CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, the results would be mentioned in two main parts. First, the factors of SBGPGS based on experimental data that consisted of technical performance, biomass supplied system, economy condition and environmental impacts, case at SERT, and based on secondary data. Second, management model of SBGPGS for community in Thailand focused on the sub-models of biomass supplied system and community, supported by secondary data.

Factors of SBGPGS

1. Factors of SBGPGS were supported by experimental data, case at SERT

1.1 The experimental results of technical performance evaluation

From the experiment, it was shown that the average biomass consumption rate was of 50 kg h^{-1}, so the input power was 255 kW. The system was operated at an average gas flow of 135 Nm^3 h^{-1}. The average calorific value of producer gas was 4.5 MJ m^{-3} and cold gas efficiency was about 66%.

The engine operated on producer gas. The engine was started up fuelled by LPG, and switched over to producer gas. The power was reduced compared to LPG operation by a power factor of 0.8. The output power was about 45 kW_e on LPG, while the maximum output power at full load was 25 kW_e on producer gas only. The oxygen (O_2) and carbon monoxide (CO) contents in the exhaust gas from the engine varied from 9% to 10% and 3% to 5%, respectively. The overall conversion efficiency of the system was about 10% from wood to electricity. The gas engine-generator set efficiency was about 15%. The parameters of this study are shown in Table 11.

Table 11 The parameters for BGPGS performance evaluation

Parameters	Average
Output power (W)	25,392
Power factor	0.8
Phase current (A)	46
Phase volts (V)	230
Input power (W)	254,755
Lower heating value (kJ kg^{-1})	18,342
Biomass consumption rate (kg h^{-1})	50
Specific gasification rate (kg m^3 h^{-1})	417
Gas compositions	
CO (%)	21.21
CH_4 (%)	5.65
H_2 (%)	14.78
N_2 (%)	41.14
CO_2 (%)	17.15
O_2 (%)	0.07
Producer gas flow rate (Nm^3 h^{-1})	135
Tar and particulate (mg Nm^{-3})	161
The heating value of a stoichiometric mixture of producer gas and air (kJ m^{-3})	4,496
Cold gas efficiency (%)	66
Biomass gas engine-generator efficiency (%)	15
Overall efficiency (%) (thermal)	10

The variations in the temperatures of different zones of the gasifier with respect to time were noted for Eucalyptus residue fuel. It was observed that temperatures at 50 mm, 250 mm, and 450 mm above the grate were irregular following the feeding interval and supplied air flow rate. The temperature started to decrease after biomass was refilled, but percentage of CO content in producer gas would start to increase. After that, the percentage of CO content in producer gas would decrease while the temperature in oxidation zone and supplied air flow rate increased as shown in Figure 18, 19 and 20.

The temperature at the 50 mm above the grate, reduction zone, was quite constant at 500 °C. The temperatures at the 250 mm above the grate, oxidation zone, and at 450 mm above the grate, pyrolysis zone, were 500 to 800 °C.

The percentage of CO content in producer gas varied from 14% to 28% and the average CO content was 21%.

Temperatures in gasifier increased followed the supplied air flow rate of gasifier as shown in Figure 19. The supplied air flow rate varied from 40 $m^3 h^{-1}$ to 75 $m^3 h^{-1}$ and the average air flow rate was about 60 $m^3 h^{-1}$.

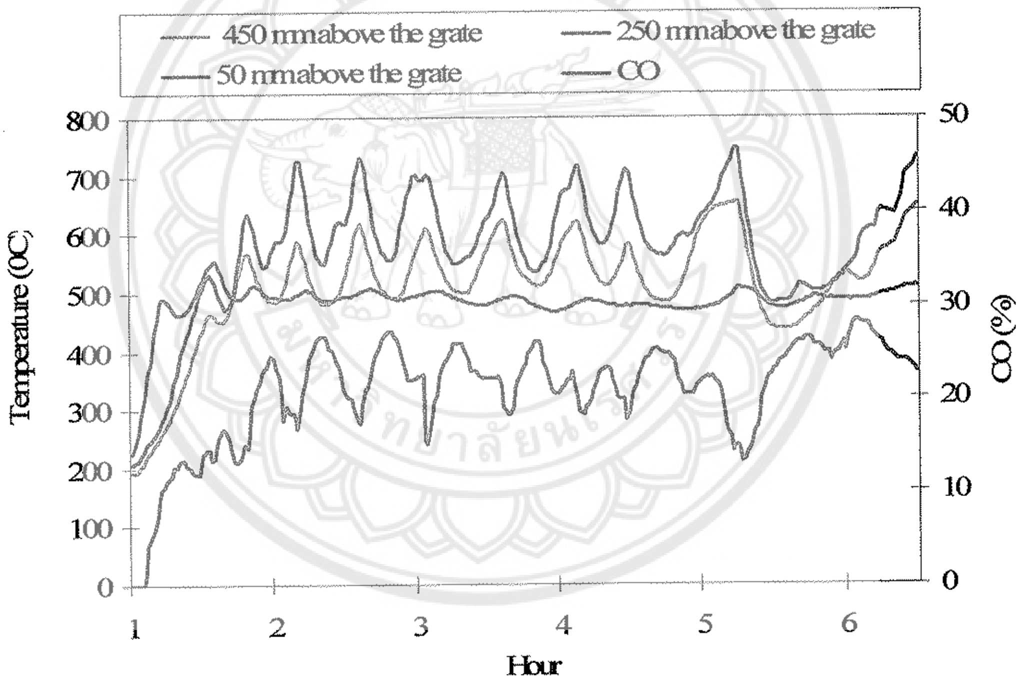

Figure 18 Temperatures in gasifier and percent of CO in producer gas

Figure 20 shows the relation between supplied air flow rate and the percentage of CO content in producer gas. The supplied air flow rate was dropped when biomass was refilled. After that, percentage of CO content in producer gas would start to increase until carbon of biomass was not enough for partial oxidation. Then, the percentage of CO content in producer gas would decrease while the supplied air flow rate increased.

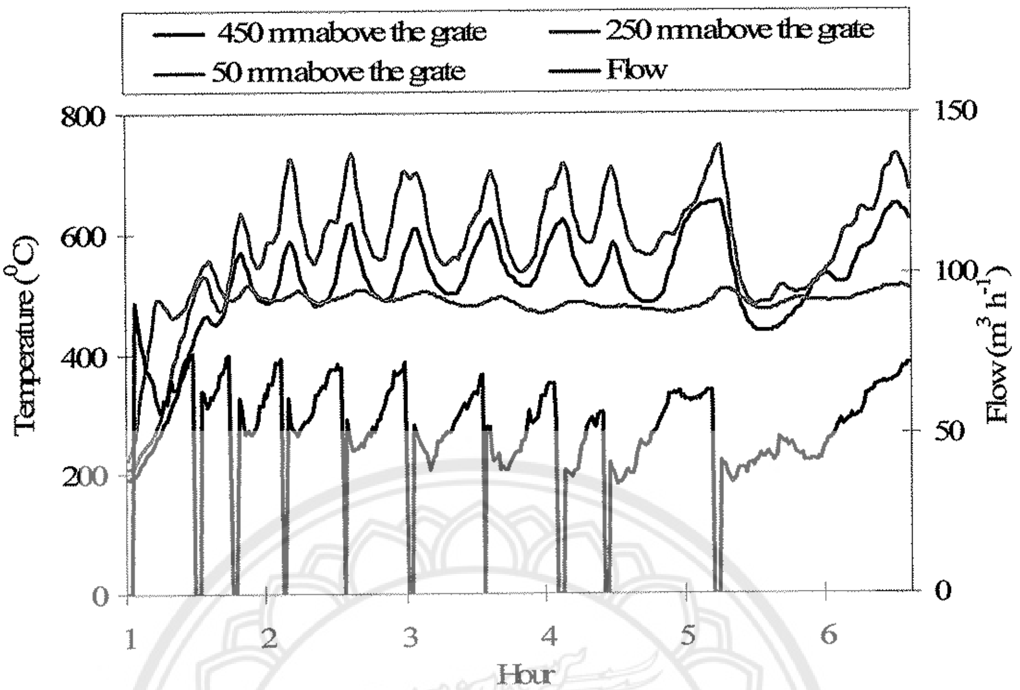

Figure 19 Temperatures in gasifier and supplied air flow rate

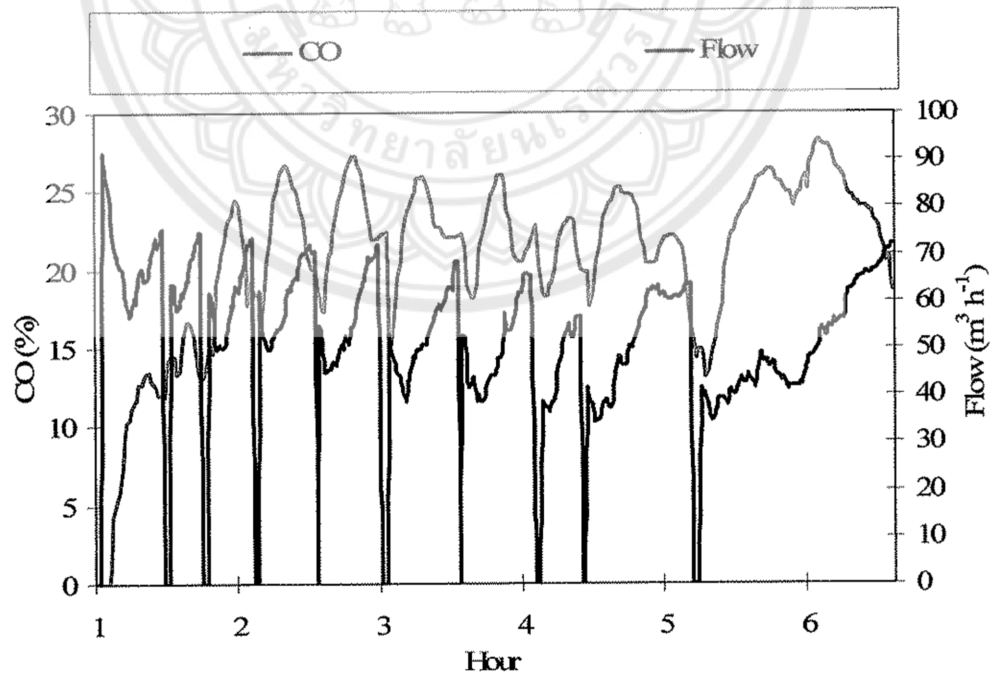

Figure 20 Relation between percentage of CO in producer gas and supplied air flow rate

1.2 The experimental results of biomass supplied system

1.2.1 Biomass plantation area

The biomass plantation area in this study was assumed to be square and circular; the detail constraints were explained in Chapter III. The biomass consumption rate and biomass plantation area of BGPGS at SERT were considered by biomass LHV referring to tropical hardwood plant, E. camaldulensis, A. mangium and L. leucocephala of 4,908, 4,381, 4,528 and 4,309 kcal kg^{-1} at dry basis, respectively, an average biomass productivity referring to tropical hardwood plant, E. camaldulensis, A. mangium and L. leucocephala of 12,800, 2,549, 3,231 and 3,469 kg Rai^{-1} $year^{-1}$ at dry basis, respectively [12, 13, 14, 66], a full load plant operation time of 7,008 h $year^{-1}$ (80% power plant capacity), gasification efficiency of 66% and gas engine-generator system of 15%.

1) Tropical hardwood plants.

Biomass plantation area (Rai) could be calculated by the 4.1 equation.

$$A_{bp} = \frac{25 \times 3,600 \times 7,008}{0.15 \times 0.66 \times 4.1868 \times 4,908 \times 12,800 \times 30\%} \quad (4.1)$$

$$= 81 \text{ Rai}$$

Biomass plantation area requirement for tropical hardwood plant of BGPGS at SERT was about 80 Rai.

2) Fast growing plants

The results of fast growing plants in Thailand indicated that E. camaldulensis and L. leucocephala are appropriate for most of the country, except areas in southern and eastern Thailand. On the other hand, A. mangium is appropriate for southern and eastern areas during times of heavy rainfall in these regions. The growing interval that was appropriate for three characteristics of fast growing plants was 1×1 m^2, because it offered the most biomass production to other growing intervals. The rotation of SRF was 2 years [14]. Therefore, biomass plantation area requirement of each characteristic of fast growing plants could be shown in Table 12.

Table 12 Biomass consumption rate and biomass plantation area requirement (Rai) of BGPGS at SERT of fast growing plants that were appropriate for growing in Thailand, E. camaldulensis, A. mangium and L. leucocephala, was classified by the amount of rain in Thailand and the interval of growing [14].

Specific characteristics	Amount of rain (mm $year^{-1}$)	Biomass productivity was classified to the interval of growing (kg Rai^{-1} $year^{-1}$) as dry basis	Biomass Consumption rate $M = \frac{P_o \times 3,600 \times OH}{\eta_e \times LHV}$	Biomass plantation area requirement (Rai)	
		1×1 m^2	$M_{dry\ basis}$ (kg $year^{-1}$)	$A_{bp} = \frac{M \times R}{P}$	
E. camaldulensis	800-1,000	1,862	347,333	373	= 289
	1,000-1,200	2,385		291	
	>1,200	3,401		204	
A. mangium	<1,200	2,751	353,137	244	= 212
	1,200-1,500	3,075		219	
	>1,500	3,867		174	
L. leucocephala	800-1,000	2,204	336,057	320	= 222
	1,000-1,200	3,773		187	
	>1,200	4,430		159	

Biomass plantation area requirement of E. camaldulensis, A. mangium and L. leucocephala were about 289, 212 and 222 Rai, respectively.

1.2.2 Logistics

At present, generating energy from biomass is rather expensive due to both technological limits related to lower convention efficiencies. and logistics constraints. In particular, the logistics of biomass fuel supply is likely to be complex owing to the intrinsic feedstock characteristics, such as the limited period of availability and the scattered geographical distribution over the territory.

The effects of main logistic variability will be mentioned by the following.

1) Specific vehicle transportation cost (baht km^{-1})

2) Vehicle capacity (t $vehicle^{-1}$)

This study specifically intended to use the residuals of E. camaldulensis from sawmills around Naresuan University, Phitsanulok, Thailand. Vehicle capacity could be classified into four specific characteristics of vehicles: 1) a tricycle, 2) a motor tricycle, 3) a pickup truck and 4) a truck. Vehicle capacity of a tricycle and a motor tricycle is equal. The other constraints had already been defined in Chapter III.

The specific vehicle transportation cost and vehicle capacity are shown in Table 13.

1) Biomass distribution density (t km^{-2} $year^{-1}$)

Biomass distribution density, D_{BD} (t km^{-2} $year^{-1}$), could be seen in Table 14.

2) A mapping of logistics direction

2.1) Square biomass plantation area

A mapping of logistic direction is showed in Figure 21, considering the total square biomass plantation area of E. camaldulensis, performance of BGPGS at SERT, growing interval of $1 \times 1\ m^2$.

Therefore, radius of the total square biomass plantation area could be calculated from the equation below, referring to only one year of E. camaldulensis plantation area.

$$r\,(km) = \frac{\sqrt{289\,(Rai) \times 1.6 \times 10^{-3}\,(km^2\,Rai^{-1})}}{2} \quad (4.2)$$

$$= 0.34\ km$$

The mapping of logistics direction is shown in Figure 21. Average distance (km) from the central area (power plant) could be calculated following the equation below.

$$D_A\,(\text{km}) = 2 \times \sqrt{(0.36)^2 + \left(\frac{(0.36)}{2}\right)^2} \quad = \quad 0.80\ \text{km} \qquad (4.3)$$

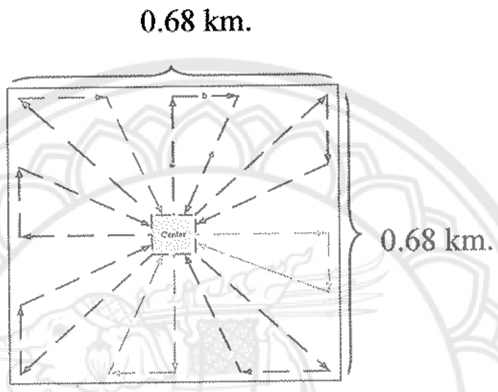

Figure 21 The logistics direction of square biomass plantation area for BGPGS at SERT

However, biomass transportation distance should be considered both when going to collect biomass and when coming back to the power plant (round trip). Therefore, the average distance was 0.76026 km.

1. Number of vehicle capacity

The specific vehicle transportation cost (baht km^{-1}) and vehicle capacity (t $Vehicle^{-1}$) E. camaldulensis residuals from sawmill by a tricycle, a motor tricycle, a pickup truck and a truck could be seen in Table 13.

The number of vehicle capacity per square kilometer per year, N_{VC} (vehicle km^{-2} $year^{-1}$) is shown in Table 14.

Then total annual traveled distance, TD (km $year^{-1}$), could be applied for calculation the vehicle cost, V (baht $year^{-1}$), as shown in Table 15.

Table 13 The specific vehicle transportation cost (baht km^{-1}) and vehicle capacity (t Vehicle^{-1}) of E. camaldulensis residuals from sawmill by a tricycle, a motor tricycle, a pickup truck and a truck [57-64].

Specific vehicle	Specific fuel of vehicle consumption	The lowest labour cost and oil price, C_{oil} (baht L^{-1})	The average specific vehicle consumption, C_{SV} (km L^{-1})	The specific vehicle transportation cost, C_{VT} (baht km^{-1})	Vehicle capacity, VC (t vehicle^{-1})
A tricycle	Nutrition 2,182 (kcal day^{-1} person^{-1})	144 (baht day^{-1})	9.3 (km day^{-1})	15.48	0.334
A motor tricycle	Gasoline 91 oil	30.89	35.0	0.88	0.334
A pickup truck	Diesel hi-speed oil	28.64	9.9	2.89	1.860
A truck	Diesel hi-speed oil	28.64	2.5	11.46	7.000

Table 14 Biomass distribution density of tropical hardwood plants, E. Camaldulensis, L. leucocephala, and A. mangium, number of vehicle capacity, and area per vehicle a year [13-15].

Specific characteristics of plants	$P_{dry\ basis}$ (kg Rai^{-1} year^{-1})	$P_{50\%\ wet\ basis}$ (kg Rai^{-1} year^{-1})	D_{BD} (t km^{-2} year^{-1})	Specific vehicle	N_{VC} (vehicle km^{-2} year^{-1})	A_V (km^2 vehicle^{-1} year^{-1})
Tropical hardwood plants	12,800	19,200	12,000	Tricycle	35,928	0.0000278
				Motor tricycle	35,928	0.0000278
				Pickup truck	6,452	0.0001550
				Truck	1,714	0.0005833
E. camaldulensis	2,549	3,824	2,390	Tricycle	7,156	0.0001397
				Motor tricycle	7,156	0.0001397
				Pickup truck	1,285	0.0007782
				Truck	341	0.0029289
A. mangium	3,231	4,847	3,029	Tricycle	9,069	0.0001103
				Motor tricycle	9,069	0.0001103
				Pickup truck	1,628	0.0006141
				Truck	433	0.0023110
L. leucocephala	3,469	5,204	3,252	Tricycle	9,737	0.0001027
				Motor tricycle	9,737	0.0001027
				Pickup truck	1,748	0.0005720
				Truck	465	0.0021525

Table 15 Vehicle cost per year of tropical hardwood plants, E. camaldulensis, L. leucocephala, and A. mangium, and total distance per year by specific vehicles.

Specific characteristics of plants	A_{bp} (Rai year^{-1})	A_{bp} (km^2 year^{-1})	D_A (km)	Specific vehicle	N_{AV} (vehicle)	TD (km year^{-1})	V (baht year^{-1})
Tropical hardwood plants	81.0	0.1296	0.40249	Tricycle	4,662	1876	29,046
				Motor tricycle	4,662	1876	1,651
				Pickup truck	836	337	973
				Truck	222	89	1,025
E. camaldulensis	144.5	0.2312	0.76026	Tricycle	1,655	1,258	19,477
				Motor tricycle	1,655	1,258	1,107
				Pickup truck	297	226	653
				Truck	79	60	688
A. mangium	106.0	0.1696	0.65115	Tricycle	1,538	1,001	15,499
				Motor tricycle	1,538	1,001	881
				Pickup truck	276	180	520
				Truck	73	48	548
L. leucocephala	111.0	0.1776	0.66633	Tricycle	1,729	1,152	17,838
				Motor tricycle	1,729	1,152	1,014
				Pickup truck	310	207	598
				Truck	83	55	630

2. Circular biomass plantation area

A logistic direction mapping of circular biomass plantation area of E. camaldulensis is showed in Figure 22. It was assumed that the other constraints were the same as a square biomass plantation area as described above.

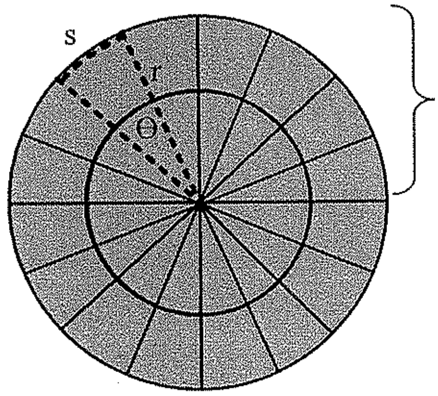

Figure 22 The logistics direction of circular biomass plantation area **for BGPG at SERT**

Vehicle cost per year of tropical hardwood plants, E. camaldulensis, L. leucocephala, and A. mangium, and total distance per year by specific vehicles are shown in Table 16 based on circular biomass plantation area of BGPGS at SERT.

Vehicle costs per year of square and circular biomass plantation area were hardly different. Therefore, the figure of area did not affected to vehicle cost of biomass logistics.

1.2.3 Biomass storage

The amount of biomass storage would be considered from biomass consumption rate at 50% moisture content (wet basis) [10], $M_{50\%\ wet\ basis}$ (t year^{-1}), that was converted from biomass consumption rate as dry basis, $M_{dry\ basis}$ (t year^{-1}), by the algorithm adopted to estimate the biomass consumption rate in Figure 13 and the 3.12 equation in Chapter III. The results of $M_{50\%\ wet\ basis}$ (t year^{-1}) and $M_{dry\ basis}$ (t year^{-1}) are shown in Table 17. However, the biomass storage should expand for covering in rainy season and collecting them near the power plant for continuous running processes. In this study, the warehouse for containing wood ships was considered by bulk density of Eucalyptus wood chips that ranging from $2\times2\times5$ cm^3 to $4\times4\times7$ cm^3 of 284 kg m^{-3} at the 80% capacity factor following the BGPGS at SERT. The biomass storage, S_b (t year^{-1}) and warehouse (m^3) were shown in Table 17.

Table 16 Vehicle cost and total distance per year by specific vehicles of circular biomass plantation area.

Specific characteristics of plants	A_{bp} (Rai year^{-1})	A_{bp} (km^2 year^{-1})	D_A (km)	Specific vehicle	N_{AV} (vehicle)	TD (km year^{-1})	V (baht year^{-1})
Tropical hardwood plants	81.0	0.1296	0.40653	Tricycle	4,662	1,895	29,337
				Motor tricycle	4,662	1,895	1,668
				Pickup truck	836	341	985
				Truck	222	92	1,049
E. camaldulensis	144.5	0.2312	0.76810	Tricycle	1,655	1,271	19,678
				Motor tricycle	1,655	1,271	1,119
				Pickup truck	297	229	662
				Truck	79	62	708
A. mangium	106.0	0.1696	0.65791	Tricycle	1,538	1,012	15,660
				Motor tricycle	1,538	1,012	890
				Pickup truck	276	183	528
				Truck	73	49	565
L. leucocephala	111.0	0.1776	0.67317	Tricycle	1,729	1,164	18,021
				Motor tricycle	1,729	1,164	1,024
				Pickup truck	310	210	607
				Truck	83	57	648

Table 18 Plant technical parameters, case at SERT

Technology	BGPGS, downdraft gasification, followed gas engine power generation
Project size	25 (kW_e)
Thermal rate	144,970 (kcal h^{-1})
Cost	(baht kW^{-1})
Tricycle	78,756 (baht kW^{-1})
Motor tricycle	79,356 (baht kW^{-1})
Pickup truck	90,156 (baht kW^{-1})
Truck	118,156 (baht kW^{-1})
The energy needs of auxiliary pieces of equipment	10%
O&M	% total capital investment cost
Tricycle	41%
Motor tricycle	44%
Pickup truck	39%
Truck	30%
Plant capacity factor	80%

Table 19 Financial assumptions, case at SERT

Parameters	Assumption
General inflation [67]	2.2 (% $year^{-1}$)
Project economic life	25 years
Discount rate [68], [69]	7 (%nominal)
Purchased biomass cost	500 (baht t^{-1})
Total project cost	Gasifier, Diesel engine, Instrumentation (Wood cutter, Moisture meter), Travel cost, Man power, Erection + commission, Training, Power station
Current market price of produced electricity with government subsidies [16]	4.1 (baht kWh^{-1})
Environmental benefit (EB) from CO_2 reduction of biomass utilization [70]	10.42 (\$ t^{-1} of CO_2) or 0.44 (baht kg^{-1} of CO_2)
CO_2 emission to air of diesel oil [71]	0.25 (kg CO_2 kWh^{-1})
Power production /diesel oil consumption for smaller unit of ICE. [72]	3.5 (kWh L^{-1}) of diesel
Diesel oil price [57]	28.64 (baht L^{-1})

An assessment results of technical and economic performance of thermal processes to generate electricity from a wood chip feedstock by gasification. The scope begins with the delivery of harvesting wood from plantation area near power plant, cutting and drying biomass, storage biomass, through conversion of the power plant and ends with the supply of electricity to dummy load. Net generating capacity of 25 kW_e case at SERT was evaluated and the electricity production costs had been calculated for 25th plant systems. The parameters of economic condition evaluation that used for explanation consisted of COE, PB, NPV and IRR that are shown in Table 20.

Table 20 Results of economic condition evaluation that consisted of COE, PB, NPV and IRR, based on tricycle, motor tricycle, pickup truck and truck.

Specific Vehicle	Parameters of Economic Condition Evaluation			
	COE	NPV	PB	IRR
Tricycle	7.20	-770,114	21.98	-
Motor Tricycle	7.73	-1,701,849	23.62	-
Pickup Truck	7.85	-2,057,077	23.98	-
Truck	8.09	-2,856,879	24.70	-

From the sensitivity analysis of NPV in Figure 23, this project was lost in investment. It meant that this system could not be competed with conventional fossil fuel. Nevertheless, the 25 kW_e BG and gas engine system generated about 175,200 kWh of electricity per year. Therefore, this project could reduce oil consumption of diesel power plant by about 50,057 liters [72] (1,433,637 bath [57]) per year and reduce CO_2 emission by about 43,800 kg CO_2 per year [71].

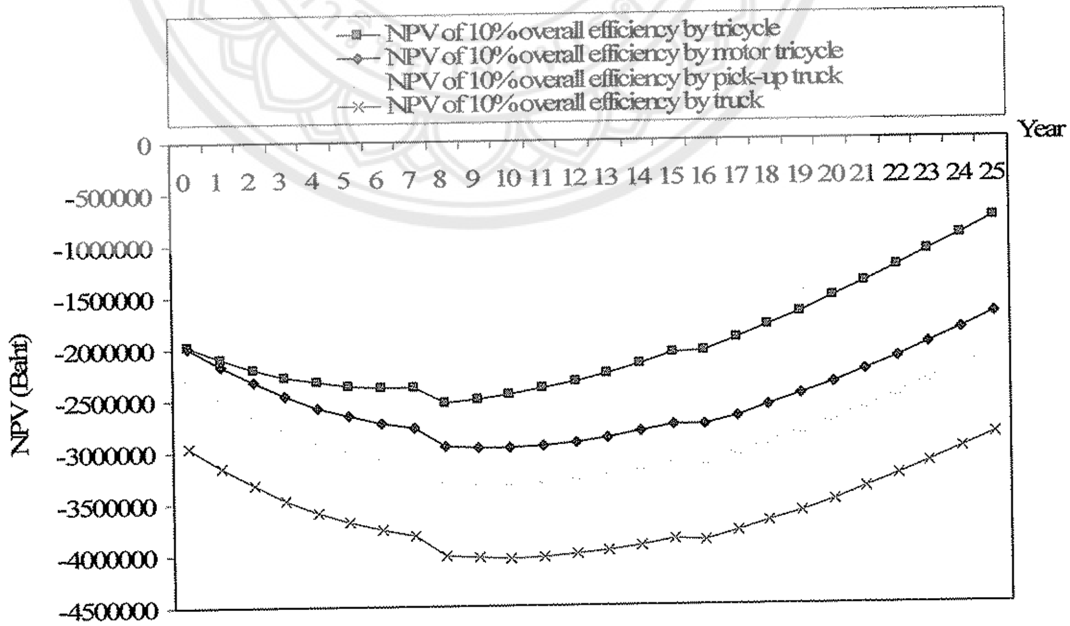

Figure 23 The NPV sensitivity analysis of BGPGS at SERT

1.4 The experimental results of environmental impacts evaluation

The environment impacts evaluation of BGPGS at SERT was classified into three parts, namely:

1.4.1 Waste water

Waste water was considered the physical properties, namely pH, conductivity Total dissolved solid (TDS), Suspended solid (SS), and Temperature (during sampling) as shown in Table 21. Waste water from wet scrubber of the cleaning system of BGPGS was analyzed by the chemical laboratory, Faculty of Agriculture Natural Resources and Environment, Naresuan University, Phitsanulok, Thailand. The methodology, industrial effluent standard values and experimental results of waste water samples are shown in Table 21. Water quality standard of industrial effluent water has to be treated before release to environment based on the 3th Thai Environment Regulation of Ministry of Science Technology and Environment, Thailand declared on January 3, 1996 [30, 73].

Table 21 Parameters, methods and equipments of environmental evaluation

Parameters	Waste water from wet scrubber		Methods and Equipments	Industrial effluent standard values [73]
	Unit	Quantity		
1. pH	pH unit	4.21	pH Meter	5.5-9.0
2. Conductivity	Microsiemens cm^{-1}	1,486	EC Meter	Not limit
3. Total dissolved solid	mg L^{-1}	767	GF/C Dry at 103 °C, 1 hour	3,000
4. Suspended solid	mg L^{-1}	26	GF/C	50
5. Temperature	°C	35	Thermometer	40

This table shows that all parameters of waste water from wet scrubber were not more than the industrial effluent standard values of Ministry of Science Technology and Environment, Thailand [73].

1.4.2 Air pollution

The standards of air quality and noise standard values are as announced by the 4th edition law of Office of Prime Minister, Thailand (1995) of government car [30].

The emissions of gas engine to air were measured in this study as shown in Table 22, by Office of Phitsanulok Province Transport, Department of Land Transport and Office of Environment Area 9, Phitsanulok, Thailand.

1.4.3 Sound standard

Sound level was measured by level meter (IEC 651 Type 2) at 0.5 m from the engine. It is shown in Table 22.

Table 22 Parameters, methods, units, measured values and standards values of air quality and noise standard values [30]

Parameters	Methods and equipments	Unit	Measured values	Standard values
1. CO	Gas analyzer (Extech 407760)	%V/V	3.84	4.5
2. HC (Hydrocarbon)	Gas analyzer (Extech 407760)	ppm.	1,482	600
3. Sound level	Sound level meter (IEC 651 Type 2),	dB.(A)	93.2	100 (any characteristic vehicles)

From the results of this table, it could be concluded that only HC was more than standard value. It meant that the energy conversion efficiency of gas engine was low. Therefore, it could not clearly convert HC to energy.

2. Factors of SBGPGS were supported by secondary data

The four factors of SBGPGS that are supported by secondary data could be considered as shown Figure 24. Some factors would be detailed such as biomass supplied system and economic condition because they were affected by technical performance [30, 73, 74].

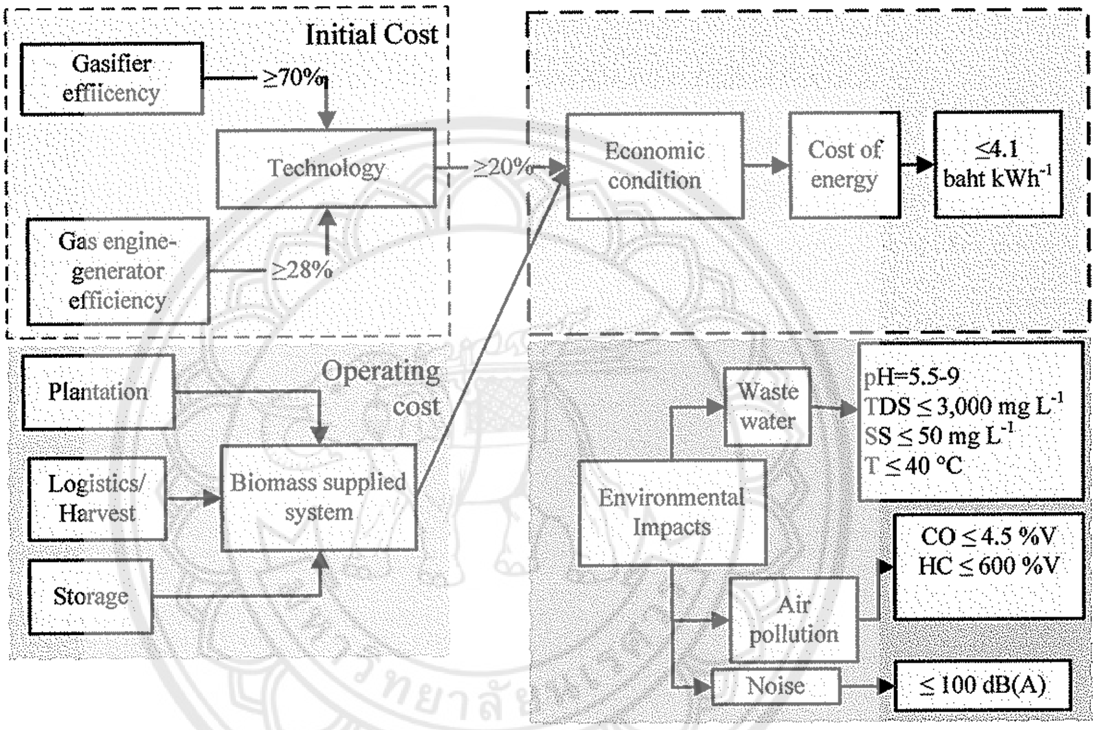

Figure 24 The four factors of SBGPGS that supported by secondary data

2.1 Technical performance evaluation

Gasifier efficiency of cold gas for internal combustion engine should not be less than 70% or overall system efficiency of woody biomass and electrical applications should not be less than 20% [74], the details of technical standard values are shown in Table 27 of appendix. Therefore, the gas engine generator system efficiency should not be less than 28%. The values would change for other applications as per the efficiency of the corresponding end use device.

When the overall efficiency increased to 20%, it meant that the power output would be increased to 50 kW by the same conditions of BGPGS at SERT.

2.2 Biomass supplied system

Following the overall technical efficiency for standard commercial level; thus, biomass supplied system would be supplied for 50 kW_e of BGPGS. Therefore, the results of both square and circular biomass plantation area, logistics (especially, vehicle costs) and biomass storage were the same results as BGPGS case at SERT.

2.3 Economic condition evaluation

The plant technical data of BGPGS are provided in Table 23. Plant financial assumptions were shown in Table 19 as described above.

Table 23 Plant technical parameters of 50 kW_e BGPGS at 20% overall conversion efficiency

Technology	BGPGS, downdraft gasification, followed gas engine power generation
Project size	50 (kW_e)
Thermal rate	144,970 (kcal h^{-1})
Cost	(baht kW^{-1})
Tricycle	39,378 (baht kW^{-1})
Motor tricycle	39,678 (baht kW^{-1})
Pickup truck	45,078 (baht kW^{-1})
Truck	59,078 (baht kW^{-1})
The energy needs of auxiliary pieces of equipment	10%
O&M	% total capital investment cost
Tricycle	41%
Motor tricycle	44%
Pickup truck	39%
Truck	30%
Plant capacity factor	80%

Results of economic condition evaluation that are used for explanation were shown in Table 24.

Table 24 Parameters of economic condition evaluation consisted of COE, PB, NPV and IRR, referring to 20% overall conversion efficiency by using tricycle, motor tricycle, pickup truck and truck.

Specific vehicle	20% Overall efficiency of BGPGS			
	COE	NPV	PB	IRR
Tricycle	3.60	11,948,185	10.99	27%
Motor tricycle	3.87	11,016,450	11.81	24%
Pickup truck	3.93	10,661,222	11.99	21%
Truck	4.04	9,861,420	12.35	16%

The 50 kW_e BGPGS generated 315,360 kWh electricity per year. This project could reduce oil consumption of diesel power plant about 90,103 liters [72] (2,580,546 baht [57]) per year and reduced CO_2 emission about 135,605 kg CO_2 per year [71].

Figure 25 shows the sensitivity analysis of NPV. It meant that the overall conversion efficiency at 20% would offer economic profit and this system could compete with used conventional fossil fuel power plants. On the other hand, these conditions would offer the SBGPGS.

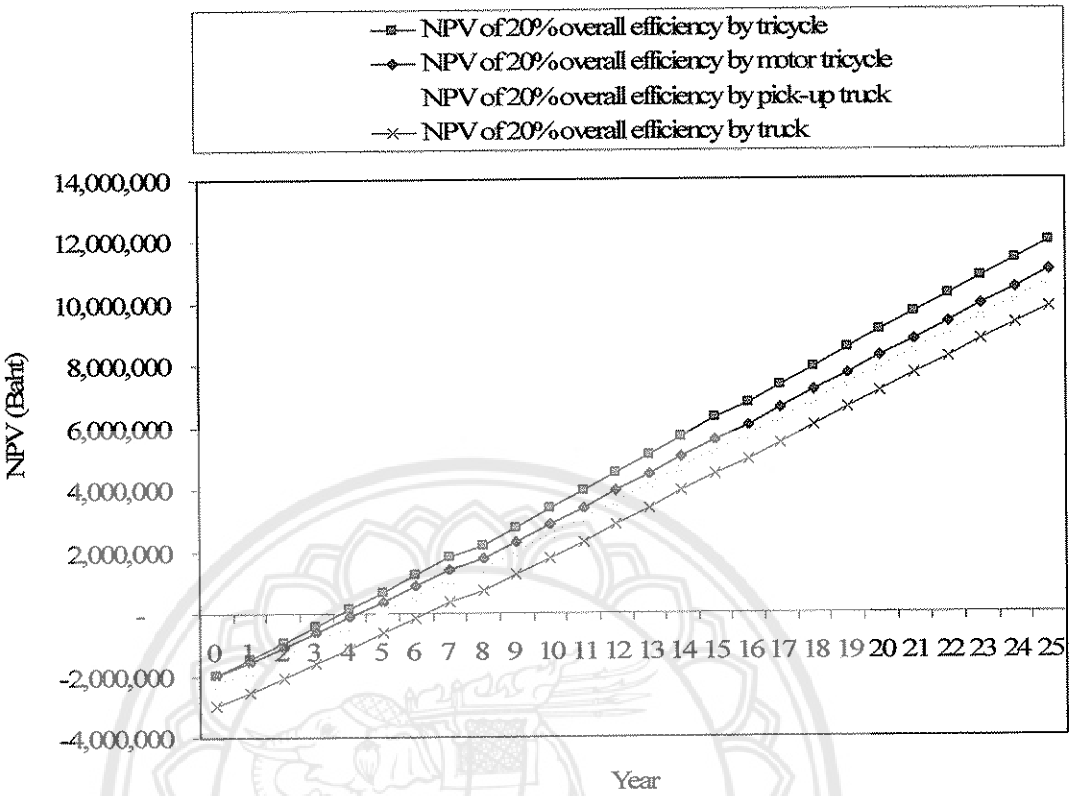

Figure 25 The NPV sensitivity analysis of 50 kW$_e$ BGPGS at 20% overall conversion efficiency

2.4 Environmental impacts evaluation

The substitution of conventional fossil fuel with biomass for energy production resulted in both a net reduction of greenhouse gases emissions and the replacement of non-renewable energy sources. When biomass is used to produce power, the carbon dioxide released at the power plant is recycled back into the power without adding to air emissions. BGPGS is the result of RE technology re-growth of new biomass. This renewable and recycling process makes it possible to generate with specific impetus on [31]:

2.4.1 Best environmental protective technology

2.4.2 Promote renewable energy

2.4.3 Improve deforested areas by reforestation

2.4.4 CO_2 neutral energy production with minimum impact to the environment

Management model of SBGPGS for community in Thailand

The management model of SBGPGS for community in Thailand is based on technical performance, biomass supplied system, economic condition and environmental impacts and community that were supported by secondary data for consideration of the most appropriate alternative of management model. According to the management model establishment of SBGPGS, risks of all factors should be managed first. Risk assessment is considered as the initial and periodical step in a risk management process. A continual process of risk assessment should identify potential problems of each factor of SBGPGS and hopefully avoid them.

The following risks were discovered and they had to be covered by suggested methods included in the table that follows.

Table 25 Risk assessment and mitigation of the main factors for SBGPGS

No.	Risk assessment	Risk management and risk mitigation
1	Biomass gasification technology - Technical limits related to lower conversion efficiencies.	1. To develop technology of country for own know-how and sustainable technology is necessary. - Tendency of technical development for commercial standard level is tar decrease of producer gas by developing gasification efficiency and especially cleaning/cooling system. In addition, gas engine-generator system should be re-designed for higher conversion efficiency and be appropriate for applications. 2. To provide technology as commercial standard level for developing management model of SBGPGS, research into this technology has been ongoing for a long time and it has received increasing attention in the energy market.
2	Biomass supplied system 2.1 Biomass plantation area	Area of sustainable plantation is necessary to produce renewable fuel in order to ensure an uninterrupted supply of biomass fuel to the power plant. Long-term source of biomass must be estimated for confidence of investors. Biomass plantation area can be provided from;

Table 25 (Cont.)

No.	Risk assessment	Risk management and risk mitigation
2		1. Deforested and fallow land reforested with an assortment of fast growing trees and tropical hard wood. The land is to be provided by a variety of Royal Thai Government Departments including Forest, Corrections, the Army, and Treasury. These departments will take responsibility for planting, maintaining, harvesting and financing the renewable wood energy crop. 2. The land controlled by The Agricultural Land Reform Office in each community. Under existing Thai law, they are required to reforest. All of these lands are available for renewable wood energy crop production and tropical hardwood reforestation especially land closest to the community power generation system will be utilized first. Farmer cooperatives will be responsible for planting, maintaining and harvesting the renewable wood energy crop.
	2.2 Scattered geography distribution over the territory	Homogeneous biomass distribution over the territory will be selected for planting sustainable biomass fuel of power plant. It is possible to cultivate all over the country except the city and the area submerged for a long time in rainy season.

Table 25 (Cont.)

No.	Risk assessment	Risk management and risk mitigation
2	2.3 Plantation crop	Not only plantation crop should be covered through a year, but also the rotation of plantation crop should be considered for enough biomass consumption rate.
	2.4 Fuel wastes that leaved from cutting biomass fuel such as leaves, small branches	Fuel waste will be managed by 1. Fuel wastes will be collected for pressing to pieces and used for fuel. 2. Fuel waste will be collected and covered around the base of trees for natural fertilizers.
	2.5 Logistics constraints	Logistics should avoid using oil for transportation because of the oil price fluctuation. Therefore, power plant should not be large scale.
	2.6 Feedstock	Feedstock should be covered in rainy season for continuous running system.
	2.7 Biomass cost	1. The risk of biomass cost will decrease by signing a contract between the investors and biomass plantation owners for long time operating projects. 2. Investors should consider about own biomass plantation area and it should be located around their projects for decreasing the cost of biomass transportation.

Table 25 (Cont.)

No.	Risk assessment	Risk management and risk mitigation
3	Economic condition	1. Small enterprises will decrease economic risk. 2. Create jobs with secure incomes. 3. Electric power that is competitive with other renewable and conventional power plants in Thailand 4. Achieve power price stability and independence on international fuel price changes.
4	Environmental impacts	It is the best environmental protective technology and the properties of exhaust emission from engines run on producer gas that are generally considered to be acceptable, comparable to those of diesel engines [10].
	4.1 CO poisoning	1. Ignited CO at flare tower during startup and shutdown system. 2. Wear gas mask. 3. Usingsuction blower for prevention producer gas leakage during actual operation.
	4.2 Fire hazard - high surface temperature of equipment - risks of sparks during refilling - flames through gasifier air inlet on refueling lid	1. Insulation of hot parts of the system 2. Installation of double sluice filling device. 3. Installation of back-firing valve in gasifier inlet.

Table 25 (Cont.)

No.	Risk assessment	Risk management and risk mitigation
4	4.3 Explosion hazard - air leakage into the gas system - air penetration during refueling - air leakage into a cold gasifier still containing gas which subsequently ignites.	1. Risk to the operator can be obviated if the gases in the bunker section are burnt off through the introduction of a piece of burning paper or the like, immediately after opening the fuel lid. 2. Another possibility is installation of a double sluice type filling system. 3. Air leakage into a coal gasifier and immediate ignition will lead to an explosion. Cold systems should always be carefully ventilated before igniting the fuel.
	4.4 Ashes	The ashes do not constitute an environmental hazard and can be disposed of in the normal way.
	4.5 Condensate (mainly water) from the cleaning section	Cleaning section should be installed as close system and treated before reuse.
	4.6 Noise The noise comes primarily from fans, air inlets, exhaust system and other machines.	1. An efficient way of controlling the noise from noise source is to place fans, hydraulic engines, etc. in a basement. 2. Growing trees around the power plant to create a buffer zone.

Table 25 (Cont.)

No.	Risk assessment	Risk management and risk mitigation
5	Community	1. Public participation 2. Distribution technical know-how and renewable education to community. 3. Thai policy tends to strongly encourage decentralized community power generation system.

1. Consideration of the most appropriate alternative

The most appropriate alternative would be considered for developing management model of SBGPGS. As described above, SBGPGS is based on five main factors. However, technical performance, economic condition and environment impacts of each enterprise varied in several designs. Therefore, the detail of sub-management model in this study focused on biomass supplied system and community.

1.1 Biomass supplied system

1.1.1 Biomass plantation area

We had to know biomass consumption rate for BGPGS first. Then it would be used for calculation biomass plantation area. From considering a power plant capacity ranged from 5 kW to 500 kW, a biomass LHV referring to tropical hardwood plant, E. camaldulensis, A.mangium and L. leucocephala of 4,908, 4,381, 4,528 and 4,309, respectively [12-14, 66] with an average moisture content of 20%, a full load plant operation time of 7,008 h $year^{-1}$ (80% power plant capacity) and overall system efficiency for commercial qualifying & acceptable performance levels at rate load (woody biomass and electric application) of 20% [74]. The estimated biomass consumption rate model per year would be shown in Figure 26.

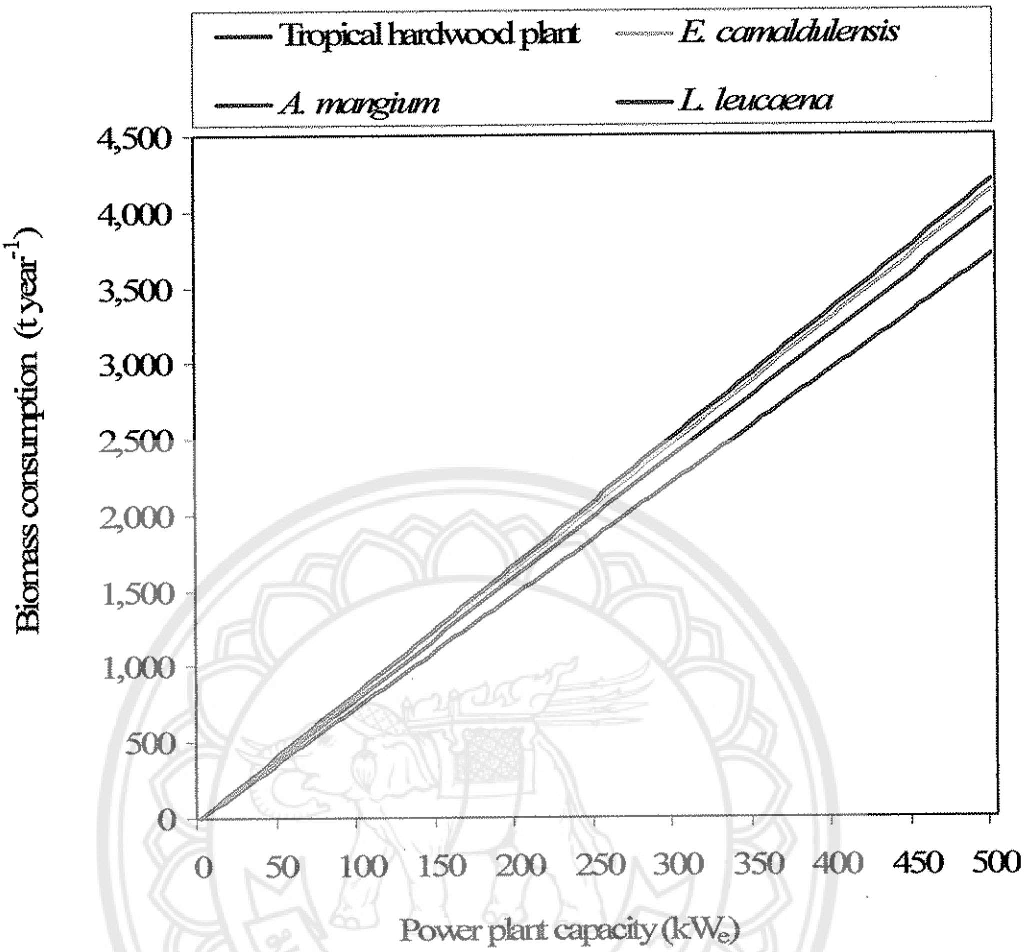

Figure 26 Estimated biomass consumption rate of SBGPGS at 20% overall conversion efficiency

From the model of biomass consumption rate for BGPGS in Figure 26 it could be concluded that biomass consumption requirement of L. luceana was more than the others. It meant that lower heating value of L. luceana was the lowest value compared to the others.

The conditions as described above could be used for calculation of the estimated biomass plantation area as shown in Figure 27, an average biomass productivity referring to tropical hardwood plant, E. camaldulensis, A. mangium and L. leucocephala of 12,800, 2,549, 3,231 and 3,469, respectively, at dry basis [12, 14].

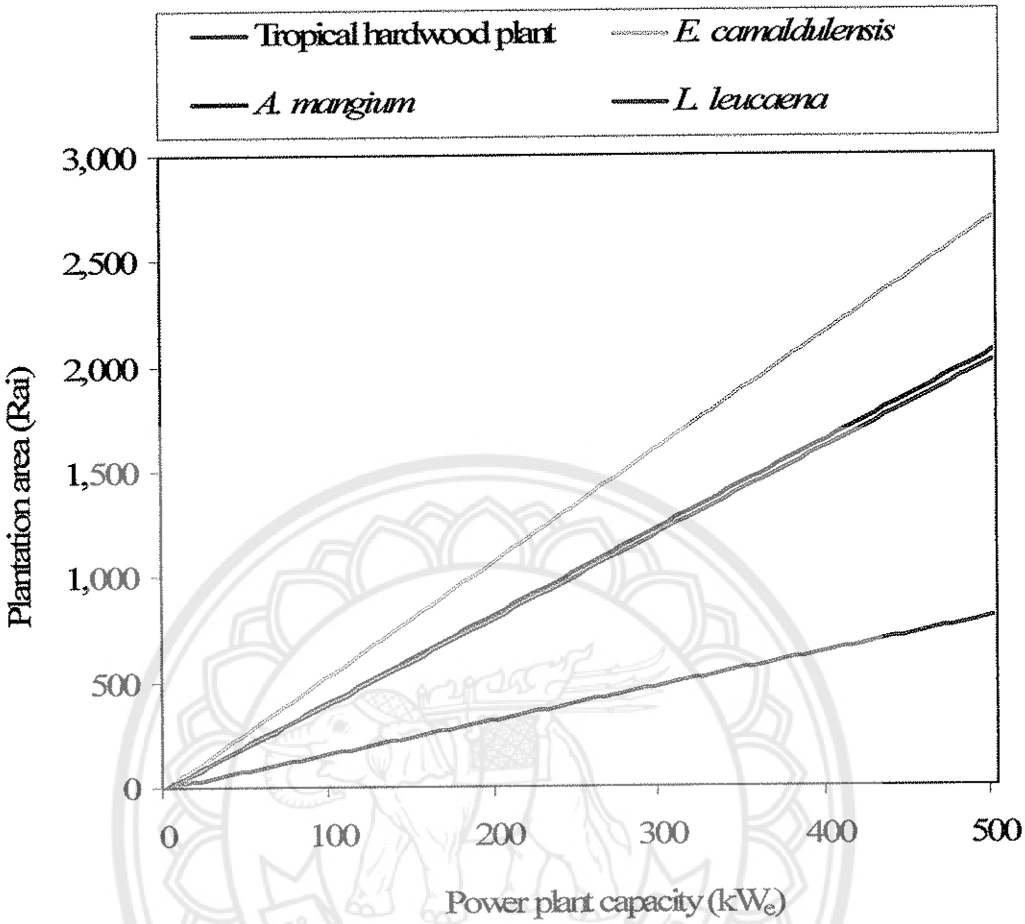

Figure 27 Estimated biomass plantation area of SBGPGS at 20% overall conversion efficiency

From this model, it could be concluded that E. camaldulensis required more biomass plantation area than the others. And it meant that biomass productivity per Rai per year of E. camaldulensis was lower than the others.

Both the model of biomass consumption rate and the model of biomass plantation area could be explained that not only lower heating value but also biomass productivity was the main effect on biomass plantation area.

1.1.2 Logistics

As described above, when we know biomass plantation area for BGPGS, we could use it for calculation of vehicle cost. Moreover, we also knew that the vehicle cost was not affected by square or circular biomass plantation area.

Therefore, this model showed only the vehicle cost referring to square biomass plantation area of different vehicles such as tricycle, motor tricycle, pickup truck and truck.

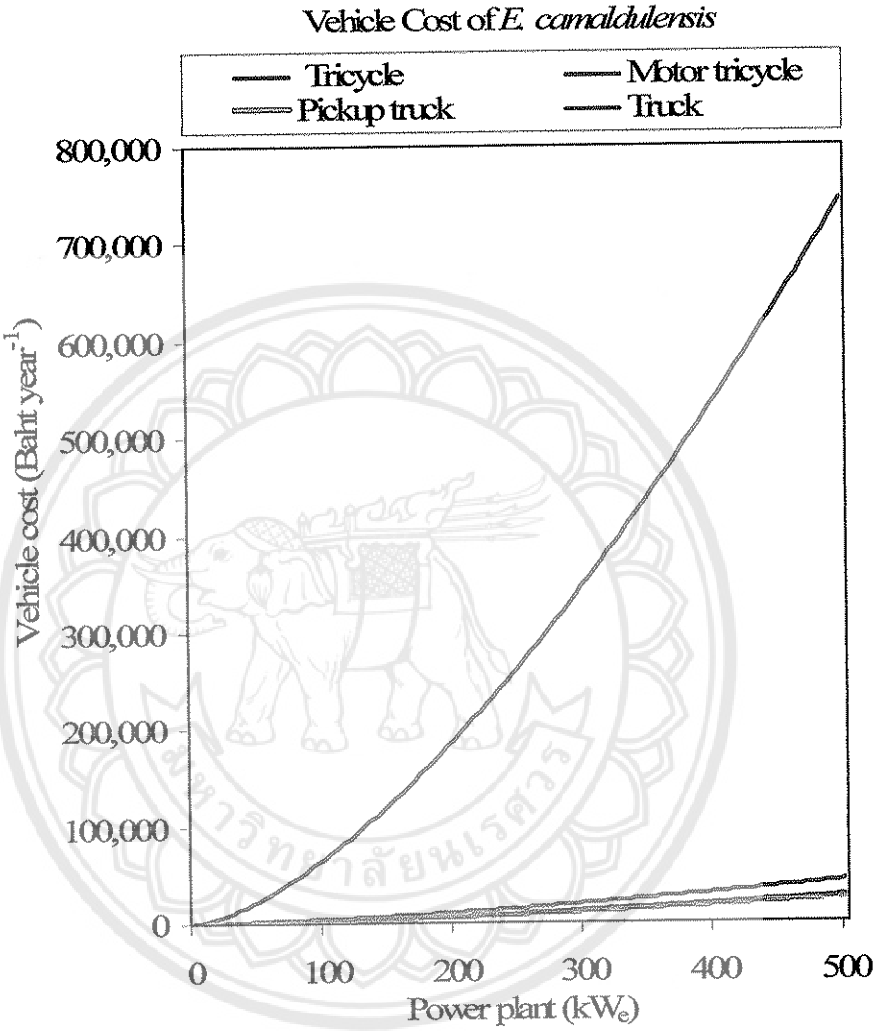

Figure 28 Vehicle cost of SBGPGS at 20% overall conversion efficiency, referring to tricycle, motor tricycle, pickup truck and truck

Figure 28 showed the model of estimated vehicle costs. It could be concluded that the highest vehicle cost was tricycle. However, economic evaluation not only considered the vehicle cost but also considered the transportation personnel costs (baht unit^{-1}). Because the biomass transportation costs (baht year^{-1}) was the combination of both the vehicle costs and the transportation personnel costs, vehicle cost of tricycle had been included by the transportation personnel cost.

Therefore, the lowest cost of biomass transportation was tricycle and tricycle was the most appropriate vehicle for small enterprises, especially these ranging from 5 kW to 50 kW.

1.1.3 Biomass Storage

This model showed the biomass storage of different kinds of plants such as tropical hardwood plants, E. camaldulensis, A. mangium and L. leucaena as well as the conditions of biomass consumption rate above.

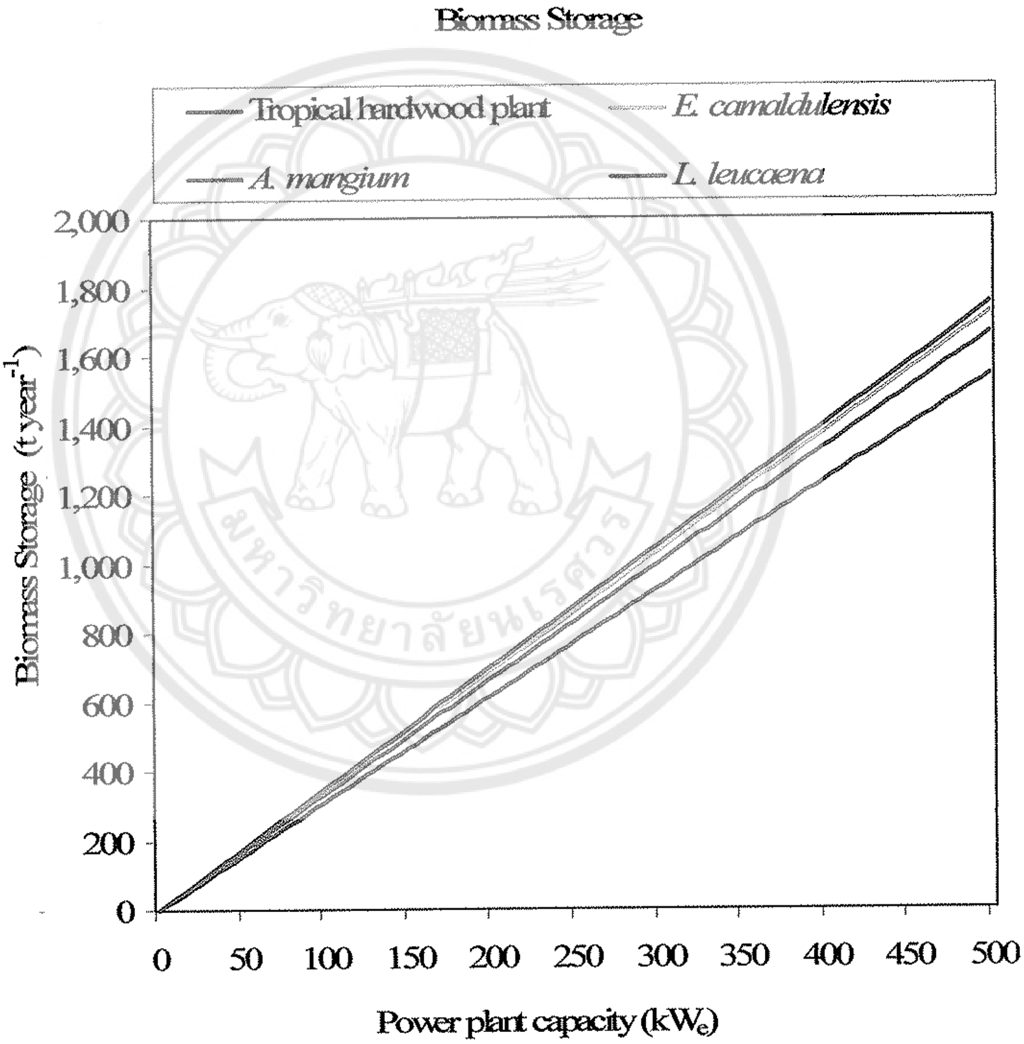

Figure 29 Biomass Storage of SBGPGS at 20% overall conversion efficiency

We found that tropical hardwood plants required the lowest biomass storage. On the other hand, L. leucaena required the highest biomass storage.

2. Community

Community means the local administrative organization of a community. Functions of community are management biomass supplied system, BGPGS and community power. The management processes flow of community for SBGPGS is shown in Figure 30.

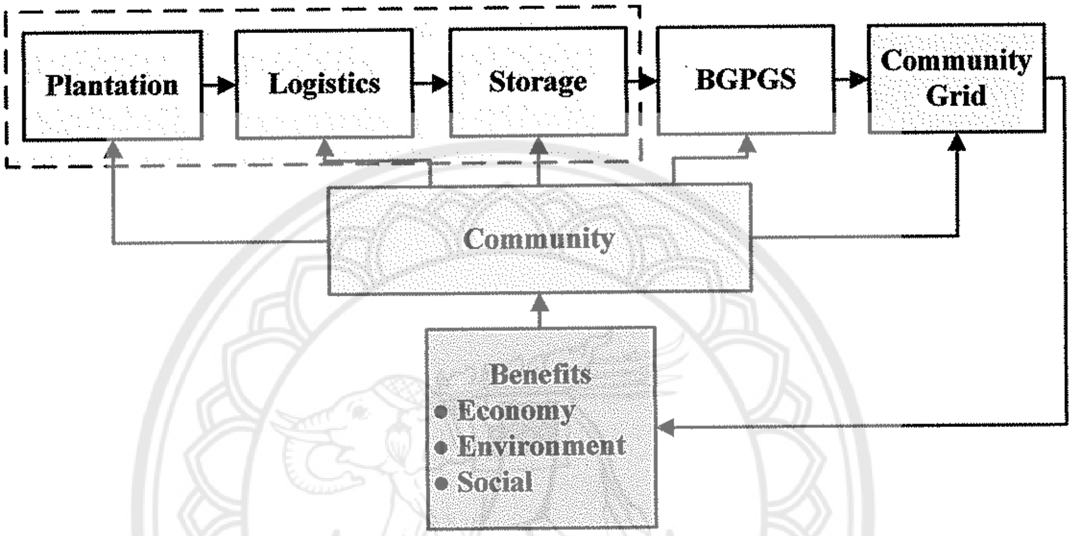

Figure 30 The management processes flow of community for SBGPGS

The details of technical performance and biomass supplied system were mentioned as above. The concept of community power management would be mentioned in the Figure below.

According to the Provincial Electricity Authority (PEA), a connection to community grid is feasible. Further investigations in the form of a load flow study have to be undertaken in co-operation with PEA. In addition, PEA may support local administration organization in the procedure of acquiring the rights of way. The model in Figure 31 shows the community power management of community.

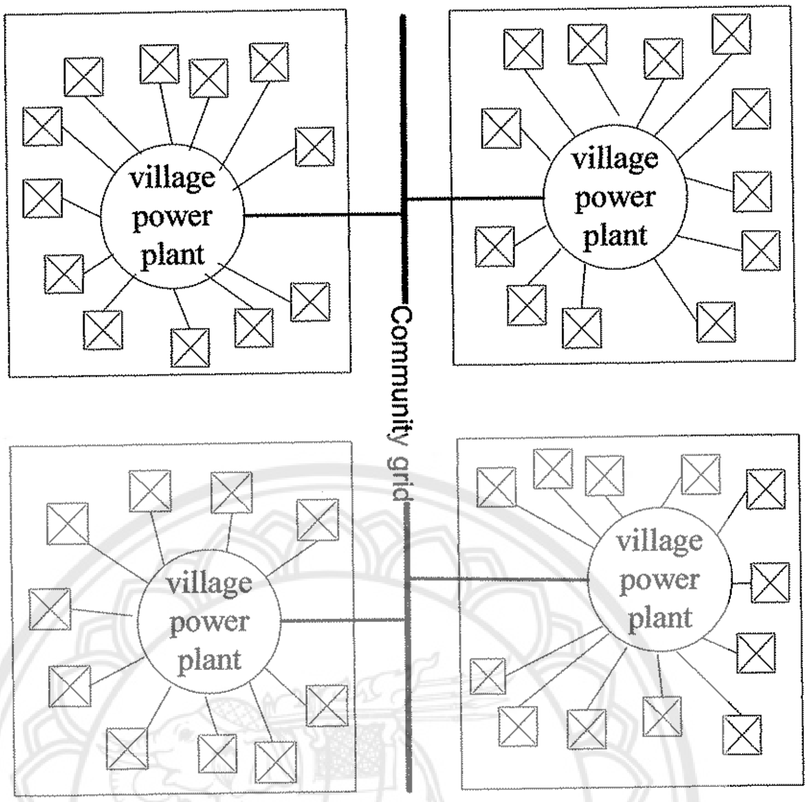

Figure 31 The model of decentralized power generation system for community

The management model of SBGPGS would present all important sub-models as in Figure 32 below. Management model was supported by the most appropriate alternatives for SBGPGS and based on basic science. This model will offer the best advantages, if inputs are accurate.

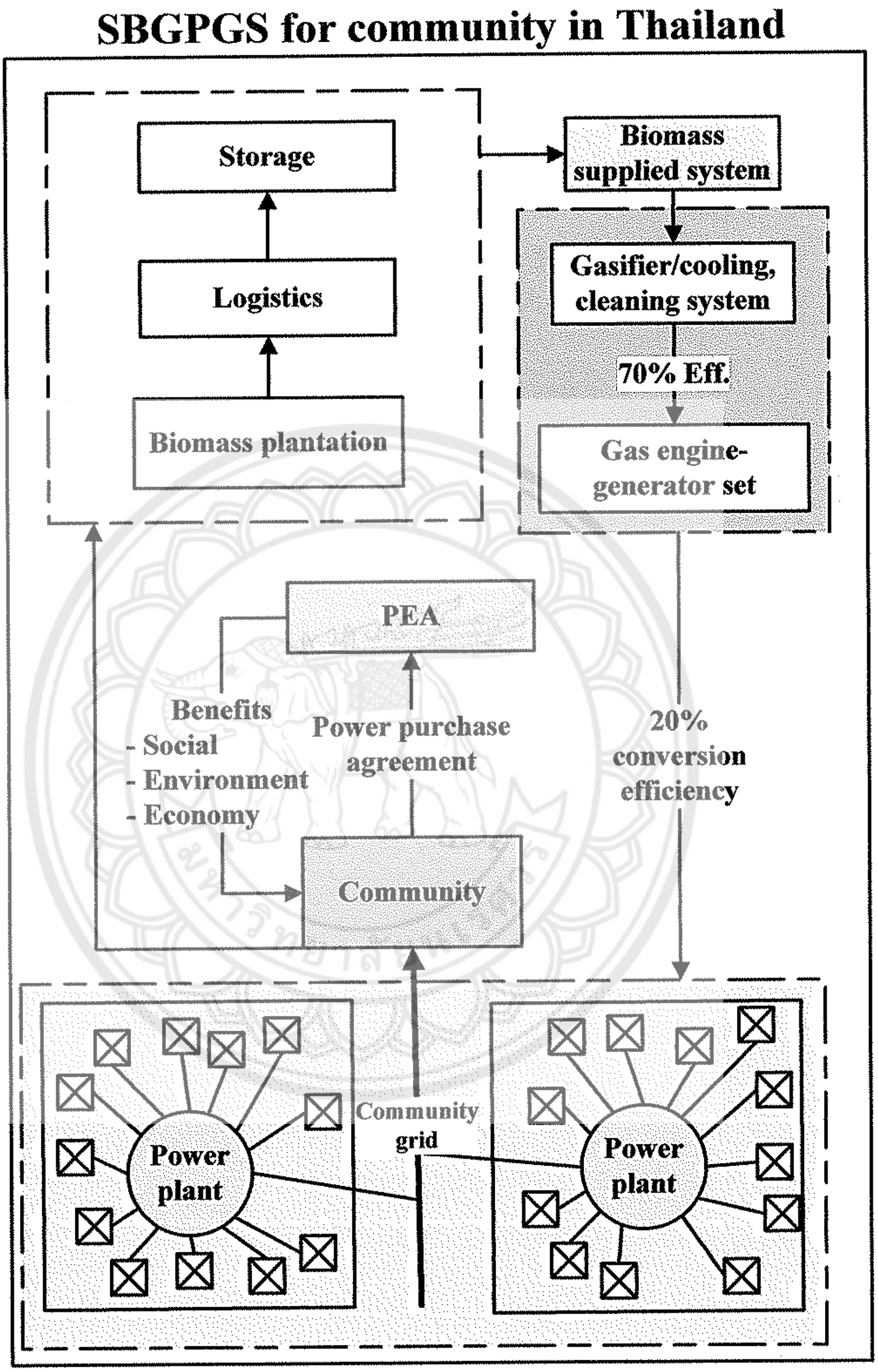

Figure 32 Management model of SBGPGS for community in Thailand