CHAPTER IV
RESULTS AND DISCUSSION

4.1 Biorefinery Model

According to biorefinery concept, a biorefinery model was created with ethanol production capacity 160 ton/day and BSA and LA production capacity 300 ton/day includes 13 major processes which are sugarcane cultivation, sugarcane milling, cassava cultivation, cassava starch production, cassava sugar production, cassava pulp biogas production, electrical energy cogeneration, BSA production, LA production, sugarcane ethanol conversion, molasses ethanol conversion, cassava ethanol conversion, and cassava rhizome ethanol conversion. The biorefinery model is shown in Figure 4.1.

Based on the biorefinery model developed in this study (Figure 4.1), sugarcane and cassava were co-utilized as feedstocks. Operation of a sugarcane plantation and harvesting were included in sugarcane cultivation process. After harvest, this sugarcane was transported to a sugar mill to extract sugarcane juice. The juice was then converted into sugar and molasses. These two products were used as raw materials for production of sugarcane-based BSA (SuBSA), sugarcane-based LA (SuLA) and molasses-based ethanol (MoE). Moreover, some sugarcane juice could be used to produce sugarcane-based ethanol (SuE) directly by the sugarcane ethanol conversion process. After cultivation and transportation of cassava, this cassava was divided into two parts. The first part was transformed to sugar via cassava starch and sugar production processes. This sugar was further used as the raw material for cassava-based BSA (CaBSA) and cassava-based LA (CaLA). The other part was chipped and used as a feedstock for cassava-based ethanol (CaE) production with dried distiller grains with solubles (DDGS) production line. Cassava rhizome remaining from cultivation and cassava starch production was produced cassava rhizome ethanol (RhE). Apart from the main feedstocks, bagasse produced from the sugar milling and sugarcane ethanol conversion process were used as fuel to generate electricity and steam for the biorefinery by using a highly efficient electrical and energy cogeneration process. And biogas recovery from production of CaE, cassava starch, cassava pulp, MoE, and BSA was used to produce electricity as well.

All processes in the biorefinery model were divided into four stages include feedstock production, feedstock transportation, feedstock processing, and product production (ethanol conversion / BSA production / LA production), as summarized in Table 4.1.

Table 4.1 Four major stages of the processes in the biorefinery model

	Feedstock production	**Feedstock transportation**	**Feedstock processing**	**Product conversion**
SuE	Sugarcane cultivation	Sugarcane transportation	-	Sugarcane ethanol conversion
MoE	Sugarcane cultivation	Sugarcane transportation	Sugar milling	Molasses ethanol conversion
CaE	Cassava cultivation	Cassava transportation	Cassava chips production	Cassava ethanol conversion
RhE	Cassava cultivation	Cassava transportation	Cassava starch and chips production	Cassava rhizome ethanol conversion
SuBSA	Sugarcane cultivation	Sugarcane transportation	Sugar milling	BSA production
CaBSA	Cassava cultivation	Cassava transportation	Cassava starch and sugar production	BSA production
SuPLA	Sugarcane cultivation	Sugarcane transportation	Sugar milling	LA production
CaPLA	Cassava	Cassava	Cassava starch	LA production

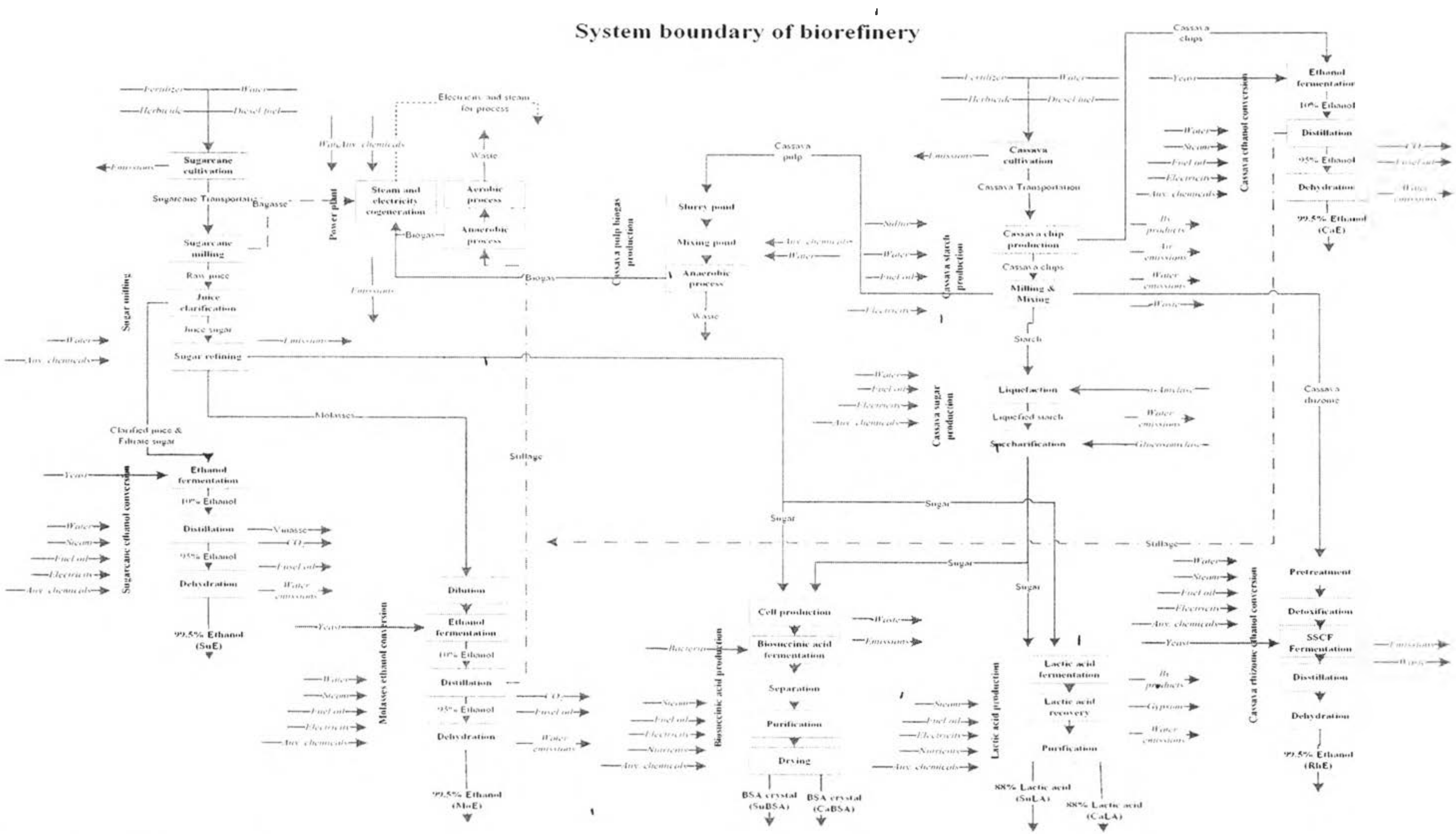

Figure 4.1 Biorefinery model.

Based on the stages and processes listed in Table 4.1, the life cycle inventory (LCI) was performed by collecting secondary data from existing bioethanol and biopolymer plants in Thailand and related studies. Details of each process are described in CHAPTER II (section 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.1, and 2.5.1) and their life cycle inventory is shown in appendix A.

4.2 Life Cycle Inventory

4.2.1 Sugarcane Based Ethanol Conversion

Sugarcane based ethanol production was modeled by using national LCI database in sugarcane cultivation section. Relevant information on sugarcane plantation was extracted from Nguyen and Gheewala (2008). For both sugarcane and cassava roots transportation phases, we assume the location of biorefinery plant in Nakhon Ratchasima province. We also assume that biorefinery plant can receive biomass feedstocks (sugarcane and cassava roots) in 100 km. around the plant by using 10-wheel truck at full load 16 tons. The inventory data of feedstocks transportation phase was taken from MTEC. After sugarcane was transported to biorefinery, the sugarcane was forwarded to sugarcane ethanol conversion process. As a sugarcane based ethanol plant has just existed in Thailand, the information for sugarcane ethanol conversion from the plant might have high uncertainty. LCI data of sugarcane ethanol conversion section from Brazil (Ometto et al., 2009) was used in order to complete the model. The products of this process are hydrated alcohol, bagasse, and vinasse. However, the hydrated ethanol was not pure enough (96% ethanol). Thus, we must add the ethanol dehydration process into the model in order to reach dehydrated ethanol (99.5% ethanol). This process was completed by simulating with commercial software named ProII. Conditions of the molecular sieve adsorption unit were 93 degree Celsius and 1.77 atm. After hydrated ethanol was produced from sugarcane ethanol conversion, the hydrated ethanol was fed to the molecular sieve dehydration unit in order to purify the hydrated ethanol. The adsorption column removes 95% of the water and a small portion of ethanol. The 99.5% pure ethanol vapor was cooled by heat exchange against regenerate condensate and finally condensed and pumped to storage.

According to biorefinery concept, bagasse – residue from sugarcane processing – was used as fuel to generate electricity and steam by using cogeneration system. The system is used in industrial plants in Thailand. In order to improve the efficiency, the low pressure steam is replaced by higher pressure steam at 68 Bar_a which is used in Europe countries. The high pressure steam can generate more electricity than low pressure steam about 70% (Tossanaitada et al., 2009). The data of cogeneration system was collected by thesis of Suranaree University of Technology (Witayapairot, 2010). Moreover, according to Department of Industrial Promotion, Ministry of Industry (2009), biogas 1 m^3 can produce electricity 1.2 kWh, CO_2 emission from biogas combustion, being of biogenic origin, are considered net zero as also bagasse combustion.

4.2.2 Molasses Based Ethanol Conversion

Molasses based ethanol production process was modeled by using data from the national LCI database. Start with sugarcane cultivation and transportation phases (the data sources used are same as above). After sugarcane was transported to sugarcane milling which is a process to produce sugar for SuBSA and SuLA, molasses produced was sent to molasses ethanol conversion process. Residue of sugarcane milling process (bagasse) can be used as fuel to generate electricity and steam by using cogeneration system. The sugarcane milling information was retrieved from MTEC. After molasses from sugar milling was produced, it was transported to molasses ethanol conversion process. The products of this process are dehydrated ethanol (99.5% ethanol), and biogas.

4.2.3 Cassava Based Ethanol Conversion

Cassava based ethanol production process started with cassava cultivation. The inventory average of cassava cultivation was taken from Khongsiri (2009). Next, cassava roots were transported to cassava chips production process. Cassava chips production data was extracted from Silalertruksa et al. (2011). Then, the cassava chips were used to produce ethanol by cassava ethanol conversion process. Dried distiller grain with soluble (DDGS) and biogas are by-products of this process. Biogas could be used as fuel for electricity generation. Life cycle inventory of cassava ethanol conversion was extracted from KAPI (2007).

4.2.4 Cassava Rhizome Based Ethanol Conversion

Since there is no cassava rhizome ethanol plant, model was from simulation. Systematic model of cassava rhizome based ethanol conversion was extracted from Mangnimit et al. (2013). Cassava rhizome by-product from cultivation, cassava chip production and cassava starch production were sent to cassava rhizome ethanol conversion process as described in section 2.3.4. Finally, 99.5_% ethanol was produced.

4.2.5 BSA Production

After cassava roots were cultivated, they are transported to cassava starch production to produce starch and biogas. The inventory data of cassava starch with biogas production line was extracted from MTEC. Cassava pulp remaining from starch production is regarded as a nice potential substrate for biogas. The inventory data of biogas from cassava pulp was extracted from Godson (2012). Then, the starch was forwarded to cassava sugar production process to produce glucose syrup. The inventory data for the sugar production were also from MTEC. The sugar from cassava and sugar from sugarcane, as described in section 4.2.2, were sent to BSA and LA production stage.

In this stage, the inventory data from Cok et al. (2013) were used as the secondary data for the production of BSA production as described in section 2.4.1. From this data sugar from sugarcane and sugar from cassava could be used in the same process and slightly different condition. However, it should be separate process into two parts for SuBSA and CaBSA because it might be risk for reaction of each other.

4.2.6 LA Production

For LA production, the inventory data from Andreanne (2010) were used as the secondary data for the production of LA production as described in section 2.5.1. From this data sugar from sugarcane and sugar from cassava could be used in the same process and slightly different condition as same as BSA production. It therefore should be separate process into two parts for SuLA and CaLA because it might be risk for reaction of each other as well.

After LCI was completed, five scenarios were created. They were divided into two groups; Group 1 (S1, S2, and S3) was obtained by the varying ratio of the two feedstocks while Group 2 (S1, S4, and S5) was obtained by varying the ratio of the products (only BSA and LA), as discussed in section 3.2.2.4. Then, the life cycle impact assessment (LCIA) was analyzed by using LCA software; SimaPro 7.1 with CML 2 baseline 2000 and Eco-indicator 95 methods in order to evaluate the performance of all five scenarios of the biorefinery model in terms of GWP, AP, EP impact (CML 2 baseline 2000) and energy resources impact (Eco-indicator 95) as discussed in the following sections.

4.3 Life Cycle Impact Assessment

4.3.1 Global Warming Potential (GWP)

The 2 main stages impacting GWP are product conversion stage and feedstock processing stage, respectively.

In the feedstock processing stage, main impact was from cassava based products especially cassava starch and sugar due to the high electricity consumption. In contrast, negative impact was gained by sugar milling since the surplus electricity and steam produced could be used in the other processes. This energy integration could significantly reduce GWP in scenarios S5, S4, and S1 than S2 and S3 due to the higher sugarcane consumption as shown in Figure 4.2.

In product conversion stage, considering 1 kg production of each product, major impact was also caused by electricity and steam consumption in BSA production. Production of CaE, LA, and MoE production were shown to be the second, third and fourth contributors, respectively, to GWP impact. However, GWP was little impacted by CaE and MoE due to the much lower production in each scenario. On the contrary, SuE production was shown to be better performance due to the surplus electricity and steam generated from the bagasse (as seen in S1 and S2).

In the Group 1, S1 - the highest production of SuE - showed the lower GWP impact than that of S2 and S3 (S1<S2<S3). While in the Group 2, S4 - the lowest BSA production - showed a lower GWP impact than that of S1 and S5

(S4<S1<S5). The net GWP was also shown to be 0.28, 0.42, 0.53, 0.22, and 0.34 10^6 kg CO_2 eq. for S1, S2, S3, S4, and S5, respectively. It can be seen that S4 has the lowest GWP among all five scenarios.

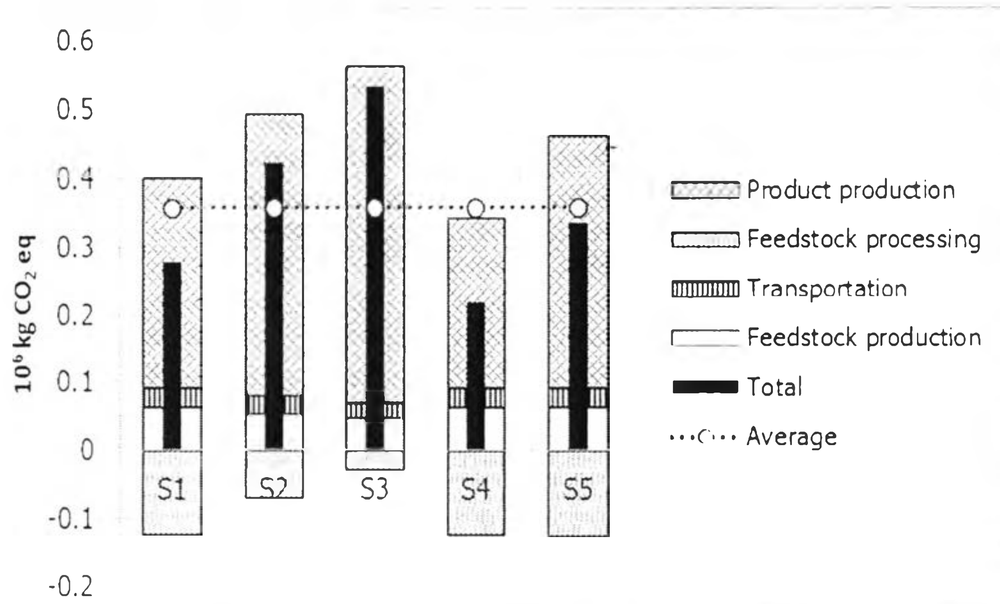

Figure 4.2 Global warming potential of scenarios in this study for each stage by using CML 2 baseline 2000.

4.3.2 Acidification Potential (AP)

For acidification potential, Figure 4.3 showed that the most impact comes from product conversion stage. This was due to the sulfuric acid and electricity consumption in LA and BSA production, respectively. However, LA production process could cause the higher AP impact.

Furthermore, sugar milling process in feedstock processing stage could compensate acidification burden because of surplus steam and electricity generated from bagasse.

Therefore, in the Group 1, S1 - the highest production of SuE - showed the lower AP impact than that of S2 and S3 (S1<S2<S3). While in the Group 2, S5 - the lowest BSA production - showed a lower AP impact than that of S1 and S4 (S5<S1<S4). The net AP was also shown to be 2.22, 2:51, 2.74, 2.47, and 1.96

10^3 kg SO_2 eq. for S1, S2, S3, S4, and S5, respectively. It can be seen that S5 has the lowest AP among all five scenarios.

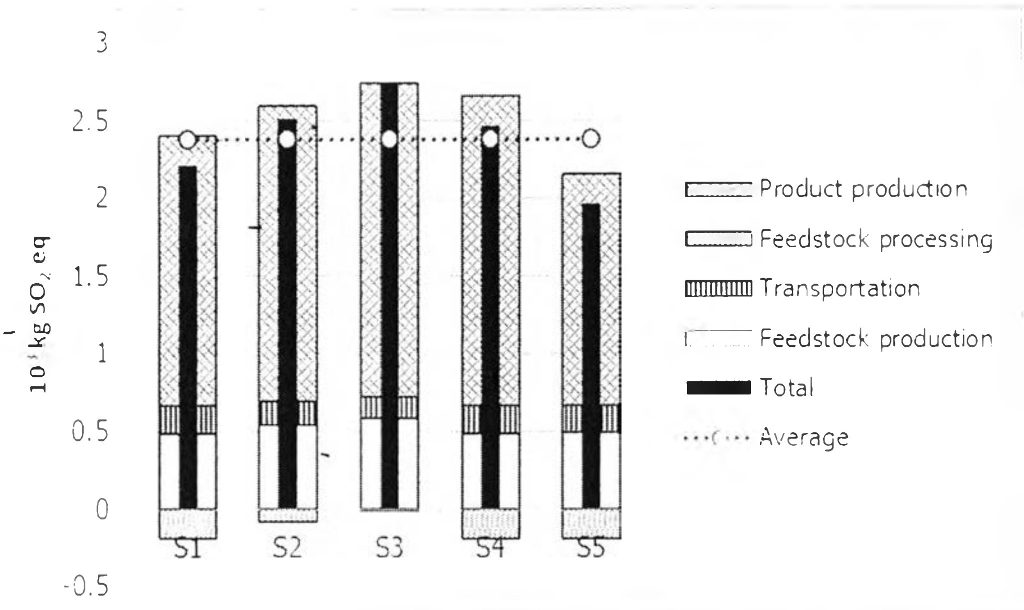

Figure 4.3 Acidification potential of scenarios in this study for each stage by using CML 2 baseline 2000.

4.3.3 Eutrophication Potential (EP)

From Figure 4.4, most eutrophication impact comes from product conversion stage. Ethanol conversion process generated much waste water especially molasses and cassava ethanol conversion process. The very high Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) could cause high EP impact although MoE was produced not much in each scenario. Moreover, most waste water of SuE could be produced to be vinasse. Therefore, SuE production hardly affects EP impact. However, varying ratio of feedstocks affects EP not constantly due to the random uncertainty of solver function in Excel. In case of low production of MoE as this result, CaE would significantly affect EP. While LA production could cause significant EP impact due to the soybean meal consumption which replaces CSL.

Therefore, in the Group 1, S3 - the highest production of CaE - showed the higher EP impact than that of S2 and S1 (S1<S2<S3). While in the Group 2, S4 - the highest LA production - showed a higher EP impact than that of S1 and S5 (S5<S1<S4). The net EP was also shown to be 1.15, 1.23, 1.30, 1.28, and 1.02 10^3 kg PO_4^{3-} eq. for S1, S2, S3, S4, and S5, respectively. It can be seen that S5 has the lowest EP among all five scenarios.

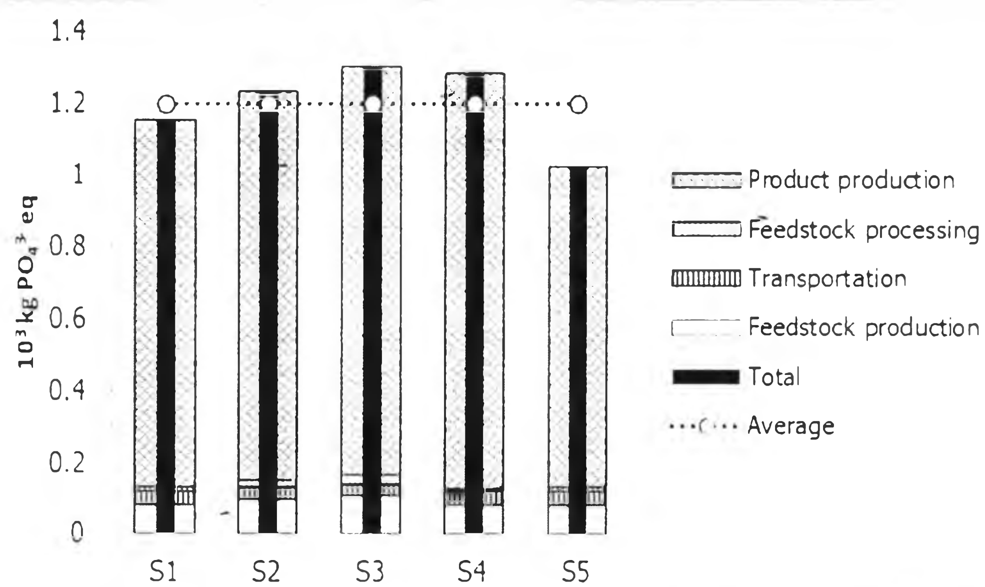

Figure 4.4 Eutrophication potential of scenarios in this study for each stage by using CML 2 baseline 2000.

4.3.4 Energy Resources

From the Figure 4.5, the important stages that significantly consume the energy resources are product conversion stage and feedstock production stage.

In the feedstock processing stage, cassava starch production consume high electricity while sugar milling generated surplus steam and electricity which could be used in other processes in the biorefinery. Therefore, scenarios S5, S4, and S1- the highest sugarcane consumed scenario – could gain avoided energy as shown in negative values.

In the product conversion stage, SuE could provide bagasse to generate compensated steam and electricity. While BSA process consumed energy little more than LA process. The number of electricity consumption in BSA process should much higher affect energy resources than that of LA process. However, LA process also consumed high steam consumption and soybean meal.

Therefore, in the Group 1, S1 - the highest production of SuE - showed the lower energy resources impact than that of S2 and S3 (S1<S2<S3). While in the Group 2, S4 - the highest LA production - showed a lower energy resources impact than that of S1 and S5 (S4<S1<S5). The net energy resources were also shown to be 4.00, 6.17, 7.80, 3.88, and 4.12 10^6 MJ LHV for S1, S2, S3, S4, and S5, respectively. It can be seen that S4 has the lowest energy resources among all five scenarios.

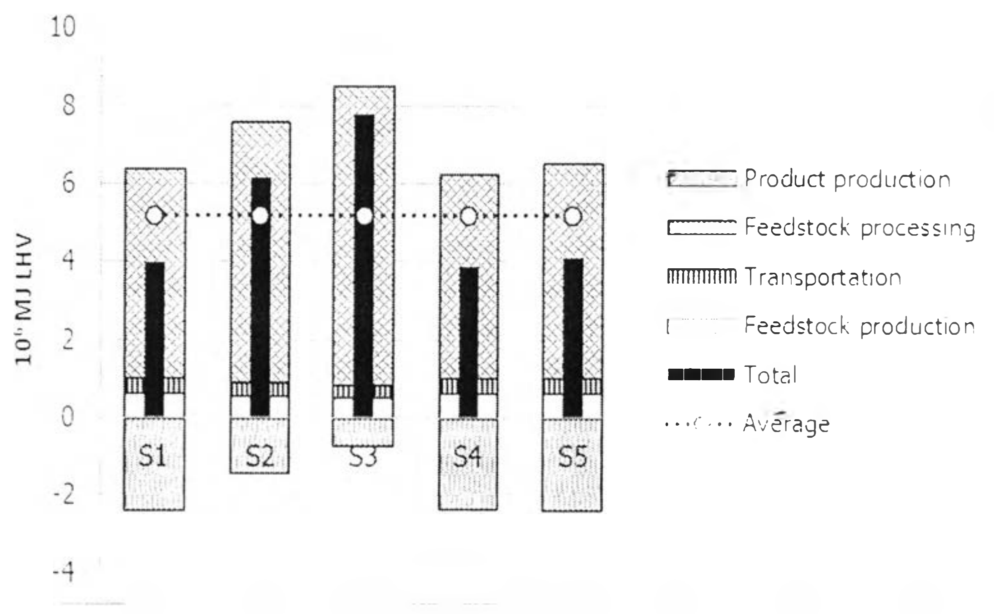

Figure 4.5 Energy resource of scenarios in this study for each stage by using Eco-indicator 95.

From Figure 4.6, all 5 scenarios were compared for each characterization. For comparison, the base case (S1) is set at 100%. The figure showed that S4 has the best environmental performance in GWP and energy resources whereas S5 has the best performance in AP and EP. From the Table 3.1, although S5 also has the highest profit generation; however, since S5 has shown to have not the best performance in GWP and energy resources. the other indicators were therefore created in order to find the best scenario in both environmental and economic aspects. Thus, in the next section, Eco-efficiency parameter has been developed in order to combine the two aspects, environment and economic, together.

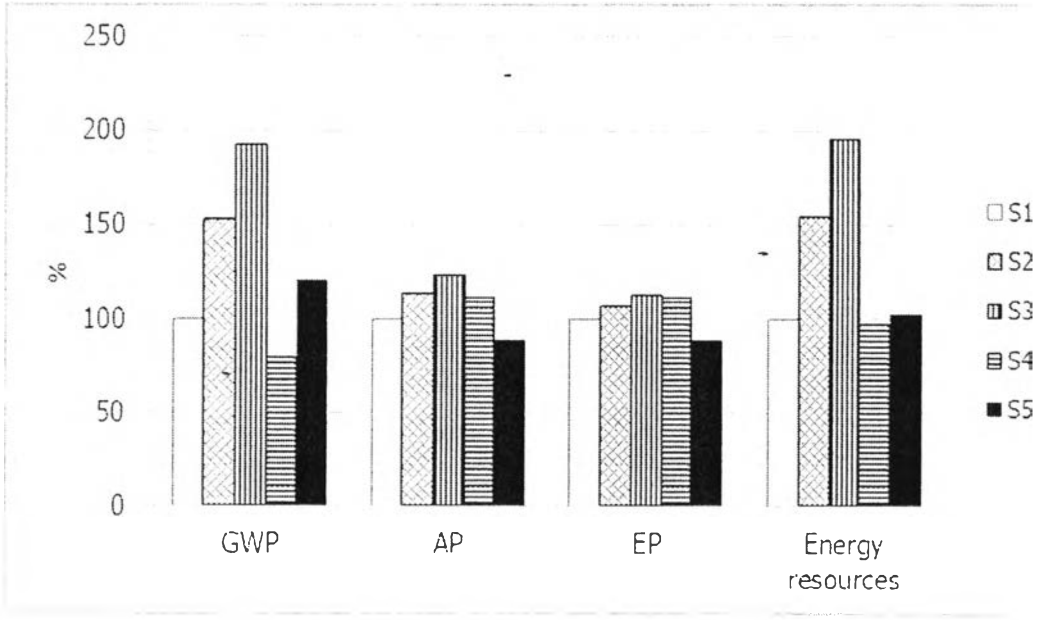

Figure 4.6 Comparison of life cycle energy use and environmental performance for 5 scenarios.

4.4 Eco-Efficiency

Eco-efficiency is an indicator that is used to help businesses to be more effective efficient and responsible for natural resources and the environment. This indicator has been shown to be relevant to both economic and environmental aspects towards sustainable development. Eco-efficiency can be expressed as the ratio of economic creation to ecological destruction as shown in equation 1, thus the higher the Eco-efficiency parameter the better it is.

$$Eco-efficiency = \frac{Value\ of\ a\ product\ or\ service}{Environmental\ impact\ of\ a\ product\ or\ service} \quad (1)$$

In this study, four Eco-efficiency parameters were developed specifically to combine environmental (GWP, AP, EP, and energy resources) and economic (profit) aspects by using ratio of normalized profit and normalized environmental impacts. The normalized values were calculated by dividing the profit and environmental impact in each scenario with the average values obtained from all scenarios studied as shown in Figure 4.7.

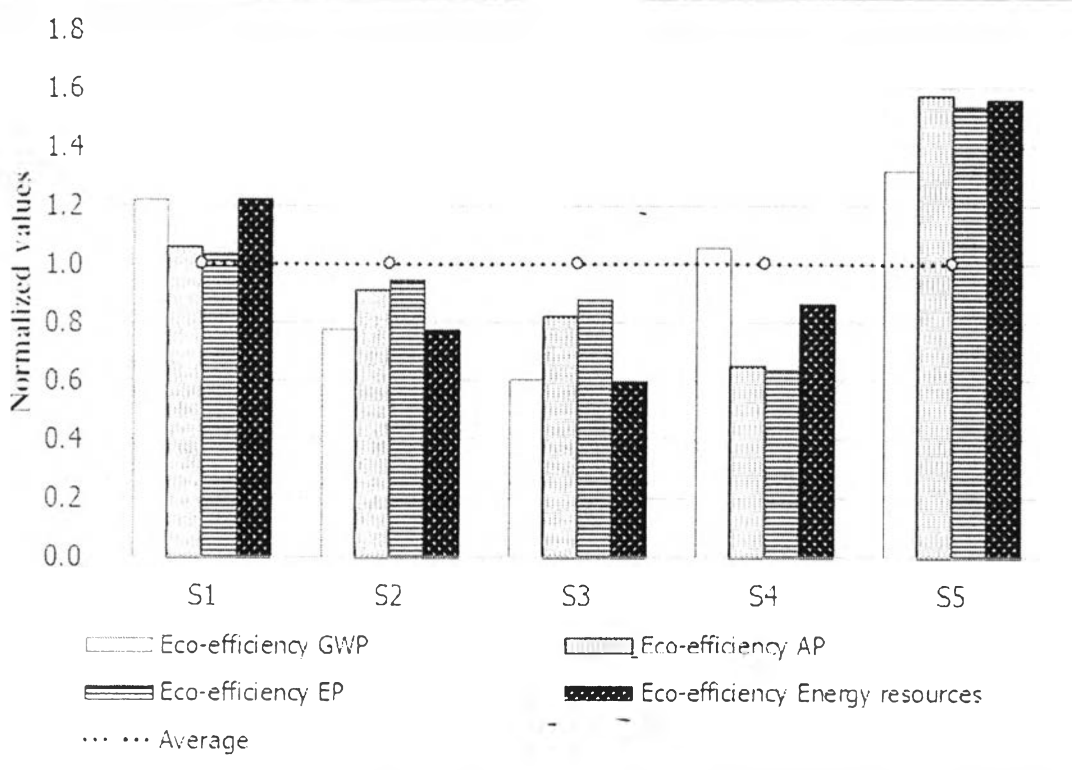

Figure 4.7 Normalized values for eco-efficiency parameter calculation.

These normalized values were used as benchmark to aid in fair comparison between scenarios studied. The four Eco-efficiency parameters (Eco-efficiency$_{GWP}$ was for GWP impact, Eco-efficiancy$_{AP}$ was for AP impact, Eco-efficiancy$_{EP}$ was for

EP impact, and Eco-efficiency$_{Energy\ resources}$ was for energy resource impact) as calculated from normalized values are shown in Table 4.2.

Table 4.2 Eco-efficiencies of scenarios in this study

Scenario	S1	S2	S3	S4	S5
Eco-efficiency $_{GWP}$	1.22	0.78	0.61	1.06	1.32
Eco-efficiency $_{AP}$	1.06	0.91	0.82	0.65	1.57
Eco-efficiency $_{EP}$	1.04	0.95	0.88	0.64	1.54
Eco-efficiency $_{Energy\ resources}$	1.23	0.78	0.60	0.87	1.56

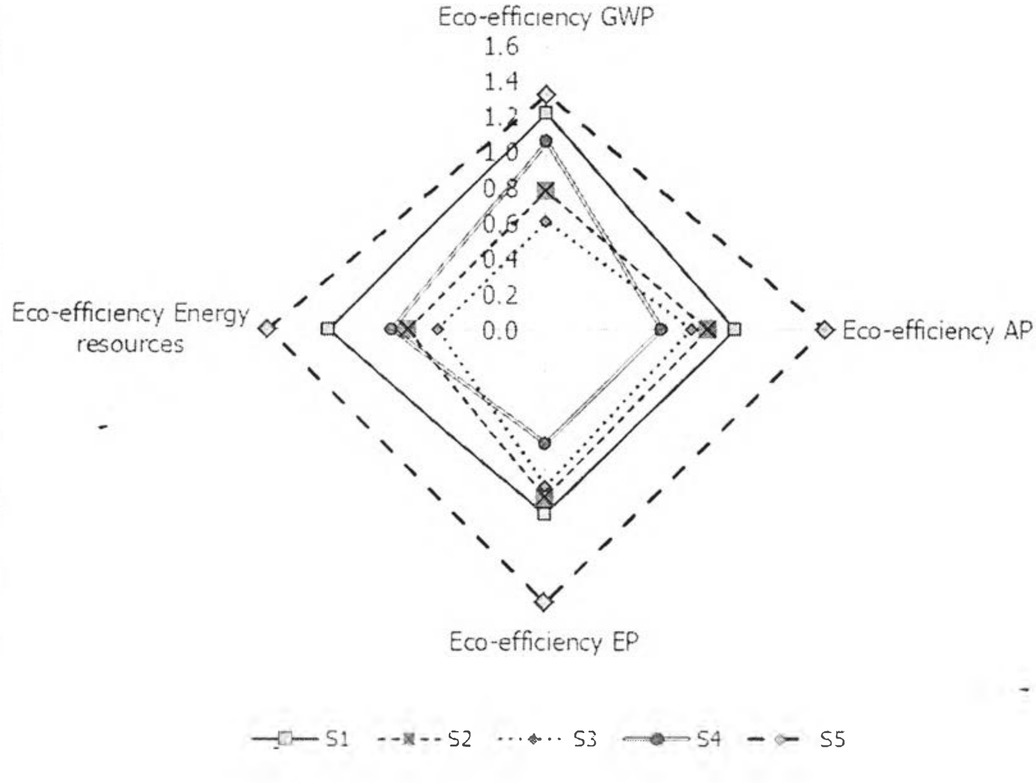

Figure 4.8 Relationship between the four Eco-efficiency.

Figure 4.8 illustrates the relationship among the four Eco-efficiency parameters in order to identify the best scenario. When being normalized, an Eco-efficiency value higher than 1 should be considered efficiency in terms of both environmental and economic aspects. In addition, the higher the Eco-efficiency value (>1) the better the performance it is. Since four Eco-efficiency parameters (Eco-efficiency$_{GWP}$, Eco-efficiancy$_{AP}$, Eco-efficiancy$_{EP}$, and Eco-efficiency$_{Energy\ resources}$) have been developed in this study, the best scenario should have high values in all parameters. Based on these criteria, S1 and S5 have all parameter values which more than 1. Furthermore, S5 was the best scenario due to the highest values in all parameters.

4.5 Biorefinery Performance Analysis

In this study, biorefinery performance was evaluated in many aspects consist of raw materials consumption, fuel and biopolymer production, and profit generation.

4.5.1 Raw Materials Consumption

The model biorefinery would have better performance in both GWP and energy resources with increased sugarcane usage. The more sugarcane was used, the more energy was produced by bagasse. The more energy was produced, the greater avoided greenhouse gas (GHG) emissions were obtained. As seen in scenario S1, S4, and S5 which have the same ratio of feedstocks consumption with 75% sugarcane and 25% cassava usage. These 3 scenarios have obviously better performance in both impacts than that in S2 (60% sugarcane and 40% cassava usage), and S3 (45% sugarcane and 55% cassava usage).

4.5.2 Fuel and Biochemicals Production

According to the previous study, due to the outstanding better performance of ethanol production, this study therefore fixed the amount of ethanol capacity. However, some products of ethanol were considered due to production changed from the varying feedstock ratio. The results showed that SuE production could significantly reduce GWP and energy resources impact due to the high steam and electricity produced. In contrast, the production of ethanol, especially MoE and CaE, could increase EP impact. This was due to the waste water released. In the other hand, increasing BSA production led to higher GWP and energy resources impacts because of much higher electricity and steam consumption than that of LA production. However, BSA production also has the better performance in the other impacts (AP and EP impact). Considering in Group 2, S5 – the highest BSA production – therefore has the best AP and EP impact but has the worst in GWP and energy resources impacts. Only the analysis mentioned in famous characterizations (GWP and energy resources), it could be primarily predicted that S4 was the appropriate scenario.

4.5.3 Profit Generation

The usage of the sugarcane got the little better profit than cassava in term of the outstanding steam and electricity generated from bagasse in spite of both cassava pulp and rhizome utilization. This could be noticed from total steam and electricity deficiency in each scenario as shown in Table 3.1. The combined energy generation could reduce the cost of energy consumption. Moreover, the production costs of SuBSA (14.17 ฿/kg) and SuLA (43.53 ฿/kg) were lower than those of CaBSA (20.75 ฿/kg) and CaLA (47.71 ฿/kg), respectively. Therefore, increasing sugarcane usage could reduce costs of those products. Since LA price was much lower than that of BSA, increasing BSA production so enhances profitability. In order to maximize the profit, the biorefinery should use sugarcane as feedstock to produce BSA.

According to the several analysis mentioned, each feedstock usage and product production provide different advantages and disadvantages. However, the biorefinery model should be still considered by principle of the biorefinery concept: to take maximum benefit of intermediate and by-products to generate additional chemicals and materials: and to maintain balance of high-value (but low-volume) bio-based chemicals and materials with high-volume (but low value) biofuels. A biorefinery might produce one or several low volume (but high-value) chemical products and a low-value (but high-volume liquid transportation fuel) at the same time generating electricity and heat for its own use and perhaps for sale. The high-value products improve the profitability, the high-volume fuel fulfills the national energy needs, and the power production reduces costs and GHG emissions. For the high-value chemical products, the local market value for the products will decide which products will be produced.

4.6 Comparison with Conventional Process

The GWP and energy consumption data of conventional processes were acquired from several journals in order to compare if each product in this study was in reliable range. From the Figure 4.9 and 4.10, it can be seen that the GWP and energy consumption of each product has the same trend because the main GWP of each product comes from energy consumption (only BSA and LA. CO_2 uptake during cultivation was count).

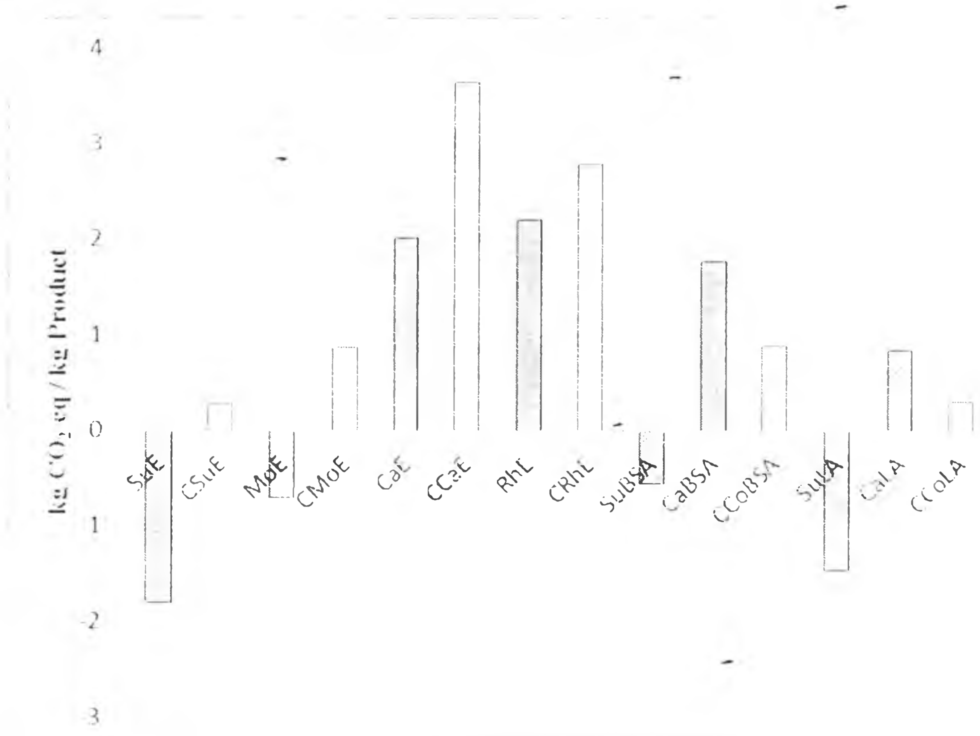

Figure 4.9 Comparison of GWP for each product between biorefinery process and conventional process.

4.6.1 <u>Sugarcane Based Ethanol</u>

Since Thailand has just had sugarcane based ethanol plant not for a long time, public data of SuE production in Thailand are unavailable. The conventional sugarcane based ethanol (CSuE) was extracted from Brazil paper (Macedo et.al. 2008). The CSuE is from cane juice by using bagasse as a fuel and generating surplus electricity with high pressure boiler and sell to national grid. The information of CSuE is obtained from many plants. The difference between SuE and CSuE is that SuE count surplus steam credit since steam can be used in other processes in biorefinery, while CSuE cannot. Moreover, cogeneration system of CSuE has low efficiency because most of plants collected data (90%) still use low pressure boilers with low energy surplus. Furthermore, sugarcane trash burning for CSuE before harvesting emits methane and nitrous oxide as well as soil emissions are deeply calculated from fertilizers and lime use. Thus, SuE has GWP and energy resource impact lower than that in CSuE.

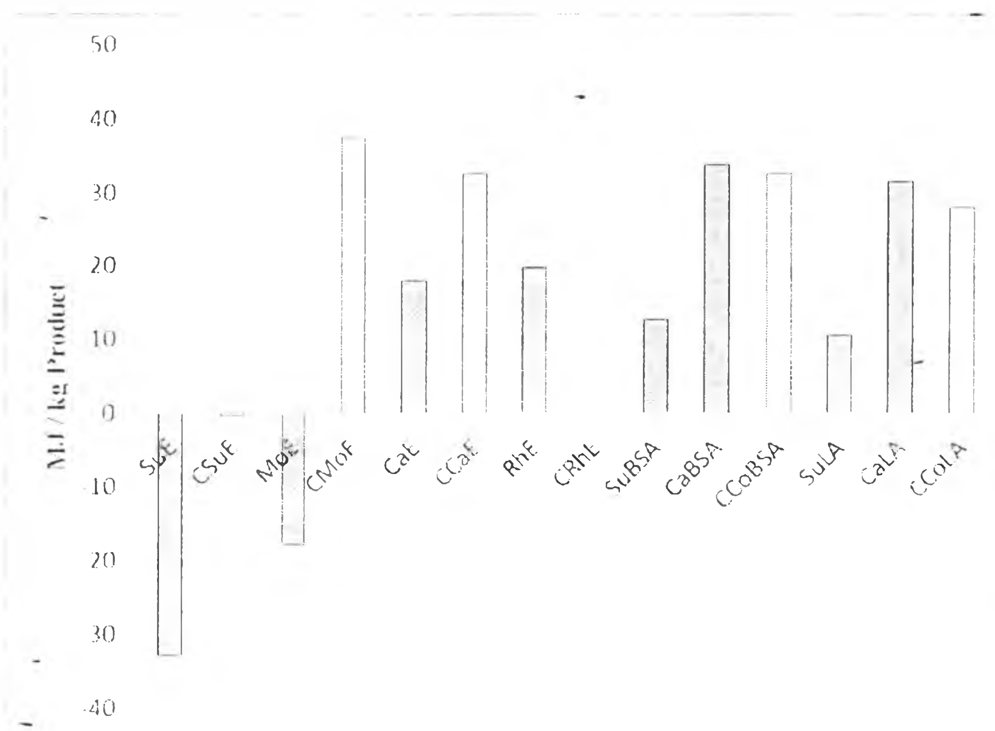

Figure 4.10 Comparison of energy consumption for each product between biorefinery process and conventional process.

4.6.2 Molasses Based Ethanol

The conventional molasses based ethanol (CMoE) impacts data was retrieved from Silalertruksa and Gheewala (2009). This data are average impacts of the three existing CMoE plants in Thailand. The main difference between MoE and

CMoE occurred because cane trash from CMoE procedure was burnt 100% whereas that from MoE was ploughed up and over to be naturally degraded. In case of 50% burning of cane trash from CMoE, GWP showed to be -0.366 $kgCO_2/kgMoE$. Therefore, cane trash burning can cause GHG, while cane trash ploughed up not only can provide fertilizer but also avoid GHG. Moreover, for MoE, steam produced from bagasse could be used in other processes in order to avoid GWP and energy resources whereas that of CMoE cannot. Thus, MoE has GWP and energy resource impact lower than that in CMoE.

4.6.3 Cassava Based Ethanol

The conventional cassava based ethanol (CCaE) impact data was also acquired from Silalertruksa and Gheewala (2009). The impacts are averaged from one existing CCaE plant in Thailand and designed operation plant in that study. The impact data of CaE were lower than that of CCaE due to the usage of coal as fuel to generate steam of CCaE for ethanol conversion stage. In case of enhanced operation of CCaE, GWP showed to be 2.43 $kgCO_2/kgCaE$. So air emissions from coal combustion can cause higher GWP impact. Furthermore, the net energy ratio of CCaE is quite low due to the low efficiency of technology. Thus, CCaE has GWP and energy resource impact higher than that in CaE.

4.6.4 Cassava Rhizome Based Ethanol

Due to the deficiency of LCA study in cassava rhizome ethanol production, conventional process (CRhE) chosen to be compared was the same one which was applied in this study (Mangnimit et al., 2013). Therefore, GWP impacts were not much different, while energy resources from CRhE were not calculated.

4.6.5 Sugarcane and Cassava Based BSA

Since the LCA study of BSA was quite rare, conventional process of corn based BSA (CCoBSA) from DSM journal (Cok et al., 2013) was therefore roughly compared.

SuBSA process showed the lowest GWP and energy resources impacts due to the avoided steam and electricity generated from bagasse. In case of comparing SuBSA and CaBSA, although cassava utilized all residues (rhizome and pulp), economic allocation could not share much burden to rhizome and pulp could not generate much electricity and steam like that of sugarcane. If considering only processes of CaBSA and CCoBSA, both processes had the closed values of impacts but corn can uptake CO_2 much better than cassava. Thus, products arranged in ascending order of impacts are SuBSA, CCoBSA, and CaBSA.

4.6.6 Sugarcane and Cassava Based LA

Although PURAC journal showed the impact data of sugarcane based PLA, the impact in the part of LA was not given. As the same reason as BSA, conventional process of corn based LA (CCoLA) from NatureWork LLC (Vink et al., 2010) was chosen to be compared.

According to the same reasons as BSA, products arranged in ascending order of impacts are SuLA, CCoLA, and CaLA.