the economy. Even though, GDP is an economic performance indicator, however, measuring the changes in GDP can indicate the amount of income generated and retained in the country itself [72]. The study determines the effects of biofuels production in Thailand on the total value added or GDP of Thai economy. To perform the analysis, the direct GDP coefficient for each sector is obtained by dividing the direct value added of each sector in the modified IO table by the sector's total output. Then, the total GDP coefficient can in turn be calculated from the multiplication of the inverse matrix and the direct GDP coefficient vector as shown in Appendix C (Table C.5). Referring to the changes in final demand due to biofuels production (Table 3.11), the total impacts of different kinds of biofuels in Thailand on GDP can be estimated as shown in **Table 4.26**.

The results show that to produce 1 M.litre of cassava ethanol, molasses ethanol, sugarcane ethanol and palm biodiesel contribute around 18, 15, 22 and 23 M.THB to the national GDP, respectively. The main contributors to the changes in GDP of biofuels are the direct impacts from agriculture followed by the indirect impacts from energy and chemicals consumptions. The high share of direct impact stems from the amount of feedstocks used and their costs (e.g. cassava, molasses, sugarcane and oil palm) which are the largest production cost component of biofuels. The shares of feedstock costs to total GDP effects range around 62-73% of direct impacts or 29- 55% of total impacts on GDP. A special remark is for the case of palm biodiesel is that the methanol used would be the second contributor to GDP development. The induced impacts of increased use biofuels to the decrease in operation of refinery sectors are not considered in the study as biofuels used in Thailand are in the blended forms between biofuels e.g. bio-ethanol and biodiesel with conventional fuels such as gasoline or diesel. Therefore, the biofuels sector will play a role in the new additional sector to economy and will have just a few affects to the refineries industry in the view of products competition. Thus, these obtained GDP effects of biofuels can be directly considered as the benefits of biofuels to the GDP of the country. In addition, this increase in GDP or value added can imply a rise in the income of the

people as the terms of “total value added” in IO table also include the primary inputs such as wages and salaries.

To provide the extent of the socio-economic impacts of biofuel policy in Thailand, the target of producing 9 M.litre bio-ethanol were achieved in 2022 with cassava, molasses and sugarcane ethanol as mentioned before will result in an additional GDP of 55,511 M.THb.

Table 4.26 GDP effects of biofuels in Thailand

Biofuels	GDP (M.THb) per ML biofuels			GDP (M.THb) per TJ biofuels		
	Direct	Indirect	Total	Direct	Indirect	Total
Cassava ethanol	9.39	8.89	18.28	0.44	0.42	0.86
Molasses ethanol	8.89	6.15	15.04	0.42	0.29	0.71
Sugarcane ethanol	10.14	12.01	22.14	0.48	0.57	1.04
Palm biodiesel	17.07	6.08	23.15	0.47	0.17	0.64

4.7.4.2 Trade balance

Another benefit of import substitution is the improvement of the country’s trade balance. Balance of trade is one of the crucial aspects for developing countries in that it measures it measures a country’s dependence on other countries and the country’s possibilities for generating income from selling to other countries [72]. Therefore, it is necessary to determine the amount of import needs for biofuels production systems in Thailand and comparing with the case of conventional fuels such as gasoline and diesel. IO analysis has been used in the same way as the analyses of impacts on GDP. **Table 4.27** shows the effects of imports obtained from the multiplication of the final demands for biofuels production and the import coefficients. The results show that producing 1 TJ of cassava ethanol, molasses ethanol, sugar cane ethanol and palm biodiesel will result in an increase of total imports around 1.05, 0.66, 1.81 and 0.54 M.THb, respectively. Nevertheless, if compared to the cases of producing gasoline and diesel at the same energy performance i.e. 1 TJ, production of biofuels to substitute petroleum fuels could decrease the country’s imports by 0.37 – 1.12 M.THb per TJ of bio-ethanol and 1.68 M.THb per TJ of biodiesel.

For imports, the largest contributors are the indirect impacts of chemicals used in biofuels conversion stage followed by the indirect impacts from energy consumed. The fractions of chemicals consumption to the imports range between 18-57% of indirect

impacts or around 13-37% of total imports. In addition, the total imports of chemicals for biofuels production share about 25-68% of total imports. Thus, if the targets of producing bio-ethanol about 9 M.litre/day (or equivalent to 69,642 TJ/day) were achieved in 2022, the bio-ethanol production could help reduce imports by 93,288 M.THB/year.

Table 4.27 Import effects of biofuels in Thailand

Biofuels	Import (M.THB) /ML biofuels			Import (M.THB) per TJ biofuels			Difference* (M.THB/TJ)
	Direct	Indirect	Total	Direct	Indirect	Total	
Cassava ethanol	6.33	16.00	22.33	0.30	0.75	1.05	- 1.12
Molasses ethanol	3.76	10.26	14.03	0.18	0.48	0.66	- 1.52
Sugarcane ethanol	13.88	24.46	38.35	0.65	1.15	1.81	- 0.37
Palm biodiesel	7.11	12.42	19.53	0.20	0.34	0.54	- 1.68

*Differences = (total import/TJ of bio-ethanol) – (total import/TJ of gasoline) or (total import/TJ of biodiesel) – (total import/TJ of high speed diesel)

4.7.4.3 Agricultural sector improvement and rural development

To satisfy the demand for biofuels production in the future, the government policies on bio-ethanol development focus on the improvement yields of cassava and sugarcane instead of expansion of cultivation areas. This is in contrast to the policy of biodiesel development where both expansion of cultivated areas and yields improvement are considered. Cassava yields are anticipated to improve as per the government’s short-term policy targets as mentioned in the 15 years renewable development plan i.e. increase yield of cassava from 3.5 to 5.4 tons roots/rai [1 rai = 0.16 hectare] by 2013 and increase yield of sugar cane from 11 to 15 tons cane/rai by 2012. These yield improvement rates would be faster than the average annual growth rates of cassava and sugarcane yields during 2000-2008 which are just about 3% and 2%, respectively annually [191]. Nevertheless, to enhance security of feedstocks supply for long-term bio-ethanol production in Thailand, cassava and sugarcane yields must be improved to 8 and 20 ton/rai by 2022, respectively [191]. This means that more research and development of high yield varieties of cassava and sugarcane is necessary as well as the promotion of good agricultural practices (GAP) such as improved soil quality by using organic fertilizers, good practices in land preparation, plantation, harvesting and regular weed control that could help reaching those yield targets [157, 180]. However, the current varieties of cassava (e.g. Kasetsart 50, Rayong 5, Rayong 72 and Rayong 9) and sugarcane (e.g. K 84-200, U thong 3 and K 90-54) being recommended to Thai farmers have the potential to yield about 5-8 ton/rai for

cassava and 15-18 ton/rai for sugarcane if cultivated in appropriate soil with good agricultural practices [157]. This is a little different from the case of palm oil biodiesel where both increase in FFB yields and expansion of new oil palm plantation need urgently to be promoted urgently by the government to avoid the shortage of CPO supply for future food and fuel production.

Besides, the creations of direct employment in agriculture which in turn results in the generation of income to workers or farmers in rural areas, some policies to promote biofuels/bio-energy of the RTG are also expected to boost rural development and raise the living standard of people in rural areas. For example, the RTG has a plan to encourage community-based biodiesel production and use in 72 communities across the country in order to reduce local communities' expenses on energy by using biodiesel derived from used cooking oil or oil plants grown in the community such as jatropha to substitute diesel in agricultural machines. Technical assistance is also provided through learning centers, financing pressing and biodiesel processing machines, as well as conducting training and information sharing on farming oil crops [193]. In addition, the increased demand for crops to produce biofuels in the future is also anticipated to raise and stabilize the selling prices of crops and this may be beneficial to farmers for a having more credit to access banks in the future. However, the nature of small farm holdings in the agricultural sector of Thailand lead to the limitation of farmer's ability to negotiate with middle man or industry for receiving the most appropriate prices of crops. Therefore, the policy instruments to protect the small scale farmers through collective bargain by the formation of cooperatives are required. Nevertheless, there will be other social and/or socio-economic benefits and risk of biofuels policy that may relevant Thai society and need further investigations and discussions. For example, biofuels policy can help security of energy supply and diversification of energy sources for the country. However, the rapid increase in demand for biofuels might be adverse impacts to people and environment in rural areas such as the trespassing on the reserve land, the poorer/small-scale farmers losing their ability to access the land to the large-scale investors, children become permanent farm labourers since an early age. Measures to against those risks need to be implemented to guarantee the sustainability of biofuels in the social and socio-economic dimension.

