An Analysis of Energy Supply-Demand System and CO_2 emission -A Case Study of Thailand Energy Scenario-

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Abstract

Presently, biomass energy has been required to use in a variety of energy, such as power generation, heat supply, and conversion to liquid and gaseous energy. On the other hand, the biomass energy has been promoted to substitute fossil fuel in many countries because of increasing of price of crude oil in the world market and carbon-dioxide emission in atmosphere. In Thailand, there are many kinds of biomass, such as rice husk, bagasse, and cassava resides. They are used as energy resources for electric power generation and heat production. However, an analysis of reduction of carbon-dioxide emission by using biomass, which can be used for fossil fuel substitution, has not been considered yet. In this paper, the linear programming model has been developed to evaluate the potential of carbon-dioxide emission reduction by using the effective biomass in Thailand. The simulated results of the energy supply demand system model are represented in the format of the energy-balance matrices. In addition, the simulation result shows that biomass resources have potential to reduce the amount of carbon-dioxide emission by about 9.8% from the base case (2001).

Keyword: Energy Supply-Demand System, CO_2 emission, Energy Modeling, Bio-energy, Thailand

1. Introduction

Biomass, which is a renewable energy source, is biological material derived from living, or recently living organisms, such as wood, waste, and alcohol fuels. It will not run out if it is managed in the sustainable manner. This is different from the case of fossil energy, such as coal, oil, and gas. In principle, utilizing biomass energy is carbon neutral in contrast to fossil fuels [1]. Biomass is used to meet a variety of energy needs, including power generation, heat supply and conversion to liquid and gaseous energy. For this reason, the biomass is one of the most important sources of renewable energy. In Thailand, the biomass energy is mainly consumed in two consumption sectors: residential and commercial sector and manufacturing sector. The Royal Thai Government has declared the objective to increase the level of renewable utilization from the level of just 0.5% by the year 2001 to 8% by the year 2011.

Bio-energy, being a renewable source of energy, does not only provide economic benefits to the country by reducing the high demand for import fossil fuel, but also provides the environmental advantage such as by replacing the Methyl Tertiary Butyl Ether (MTBE) presently used as an additive in gasoline.

Bio-energy in Thailand is considered as an energy source for substitution of diesel oil and gasoline since 2004 and 2005, respectively. The use of agricultural products, such as cassava and molasses, for ethanol production has been given particular attention because the ethanol, which is 99.5% pure alcohol by volume, can replace the use of MTBE. Efforts to use the ethanol as alternative fuel actually commenced in 1977, but the cost of the ethanol production then was much higher than oil prices. Therefore, commercial production was not materialized. However, at present, the oil price has been given to increase continually. Consequently, the ethanol is considered as a viable alternative fuel for the transportation sector.

Ministry of energy had set the target on using an ethanol for MTBE substitution in gasoline 95 by one million liters per day by 2006 and on using an ethanol for MTBE substitution in gasoline

91 for three million liters per day by 2011. The main raw materials for ethanol production are molasses, sugar cane, and cassava. In 2007, there are seven ethanol production plants with average total production 545,000 liter a day [2].

Bio-diesel, another alternative fuel for vehicles, can be produced from oil plants, such as coconut, soy bean, palm, and sunflower, via a chemical process (Transesterification or Alcoholysis), using alkaline as a catalyst to transform fatty acid into ester or bio-diesel. It has similar properties to those of diesel oil. In Thailand, bio-diesel standards are yet to be established. The current mixtures vary, for example, between diesel and ester extracted from palm oil, diesel and ester extracted from coconut oil, or diesel and ester extracted from used cooking oil.

A present production capacity of bio-diesel is 500,000 liters per day from palm oil left from domestic consumption and the raw palm oil extraction factories with expanding capacity for receiving of increased raw palm almost in double. Due to the total capacity of raw palm oil extraction factories by 10.81 million ton of fresh palm fruits per year. Comparison with the feedstock, the raw palm oil extraction factories will have capacity of 50 percent in excess. Raw materials for bio-diesel production in Thailand are such as: the used cooking oil and new extracted vegetable oil of these following eight plants namely: palm oil, coconut oil, soy bean oil, ground nut oil, castor oil, sesame oil, sunflower oil, and *Jatropha oil*. The main feedstock for bio-diesel production is oil palm. Because oil palm is a plant with high competitive potential due to its lower costs in production and marketing when compared with other plants. Besides, palm can be utilized diversity in consumption goods.

Based on Bio-energy Strategy plan (2005 – 2020) [2] for biodiesel production, oil palm and Jatropha plantation will be increased to 5 million rai and 4 million rai (1 rai = 0.16 hectare) respectively to reach the target of biodiesel production with 12 million liter a day by the year 2020.

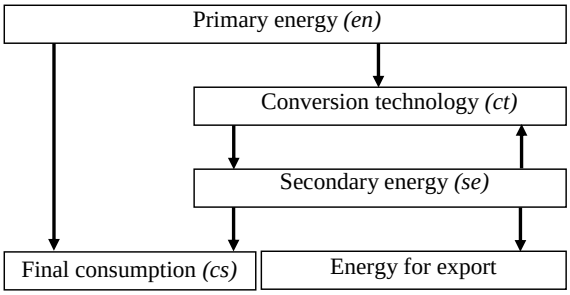
The aim of the study is to develop the energy supply-demand system by considering the use biomass and bio-energy. Biomass is relevant as study target because Thailand is an agricultural country and has a vast amount and variety of agricultural products, which could be used as energy source and replace the fossil fuels such as coal, oil, and natural gas.

2. Model Structure

An energy supply-demand model is developed for analyzing and evaluating the biomass and bio-energy use in Thailand. In this model, Thailand's energy balance sheet 2001 is used as reference. Amount of biomass residue, agricultural product, Ex-refinery price of petroleum product, etc. of the year 2001 is used as parameters for modeling. Moreover, the bio-energy strategy plan at the year 2020 for ethanol and bio-diesel production is considered as future expectation for biomass utilization as the energy source.

2.1 Outline of energy supply and demand model

Figure 1 shows the outline chart of energy supply-demand model for evaluation of bio-energy in Thailand. Energy supply – demand model consists of four main parts namely (i) primary energy (en), (ii) conversion technology (*ct*), (iii) secondary energy (*se*), and (iv) final energy consumption (*cs*).



***Primary energy (en)**: fossil fuel, such as crude oil, coal and its products; biomass such as bagasse, rice husk, palm oil residue; agricultural product such as palm oil, sugar, cassava; and some secondary energy such as LPG, Fuel oil can use for energy production*

***Conversion technology (ct)**: transestherification for biodiesel production, gasification technology for electric and heat production, fermentation technologies for ethanol production*

***Secondary energy (se)**: petroleum products, electricity, heat, biodiesel, ethanol;*

***Final energy consumption (cs)** : agricultural sector, mining sector, manufacturing sector, construction sector, residential & commercial sector, and transportation sector (road, railway, airway, and waterway)*

***Energy for export**: petroleum products, crude oil, coal and natural gas*

Fig. 1 Outline chart of energy supply-demand model.

2.2 Assumptions and structure of the model

According to "Thailand Energy Situation 2001"main fuels for electricity generation in Thailand are 'natural gas' and 'coal'. Over 90% of coal consumption for power generation in Thailand is 'Lignite', which has much larger carbon emission amount than 'Natural gas'. Therefore, biomass is assumed to be an alternative fuel to lignite and natural gas for generating electricity in this model. It is also assumed to be an alternative to fossil fuel, whose consumption is the highest in manufacturing sector, for heat generation. Bio-diesel is assumed to be alternative with diesel oil, called 'High Speed Diesel (HSD)', and ethanol is assumed to be alternative with Unleaded Gasoline octane number 95 (ULG95). There are many parameters, which are assumed and used in this model such as availability factor, conversion efficiency, production cost of energy, and so on.

2.3 Mathematical equations of the model

In this model, biomass and agricultural products are parts of primary energy, which is used as raw material for producing secondary energy, such as biodiesel and bio-ethanol.

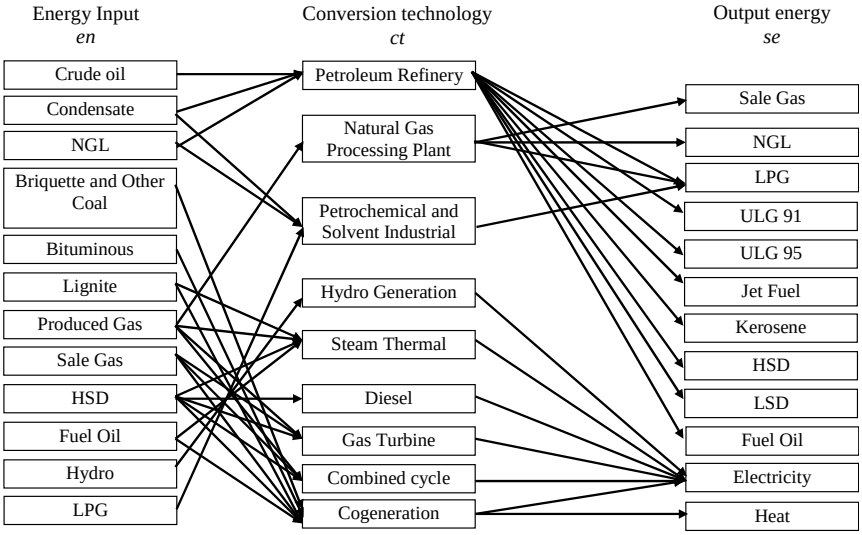


Fig. 2 Model structure (Fossil fuel conversion).

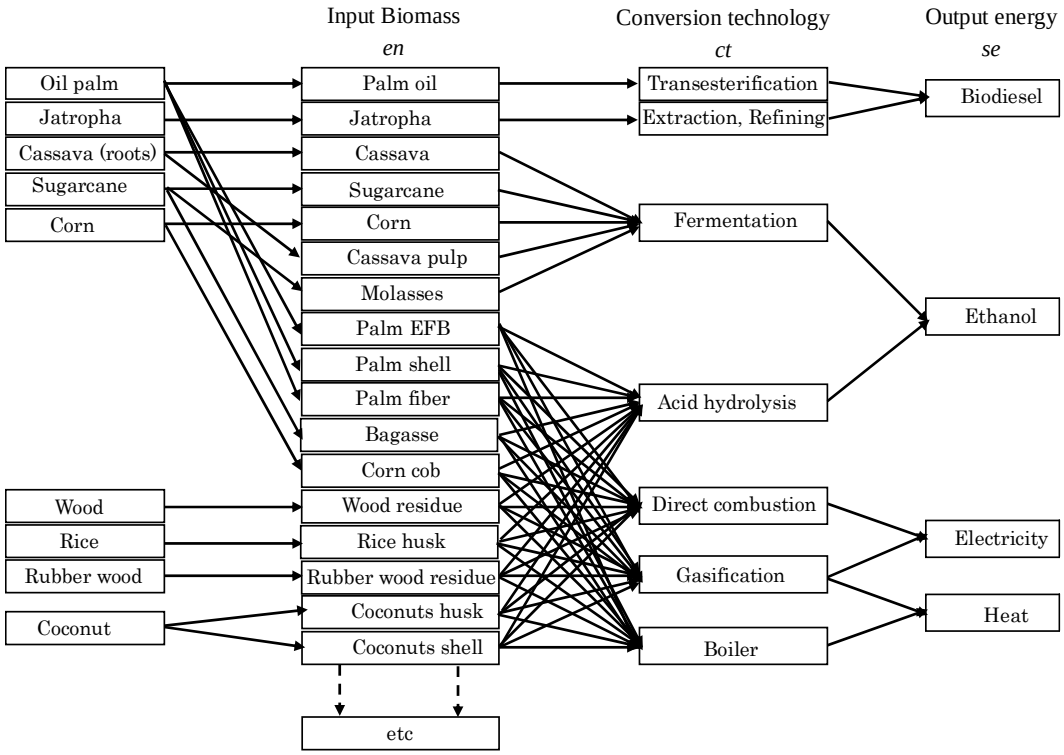


Fig. 3 Model structure (Biomass conversion).

Therefore, the amout of biomass and agricultural product are also used as parameters like fossil fuel, coal, crude oil and etc. Figures 2 and Figute 3 show the model structure for energy conversion from fossil fuel and biomass, respectively.

The objective function is to minimize the total production cost in the view point of energy producer by adding biomass and bio-energy into the energy supply-demand model.

Biomass, besides being used as fuel in direct burning instead of coal, is also used as raw material for bio-energy production. Bio-energy consisting of bio-diesel and bio-ethanol will be used instead of high speed diesel (HSD) and ULG95 respectfully.

A linear programming is used in this model to minimize the total energy production cost. A simplified form of the objective function can be written as follows.

$$TotolProdCost = \sum_{en} MATERAIL\_COST_{(en)} \cdot TotalInput_{(en)} + \sum_{ct,en,se} Output_{(ct,en,se)} \cdot PROD\_COST_{(ct,en,se)} + \sum_{PP \in se} TotalOutput_{(PP)} \cdot EX\_REF\_PRICE_{(PP)} \quad (1)$$

subject to:

(a) Energy conversion

- Petroleum refinery products

$$OutputPP_{(ct,en)} = PPConvEF_{(ct,en)} \cdot InputPP_{(en)} \quad (2)$$

- Electricity generation and Heat generation

$$Output_{(ct,en,se)} = ConvEF_{(ct,en,se)} \cdot Input_{(en)} \quad (3)$$

- Bio-diesel production

$$Output_{(ct,en,Biodiesel)} = ConvEF_{(ct,en,Biodiesel)} \cdot Input_{(en)} \quad (4)$$

- Ethanol production

$$Output_{(ct,en,Ethanol)} = ConvEF_{(ct,en,Ethanol)} \cdot Input_{(en)} \quad (5)$$

where:

OutputPP	output of petroleum product;
Output	output of electricity, heat, ethanol, and biodiesel production;
PPConvEF	conversion efficiency for petroleum production;
ConvEF	conversion efficiency for electricity, heat, ethanol, and biodiesel production;
InputPP	input energy for petroleum production;
Input	input energy for efficiency for electricity, heat, ethanol; and biodiesel production

(b) Total Energy Input

$$TotalInput_{(en)} = \sum_{en} Input_{(en)} \quad (6)$$

where:

TotalInput	total energy input for energy production

(c) Total Energy Output

$$TotalOutput_{(en)} = \sum_{en} Output_{(ct,en,se)} \quad (7)$$

$$TotalOutput_{(Biodiesel)} = \sum_{BiodieselProd_{(ct,en,Biodiesel)} \in Output_{(ct,en,se)}} BiodieselProd_{(ct,en,Biodiesel)} \quad (8)$$

$$TotalOutput_{(Ethanol)} = \sum_{EthanolProd_{(ct,en,Ethanol)} \in Output_{(ct,en,se)}} EthanolProd_{(ct,en,Ethanol)} \quad (9)$$

where:

$TotalOutput_{(en)}$	total energy production;
$TotalOutput_{(Biodiesel)}$	total biodiesel production;
$TotalOutput_{(Ethanol)}$	total ethanol production;

(d) Constraints

- Total primary energy supply constraints,

$$TPES_{(en)} \le UBTPES_{(en)} \quad (10)$$

$$UpBoundBM_{(en)} = PROD_{(en)} \cdot AVFac_{(en)} \cdot BMCV_{(en)} \cdot RPR_{(en)} \quad (11)$$

where:

$TPES_{(en)}$	Total primary energy supply en
$UBTPES_{(en)}$	Upper bound of total primary energy supply
$UpBoundBM_{(en)}$	Upper bound of biomass
$PROD_{(en}$	Agricultural production en in ton
$AVFac_{(en)}$	Availability factor
$BMCV_{(en)}$	Calorific value of Biomass
$RPR_{(en)}$	Residue to Product Ratio

(e) Energy supply – demand balancing constraints,

$$TPES_{(en)} = TotalInput_{(en)} + \sum_{cs} FECS_{(cs,en)} \quad (12)$$

where: .

FECS	final energy consumption

(f) Energy supply – demand balancing constraints for other energy,

$$FECS_{(cs,en)} \ge DEMAND_{(cs,en)} \quad (13)$$

where:

DEMAND	energy demand

(g) Calculating the carbon dioxide emission reduction according to biomass

$$CO_2Emission_{(BM)} = \frac{44}{12}\left(CEMIS_{(se)} \cdot Output_{(ct,en,se)}\right) \quad (14)$$

where:

$CO_2Emission_{(BM)}$	Carbon dioxide emission of energy from biomass (kt-CO_2)
$CEMIS_{(se)}$	Carbon dioxide emission factor of fossil fuel (kt-C/ktoe)

3. Description of scenarios

Two scenarios with respect to restrictions on CO_2 emission are analyzed.

3.1 Base case scenario: Agricultural production i.e. sugarcane, cassava, coconut, maize, cotton, groundnut, oil palm, rice, sorghum, soybean, and wood in the year 2001, RPR and maximum availability factor are used for calculating the available amount of biomass for energy production. Agricultural production in the year 2001 is shown in Table 1.

3.2 Enhanced indigenous bio-energy production scenario: Based on bio-energy strategy plan (2005 – 2020), the target of bio-diesel production and ethanol production with 12 million liters a day for each is realized by increasing oil palm and Jatropha plantation for bio-diesel production to 5 million rai (1 rai = 0.16 hectare) and 4 million rai respectively and increasing of yield per rai of cassava and sugarcane for ethanol production to 10 tons per rai and 20 tons per rai, respectively. This strategy plan is

expected that the amount of biomass residue especially oil palm residue, cassava residue, and sugarcane residue will be increased. If the plant area of cassava and sugarcane in the year 2007 with $7,429\times10^3$ rai and $6,207\times10^3$ rai, respectively, and yield per rai of oil palm, with 2,629 kg per rai, is used for estimating of cassava, sugarcane, and oil palm, the expected agricultural production and amount of biomass residue in the year 2020 will be increased which is shown in Table 2.

Table 1 Agricultural production in the year 2001.

Agricultural product	**Production (10^3 ton) [3]**
Sugarcane	49563
Cassava	18396
Coconut	1897
Maize	4466
Cotton	61
Ground Nut	107
Oil palm	4097
Rice	28634
Sorghum	145
Soy Bean	261
Wood	2561

Table 2 Amount of biomass based on bio-energy strategy plan [5]

Agricultural Product	**Amount (10^6 ton)**	**Residue**	**RPR[4]**	**Availability Factor [4]**
Cassava	74.790	Cassava Stalk	0.121	0.8
		Cassava Rhizome	0.091	0.8
Oil Palm	13.145	Palm EFB	0.215	0.9
		Palm Fiber	0.149	1.0
		Palm Shell	0.129	1.0
Sugarcane	124.14	Bagasse	0.303	0.95

4. Simulation results

Energy balance matrix is shown in Table 3 as the result from energy supply-demand model. There is no amount of biodiesel and ethanol production in this model because biodiesel and ethanol production cost is higher than ex-refinery price (assumed as petroleum production cost) of petroleum product. Figure 4 shows the CO_2 emissions reduction by types of biomass, which is the result from energy-supply model. Biomass based on amount of agricultural product, RPR, and availability factor is used as raw material for energy production to replace fossil fuel, such as lignite and natural gas. In this Figure, it has no the CO_2 emission reduction from raw material for biodiesel and ethanol production because biodiesel and ethanol production cost are higher than Ex-refinery price of petroleum product.

Figure 5 shows the maximum amount of CO_2 emission reductions by type of biomass. In this case, if all biomass is used as energy source for generating electricity to replace fossil fuel, lignite.

Based on Bio-energy strategy plan, the amount of biomass residue especially oil palm residue, cassava residue, and sugarcane residue will be increased. The expected amounts of biomass residue in the year 2020 are shown in Table 2. If these amounts of bagasse, palm oil EFB, palm oil shell, palm oil fiber, cassava stalk, and cassava rhizome are used as energy for power generation, they will lead to decreasing of CO_2 emissions. Figure 6 shows the amount of CO_2 emission reductions by types of biomass based on Bio-energy strategy plan.

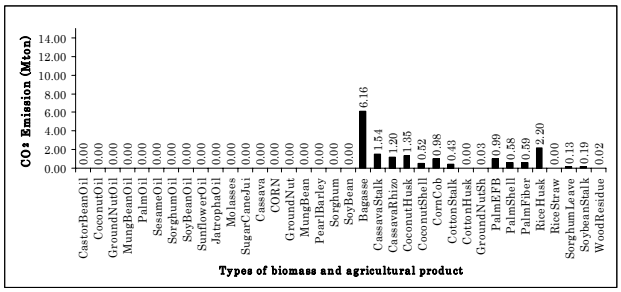


Fig. 4 CO_2 emission reductions by types of biomass and agricultural product (2001).

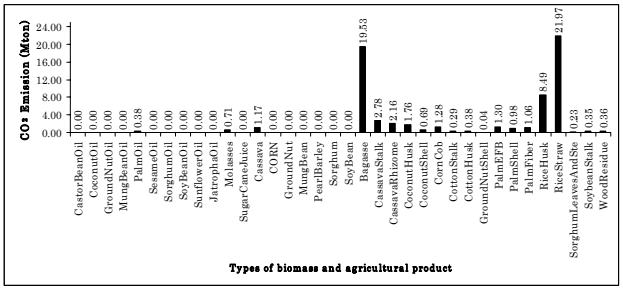


Fig. 5 Maximum CO_2 emission reductions by types of biomass and agricultural product (2001).

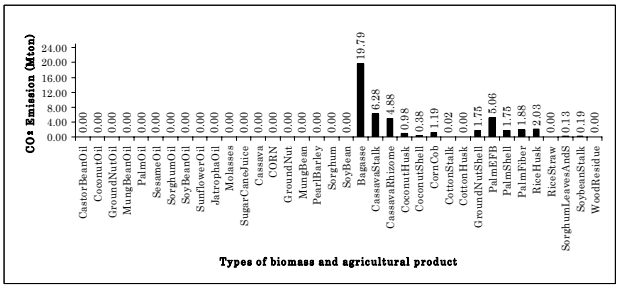


Fig. 6 Future expectation of CO_2 emission reductions (based on bio-energy strategy plan 2020).

Figure 6 shows the amount of CO_2 emission reductions by types of biomass based on Bio-energy strategy plan.

Figure 7 shows the comparison of CO_2 emission reduction by type of energy namely coal, natural gas, and petroleum product. The simulation results show that biomass resources have potential to reduce the carbon-dioxide emission by about 9.8% by using the energy balance sheet of 2001.

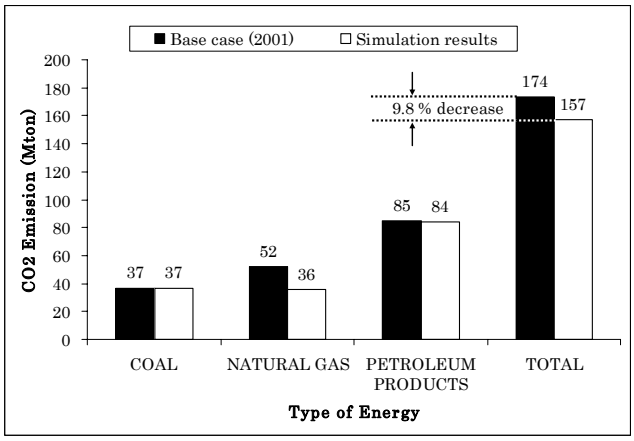


Fig. 7 Maximum CO_2 emission reductions by types of energy.

5. Conclusion

In this study, the model for estimating the biomass utilization in Thailand has been developed by using the linear programming. The simulation results show that biomass resources have potential to reduce the carbon-dioxide emission by about 9.8% by using the energy balance sheet of 2001. Paying attention to the amount of the carbon dioxide emission reduction by fuel and the amount of the emission reduction in the oil consumption is more than those in the coal and gas consumptions.

6. Acknowledgement

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Table 3 Energy balance matrix (results).

Result	COAL& ITS PRODUCTS							PETROLEUM						PETROLEUM PRODUCTS									ELECTRICITY		GRAND TOAL COMERCIAL ENERGY	HAET	BIODIESEL	ETHANOL
										NATURAL GAS																		
	ANTHRACITE	BITUMINOUS	COKE	BRIQUETTES& OTHER COAL	SUBTOTAL	LIGNITE	TOTAL COAL& ITS PRODUCTS	CRUDE OIL	CONDENSATE	PRODUCED GAS	SALE GAS	NGL	TOTAL PETROLEUM	LPG	ULG91	ULG95	JET FUEL	KEROSENE	HSD	LSD	FUEL OIL	TOTAL PETROLEUM PRODUCTS	PRIMARY	PRODUCED				
DOMESTIC PRODUCTION						1852	1852	3091	2350	17035			22476									0	1397		25725			
IMPORTS	175	1745	37	1154	3111		3111	35592		5644			41236		107		3		278			388		246	44981			
EXPORTS								- 1826				- 81	- 1907	- 901	- 285	- 818	- 399	- 323	- 1416		- 1416	- 5558		- 23	- 7488			
STOCK CHANGE/ STATISTICAL DIFFERENCES						- 44	- 44	737	34			5	776	- 36	- 19	- 72	48	- 110	- 70	- 2	- 310	- 571			161			
TOTAL PRIMARY ENERGY SUPPLY	175	1745	37	1154	3111	5705	8816		2384	17086		- 76	19394	- 937	- 197	- 890	- 348	- 433	- 1208	- 2	- 1726	- 5741	1397	223	24089	1000		
PETROLEUM REFINERIES								- 36638	- 569			- 67	- 37273	1721.17	2873	2236	3038	47	12968	91	3653	26627			- 10646			
NG.PROCESSING PLANTS										- 9243	9097	453	306	929.83								930			1236			
POWER PLANTS		- 241		- 269	- 510	- 3929	- 4439			- 7210	- 4467		- 11676										- 1397	8950	- 8562			
HYDRO																							- 1397		- 1397			
STEAM THERMAL						- 3929																						
GAS TURBINE																												
COMBINED CYCLE										- 7210	- 4467		- 11676											1876	- 9800			
DIESEL																												
COGENERATION		- 241		- 269	- 510		- 510																		- 510			
OTHERS																												
DIRECT COMBUSION																								12	12			
GASIFICATION																								7062	7062			
HEAT																										1000		
DIRECT COMBUSION																										244		
GASIFICATION																												
BOILER																										756		
BIODIESEL																												
TRANS ESTERIFICATION																												
EXTRACTION																												
ETHANOL																												
FERMENTATION																												
ENZYMES FERMENTATION																												
ACID HYDROLYSIS																												
OTHER CONVERSION														195								195			195			
TOTAL TRANSFORMATION		- 241		- 269	- 510	- 3929	- 4439	- 36638	- 569	- 16453	4630	386	- 48643	2846	2873	2236	3038	47	12968	91	3653	27752	- 1397	8727	- 18000	1000		
OWN USES										- 633	- 3072		- 3705									0		- 283	- 3988			
LOSSES								- 151					- 151									0		- 803	- 954			
TOTAL FINAL ENERGY CONSUMPTION	175	1504	37	885	2601	1776	4377		1803		1558	309	3670	2846	2873	2236	3038	47	12968	91	3653	27752		7864	43663	1000		
FINAL NON- ENERGY USES									1803			309	2112	452								452			2564			
FINAL ENERGY CONSUNPTION	175	1504	37	885	2601	1776	4377				1558		1558	2394	2873	2236	3038	47	12968	91	3653	27300		7864	41099	1000		
AGRICULTURE														2	51	2		1	2772		4	2832		15	2847			
MINING																			7		9	16		77	93			
MANUFACTURING	175	1504	37	885	2601	1776	4377				1556		1556	399	7	9		37	621	12	2903	3988		3494	13415	1000		
CONSTRUCTION																			108		20	128			128			
RESIDENTIAL& COMMERCIAL														1698				9		1	1	1709		4275	5984			
TRANSPORTATION											2		2	295	2815	2225	3038	0	9460	78	716	18627		3	18632			
ROAD											2		2	295	2815	2225			9301			14636			14638			
RAIL																			102			102		3	105			
AIR																	3038					3038			3038			
WATERWAY																			57	78	716	851			851			

Table 3 Energy balance matrix (results) (Cont.)

Result	NEW& RENEWABLE ENERGY																		TOTAL NEW& RENEWABLE ENERGY	GRAND TOTAL
	CHARCOAL	BAGASSE	CASSAVA STALK	CASSAVA RHIZOME	COCONUT HUSK	COCONUT SHELL	CORN COB	COTTON STALK	COTTON HUSK	GROUNDNUT SHELL	PALM EFB	PALM SHELL	PALM FIBER	RICE HUSK	SORGHUM LEAVE, STE	SOYBEAN STALK	WOOD RESIDUE	WOOD		
DOMESTIC PRODUCTION		4610	657	511	416	162	302	68	91	10	306	232	249	2004	54	83	9	9648	19412	45137
IMPORTS	7																		7	44988
EXPORTS	- 2																		- 2	- 7490
STOCK CHANGE/ STATISTICAL DIFFERENCES																			0	161
TOTAL PRIMARY ENERGY SUPPLY	5	4610	657	511	416	162	302	68	91	10	306	232	249	2004	54	83	9	9648	19417	44506
PETROLEUM REFINERIES																				- 10646
NG.PROCESSING PLANTS																				1236
POWER PLANTS		- 2621	- 657	- 511					- 91			- 190	- 249	- 905	- 54	- 83	- 9	- 48	- 5417	- 13979
HYDRO																				- 1397
STEAM THERMAL																				0
GAS TURBINE																				0
COMBINED CYCLE																				- 9800
DIESEL																				0
COGENERATION																				- 510
OTHERS																				0
DIRECT COMBUSION																	- 9.00	- 48	- 57	- 44
GASIFICATION		- 2621	- 657	- 511					- 91			- 190	- 249	- 905	- 54	- 83			- 5360	1701
HEAT	2281				- 416	- 162	- 302	- 68		- 10	- 306	- 42							975	1975
DIRECT COMBUSION											- 306								- 306	- 62
GASIFICATION																				0
BOILER					- 416	- 162	- 302	- 68		- 10		- 42							- 1000	- 244
BIODIESEL																				0
TRANS ESTERIFICATION																				0
EXTRACTION																				0
ETHANOL																				0
FERMENTATION																				0
ENZYMES FERMENTATION																				0
ACID HYDROLYSIS																				0
OTHER CONVERSION	2281													- 196				- 6335	- 4250	- 4055
TOTAL TRANSFORMATION	2281	- 2621	- 657	- 511	- 416	- 162	- 302	- 68	- 91	- 10	- 306	- 232	- 249	- 1101	- 54	- 83	- 9	- 6383	- 10974	- 27973
OWN USES																				- 3988
LOSSES																				- 954
TOTAL FINAL ENERGY CONSUMPTION	2286																		2286	46949
FINAL NON- ENERGY USES																				2564
FINAL ENERGY CONSUNPTION	2286	1989												903				3265	8443	50542
AGRICULTURE																				2847
MINING																				93
MANUFACTURING		1989												862				656	3507	17922
CONSTRUCTION																			0	128
RESIDENTIAL& COMMERCIAL	2286													41				2609	4936	10920
TRANSPORTATION																				18632
ROAD																				14638
RAIL																				105
AIR																				3038
WATERWAY																				851