CHAPTER 3

COMMUNITY-SCALED ELECTRICITY GENERATION FROM PLANTATION OF FAST-GROWING WOOD

3.1 Background Remarks

The previous and current Thailand energy master plan has cascades their policies and strategies, mostly in top-down fashion. However, the implementation has faced difficulties, suffered from ineffectiveness, and required resolutions. It is an objective of this investigation to propose one of possible resolutions to be deployed in small area as the village. This work will show the feasibility to generate electricity for the small-scaled community as decentralized unit to promote local sustainability. Cost analysis and life cycle assessment of biomass-powered systems will be suggested in such as way those community members can benefit from this work as well as the policy makers to steer the national directions.

The Royal Thai government sets a long-term target to increase the renewable energy utilization from 6.4% in 2008 to 20% within 2022. The mid-term plan from 2012 to 2016 also focuses on renewable energy for community. The power consumption in the community level is not so large. KhamBoonruang et al. (2006) suggest that rural and an agriculture community is normally small and consumes energy in a low level. ERDI (2012) reports that the energy usage in most of the communities are in the form of diesel and electricity, respectively. Local energy planning, i.e. demand side management, the appropriate energy resource selection, and also the community empowerment are the key success as such the Ministry of Energy has established the Local Energy Planning Center (LEPC) in 2011. It could be hinted that the community energy planning in Thailand is en route but is still forming. Aside from increasing the community awareness in renewable energy, LEPC also promotes all renewable energy's potential in communities including municipal solid waste (MSW), biodiesel, biogas, solar energy, wind energy, etc. All sources can be converted into modernized electricity to be used in variety of possibilities for households, businesses, governmental infrastructures. Unlike some alternative power sources, electricity can be stored, directly used, or even sold to the national or regional grid which will give financial advantage to the community. However, Thailand has not generated sufficient amount of required electricity as 159,518 GWh is partially imported from other countries. To minimize this risk, it is interesting to promote the independence of imported energy in the agriculture and small-scaled communities which are the derivative units of Thai society. There are several factors indicating that small-scaled agriculture community has so many potentials to be independence in terms of energy sufficiency. Most of them are in agricultural areas country where a huge amount of agricultural products are produced and yields relatively large amount by-products and residues. Some agricultural residue shows high potential to generate energy, especially in a form of electricity. Nevertheless, raw agriculture materials strongly are seasonal and sensitive to market value which contradicts to the idea of the establishment of sustainable energy/electricity generation in community unless the community can secure the feedstock. It is important to arrange the consistent amount of input material at all time especially when the electricity is aimed to be sold back to the grid or when carbon credit earning is anticipated. Feedstock has to be carefully selected and it should be deliver high heating value. Cellulose biomass is full of potential. There has been investigations exploring the use of this biomass ranging from the direct burning, hence, giving out heat, and fuel transformation such as bioethanol and biodiesel. However, to utilize it for the community benefit, one of the effective approaches is to produce community electricity from the biomass which can be retrieved from the community activities itself. There are a number of previous work that shown the technical feasibility to convert community biomass into electricity. Demirbas (2005) suggests the use of direct combustion in steam boiler to generate heat to be use in electricity production. There has been report of the electricity production from biomass from the work of Viriyabancha et al. (2007), Kopetz (2007), Arjharn et al. (2009), Basu (2010), and Saidura et al. (2011). Additionally there has been suggestion that fast-growing wood might be one of the effective biomass source to produce the electricity for the community from the work of Jayasinghe et al. (2006) and Dwivedi et al. (2008).

The main objective of this research is to explore the potential of community electricity generation from plantation of fast-growing trees. In addition, cost effectiveness of the whole system and the environmental impacts will be suggested.

3.2 Operation setup, assumption and suggestion

To optimize the benefit to the community and to make the project sustainable, the power plant should be owned by the community and well managed. This will be possible for the local government which should be in its strength with excellent leaderships. Dwivedi et al. (2008) suggest the benefit of having the facility owned by the community itself. The foremost important task is wood cultivation and harvest which should be done systematically and the local people should participate (Jayasinghe et al., 2006). The power plant should be supported by the community budget or funding (at least partial if not full) as the project owned by the community.

From this point on, this work will be carried out by making assumption that the power plant and all its activities are led, owned, and managed by the local community, fuel feedstock is assumed to be grown in the community and can generate the income back to the community. Plantation of fuel wood should be in rotation and well managed.

Figure 3.1 shows main key operations in community power plant which consists of four managerial aspects; (1) management of fast-growing woods plantation, including plant selection and plantation management including cultivation and postharvest processes (2) logistic of woody supply from plantation site to the power plant. (3) form reduction of raw material which helps to increase energy density of woody fuel and (4) electricity generation by conventional technology, i.e. gasification system and steam engine system.

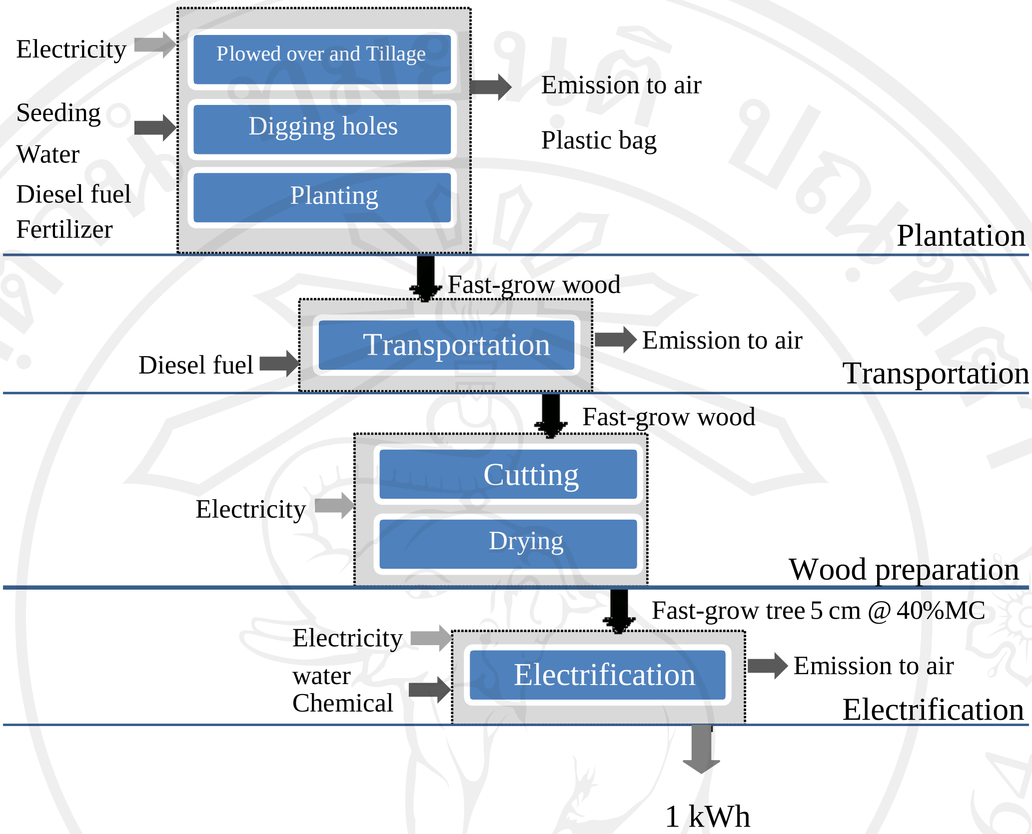

Figure 3.1 Operation of community–scaled electricity power plant

The details key operations are described in the followings:

3.2.1 Wood Plantation

a) Wood selection

Species selection is significant as growth rate of the crop should be fast and resistive, however, it should not pose too complicated environment penalties (Tudsri et al., 2007).

Thailand climate can accommodate many kinds of fast-growing plants such as *Eucalyptus camaldulensis* Dehm, *Acacia mangium* Willd, *Cassia siamea* lam, and *Leucaena Leucocephala* (previously described the details in the section 1.2.1). It is reported that *Eucalyptus camaldulensis* Dehm gives the highest yield per unit area of 192.13 ton/ha when the plot is 1m x 2m. The rate of growth of most fast-growing wood will be slower after 3 years and the size is suitable for relevant processing (chipping, drying, etc.). The LHV is approximately 15.72 MJ/kg (Rubsombut, 2012). *Eucalyptus camaldulensis*

Dehm has been used for various purposes, for instance in construction of building or raw material in paper and pulp industries. With high value in those industries, it is skeptical to be used to electrical power generation. For pulp and paper industry, the raw material pricing is about 500 – 1,070 baht/ton depending on the size of trees (Forestry Industrial Organization, 2012). Unless its value diminishes, it might rather have primary value in those industries than the alternate energy utilization.

Leucaena Leucocephala gives the secondary highest yield and it has less economic value, not in the same level as *Eucalyptus camaldulensis* Dehm. It might be used in construction sites and not preferable, in comparison with *Eucalyptus camaldulensis* Dehm. While its LHV is reported to be 14.93 MJ/kg (KAPI, 2007), The *Leucaena Leucocephala* could yield 99 ton/ha (15.84 tons/rai) within 3 years. It is reported If the *Leucaena Leucocephala* is grown in the spacing area of 2x2 and 1x1 meters, bark volume at 5% and 10% of wood can also be collected. Its tops and leaves of this plant could be used for farm animals. Unlike *Eucalyptus camaldulensis* Dehm, *Leucaena Leucocephala* has rhizobium fungi at the peanut root knot which, in turn, can help to embed nitrogen back into soil. As nitrogen is the important nutrient to help plants grow fast, planting *Leucaena Leucocephala* can restore the soil condition which is important for the next rotation.

When compared to other possible fast-growing species, others offer less yields and either have less lateral benefit or too much economic value for other use. This research will base the calculation on *Leucaena Leucocephala's* properties such that yield of appropriate species for Thailand is approximately 87.5 tons/ha (14 ton/rai) on three-year rotation with the spacing area of 2x2 m and with the lower heating value (LHV) of 12.50 MJ/kg.

3.2.2 Plant Rotation

The majority of targeted agricultural communities for energy sufficiency and independency in Thailand are small (~150 households) where their electricity demands are less than 100 kW. In this research, it is suggested that the fast-growing plants are grown as a plantation in rotation. Cultivating and harvesting are designed to complete within three years to maximize its growth rate and size at case for later required processes. Designated plots and their rotations have to be carefully planned such that there will be a continuous feedstock for the electrical generation. Required area can be estimated from properties of the species selected the performance of the power generation system. The proper areas for fast-growing plants plantation are suggested to be (1) the empty land of the people in the communities who participate in the programme where suitable for planting and locate in the fit areas (2) the public areas or the common-pool resources. On financial standpoint, the community or local authority is expected to own the plantation. The quality and quantity of feedstock has to be ensured. As the communities should own the whole project, participation and collaboration are the key and should be used for later profit sharing among community members.

Each of plantation batch should be harvested within 3 years. If operation is annual, there should be at least three batches of plantation and each should be cultivated in consecutive years. At the end of third year of cultivation, the first batch should be ready for harvesting. In each batch if cutting period can be done in every three months, there should be 4 plots such that there will be cutting four times a year. Thus, the plantation area should be divided into 12 plots. Each plot can respond to fuel demand of the power plant continuously in three months. The replanting should be done immediately after cutting for adequate circulation. The fast-growing plant should be planted before the power plant construction is completed. The process of fast-growing cultivating is shown in Figure 3.2.

From the interview of the local market, the cost for prepare the sprout or young plant is around cost 2 baht/plant. Estimation shows that only 85% of these young plants will survive after planting (Viriyabuncha et al., 2007). Soil condition has to be prepared either by man or machine but, in this work, machine will be preferable because of the vast area of plantation. The cost of mechanization is on hiring basis. Plant spacing is designated to be around 2 x 2 meters in this work. Raining season is proper for fast-growing plantation because of suitable amount of moisture in soil. Table 3.1 shows the fuel consumption rate of agriculture machinery and Table 3.2 shows the emission factor of diesel engine tractor which used in the plantation.

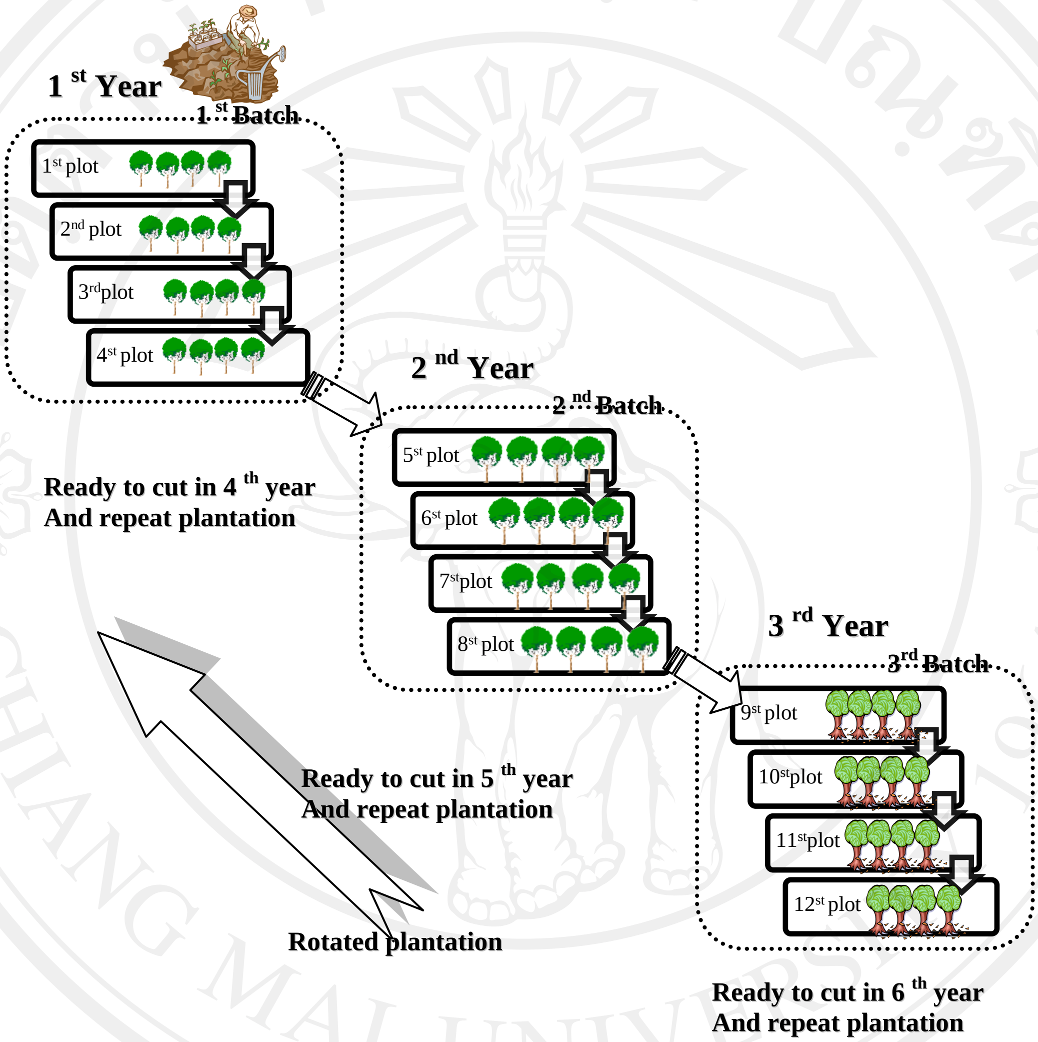

Figure 3.2 The rotation-cultivation planning of fast-growing tree.

Fertilizer should be given to enrich the soil two times in the first year. The first time is in the first or second month depending on the original soil condition. Most of the time, the suitable fertilizer formula might be N-K-P/15-15-15 for 60 grams per plant (Tanasombat and Haruthaithanasan, 2007). The next fertilizing time is within 5 to 6 month after the first condition and the amount should be doubled. In the second year, fertilizer is given before and after the rainy season with 100-150 grams per plant. In the next year, the fast-growing plants need no fertilizer because they should be able to depend on the already-enriched soil. However, after two years, the weed around the fast-growing plant should be eliminated and contained. Cutting and collecting should be priced as the cost of operations; however, it is suggested that it should be done by community members.

The cost of plantation (C_P) is calculated from

$$C_P = C_s + C_L + C_W + C_{FP} + C_{FL} + C_{WC} + C_{CL} \quad (3.1)$$

where
C_s = Seedling cost (baht)
C_{LP} = Labors for planting cost (baht)
C_W = Watering cost (baht)
C_{FP} = field plugging cost (baht)
C_{FL} = Fertilizer cost (baht)
C_{WC} = Weed control cost (baht)
C_{CL} = Cutting and landing cost (baht)

Table 3.1 Fuel consumption rate of agriculture machinery

Machinery	fuel Type	Consumption rate	
Tractor	Diesel	4.64 liter/rai	29.00 liter/ha
11.5 hp automotive wheel plow	Diesel	1.02 liter/rai	6.38 liter/ha

Table 3.2 Emission factor of diesel engine tractor

Emission category	Emission factor
Carbon dioxide (CO_2) (kg/liter$_{diesel}$)	2.7
Carbon monoxide (CO_2) (g/liter$_{diesel}$)	18.57
Methane (CH_4) (g/liter$_{diesel}$)	0.36
Nitrogen oxides (NO_x) (g/liter$_{diesel}$)	36.78
Nitrous oxide (N_2O) (g/liter$_{diesel}$)	0.07
Non-methane volatile organic compound (NMVOC) (g/liter $_{diesel}$)	6.56

3.2.3 Transport Logistics

In this research, it is assumed that the area of plantation is clustered around the power plant in the radius within 20 km. Raw materials are transported by the light truck, which is available and quite popular in Thailand, from the plantation site to the power plant. Figure 3.3 typical shows the diesel light truck with 11-ton capacity. Later analysis will depend on the community's labor force for the loading up and down. Normal wage for the labor is approximately 937.5 baht per hectare (150 baht per rai). The tree could be cut in a length of 6 m. and taken to the truck. The fuel consumption of light truck with no load and full load is 0.1775 liter of diesel/ kilometer and 0.2272 liter of diesel/ton of load/kilometer, respectively (MTEC, 2010). Fuel consumption of the truck causes environmental pollution along the way and it can be shown in Table 3.3. These data is later used to evaluate the environmental impacts and the cost of damage.

Figure 3.3 The light truck which is available and quite popular in Thailand

The cost of fuel Logistics (C_L) is calculated from

$$C_L = C_F + C_{LG} + C_T \tag{3.2}$$

where C_{FG} = Fuel cost (bath)

C_{LG} = Labors cost (bath)

C_{TG} = Truck cost (bath)

Table 3.3 Inventory of Vehicles "Big sized six wheels truck" with 11 tons full load under the normal working condition.

Descriptions	Loading pattern			
	No load	50% of Loading weight	75% of Loading weight	Full load
Power (Inputs)				
- Diesel : liter [(2)]	0.1775	0.2005	0.2134	0.2272
Emission to Air				
- Carbon dioxide (CO_2): gram	434.1464	490.5220	521.9946	555.8302
- Carbon monoxide (CO): gram	0.9132	1.0318	1.0980	1.1692
- Nitrogen oxides (NO_x): gram	1.7484	1.9755	2.1022	2.2385
- Particulate matter (PM): gram	0.0904	0.1022	0.1087	0.1158
- Hydrocarbons (HC): gram	0.2110	0.2384	0.2537	0.2702
- Methane (CH_4): gram	0.0051	0.0057	0.0061	0.0065
- Benzene (C_2H_6): gram	0.0040	0.0045	0.0048	0.0051
- Toluene (C_7H_8): gram	0.0017	0.0019	0.0020	0.0022
- Xylene (C_8H_{10}): gram	0.0017	0.0019	0.0020	0.0022
- Non – methane volatile organic compounds (NMVOCs) : gram	0.6981	0.7887	0.8393	0.8937
- Sulfur oxides (SO_x): gram	0.1006	0.1137	0.1210	0.1288
- Nitrous Oxide (N_2O): gram	0.0181	0.0205	0.0218	0.0232
- Cadmium: gram	1.44E-06	1.62E-06	1.73E-06	1.84E-06
- Copper: gram	2.44E-04	2.76E-04	2.94E-04	3.13E-04
- Chromium : gram	7.19E-06	8.12E-06	8.64E-06	9.20E-06
- Nickel : gram	1.01E-05	1.14E-05	1.21E-05	1.29E-05
- Selenium : gram	1.44E-06	1.62E-06	1.73E-06	1.84E-06
- Zinc: gram	1.44E-04	1.62E-04	1.73E-04	1.84E-04
- Lead: gram	1.58E-08	1.79E-08	1.90E-08	2.02E-08
- Mercury : gram	2.88E-09	3.25E-09	3.46E-09	3.68E-09

Note: (1) Normal working condition was transportation on normal way like highway outside of the town with the speed of 60 – 90 kilometer per hour and with stoppage or delay less than 40 % of the total transportation way.

(2) The quality of the diesel fuel was as the standard of the declaration of The Department of Energy Business issue 2 B.E. 2550 and issue 3 B.E. 2551, and the standard of SAEJ-313C.

Source: MTEC (2010)

3.2.4 Material Preparation

Material preparation are divided into two parts i.e. size reduction and drying. Size of fast-growing wood should be reduced to increase its energy density (more detail energy density see Table 1.2) and fitted to the energy conversion equipment such as combustion chamber or gasifier reactor. The heating value of the fuel should also be maximized by reducing the moisture of the wood fuel. These processes should be centralized and close to the vicinity of the power plant. The responsibility should also lay open the community members for the benefit of the community.

A) Size reduction

There are chipping machine available in the market with variety of price and cost. However, in this work, the later analysis will base on the chipping machine developed by University of Suranaree Technology (Khompis et al., 2009) as it is domestic, made for the use of small power plant, and easy to operate by local community. The designed chipping capacity is three tons of wood per hour. Figure 3.4 shows the machine drawing which has four chopping blades of 830 x 1450 x 1150 mm. There is 800 mm chop dish with electric motors of 22 kW, rotating with the speed of 900 RPM. The timber with 5-cm diameter should be chopped down to the length of 15 cm before being fed into the machine and being shredded. Costs of energy and labor are tabulated in Table 3.4 depending on the size of timber.

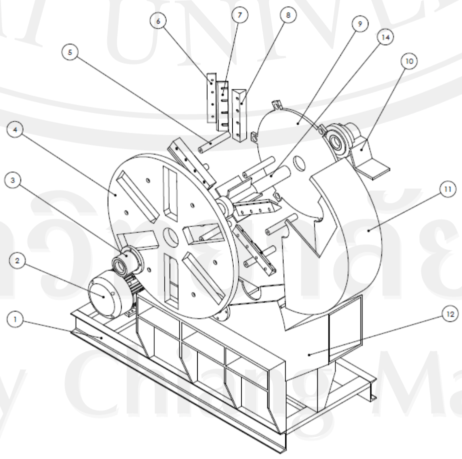

Figure 3.4 The drawing of shredder with rotating dish
(Source: Khompis et al., 2009).

B) Wood Drying

Moisture affects heating value of the fuel wood. The moisture of the newly cutting wood is approximately 60% MC. The suitable moisture content for energy conversion should be between 15-40% MC (Senelwa and Ralph, 1999) to achieve the heating values in a range of 12 – 16 MJ/kg (Singh and Torgy,1994, Kuntong et al., 2002, Viriyabancha et al., 2007, Sukkasem et al., 1994). Being in tropical climate where the ambient is warm and dried, woodchips can be left to be dried by the solar radiation; hence, it helps to save some cost. However, this can be done during summer only. Drying chambers should be used during autumn or as auxiliary. There are various kind of driers such as rotary type, flash type, disk type, and cascade type. Table 3.5 shows the comparison among the dryer types. It is found that the rotary dryer is suitable for biomass fuel drying because of its low cost and it could use multiple forms of heat source, i.e. hot gas or steam. Later analyses will refer to the 3-ton of rotary dryer of Suranaree University of Technology (Khompis et al., 2009). Waste heat is used to warm the air up to 120 -130 °C. The dryer could also be utilized for other agricultural products in the area, such as longan, and tobacco during the harvesting season as well; hence, generating extra income to the community.

The cost of wood preparation (C_{PR}) is estimated from equation:

$$C_{PR} = C_{RS} + C_{RM} \tag{3.3}$$

where C_{RS} = Reducing size cost (bath)

C_{RM} = Reducing moisture cost (bath)

Table 3.4 Comparison of capital of chopping in different size of the *Leucaena Leucocephala.*

Material	Capital of chopping (Baht per ton)						
	Cost of reducing machine	Maintenance of blade sharpening	Power to chop		Labor	Total	
			Electricity	Diesel		Using electricity	Using Diesel
Leucaena Leucocephala							
D x L = 2.5 x 150 cm^2	81	12.2	39	85	33.5	166	212
D x L = 2.5 x 220 cm^2	72	10.9	34	76	29.9	147	189
D x L = 6 x 150 cm^2	58	8.8	36	61	24.1	127	152
D x L = 6 x 350 cm^2	55	8.2	35	57	22.7	120	143

(Source: Khompis et al., 2009)

3.2.5 Electricification

Technologies for generating electricity should not be too complex for the local community. Downdraft gasifier and rankine steam power are simple and viable options available in the local market.

Table 3.5 Comparison of advantages and disadvantages of the dryer.

Type of dryer	Need small materials	Need materials approximately the same size	Expediency to reuse the heat	Risk of spark	Steam use	Costs
Rotary Dryer	No	No	Difficult	High	Usable	Low
Flash Dryer	No	No	Difficult	Medium	Unusable	Medium
Disk Dryer	No	No	Easy	Low	Usable	High
Cascade Dryer	No	No	Difficult	Medium	Unusable	High
Superheated Steam Dryer	No	No	Easy	Low	steam	High

Source: Wade (1998)

This research refers to the performance of a 50 kW rankine steam system constructed and installed at Chiang Mai University (Sri Buaban Campus) and also the 100 kW downdraft gasifier installed at Suranaree

Technology University both of which are designated for community use. The detail of the biomass gasification system is shown in Table 3.6. The total efficiency and the fuel wood consumption are reported to be 17.7 % and 1.98 kg/kWh, respectively. In case of the steam power system, it consumes fuel wood at 4.78 kg/kWh while the efficiency of the steam power system at 7.2 % as detail show in Table 3.7. Later analyses will pose several fair assumptions. Annual working hour is 80% or 7,008 hours per year as void duration will be spent on checking maintenance. Lifetime of both systems is expected to be 30 years.

The cost of electricification (C_{EF}) is estimated from equation:

$$C_{EF} = C_{PS} + C_{CG} + C_{EL} + C_{PC} + C_{PS} \tag{3.4}$$

where C_{PS} = Power generation system cost (bath)
C_{CG} = Connection grid-line system cost (bath)
C_{EL} = Labors cost (bath)
C_{PC} = production cost (bath)
C_{PS} = Sale management cost (baht)

3.3 Assumptions on Economical Analysis

Size of power plant strongly depends on not only electricity demand but also raw material fuel available in the community. From previous literature, the community biomass power plant uses either gasification system and steam power system with a capacity of 100-1,000 kW (Basu, 2010). The economical analysis conditions are based on both systems in 3.2.5 which were designated to be used in small community with the capacity not exceeding 100kW. The fuel selection is aligned with what is described in the section 3.1.1 from which the simple analysis shows the fast-growing plantation can produce 87.5 ton of wood/ha (14 ton/rai) within 3-year rotation period. The fuel consumption rate per year could be well calculated from the system capacity, system characteristics, for example, system efficiency, and operation hours, etc. Then the area requirement for plantation could then be calculated from percentage yield per year and the fuel consumption rate per year, above. As 3-year plantation is required under previous assumption, the area of plantation is triple of what is really needed annually. The life cycle cost of power generation is evaluated by the life cycle phases, including plantation which consists of costs of field plugging, seeding, fertilization, plantation labor, watering, herbicides, weed control, cutting, loading, all logistics, and electrification system. Table 3.8 shows the detail of corresponding cost analysis.

Table 3.6 Biomass Gasification Power Plant Equipments

Biomass Gasification Equipment		Biomass Fuel Pretreatment System	
1	Biomass Fuel Hopper	22	Biomass Fuel Crusher Unit
2	Screw Feeder Unit	23	Biomass Fuel Dryer Unit
3	Biomass Gasifying furnace	24	Pretreatment System Conveyor Unit
4	Dry-Type Cyclone	Biomass Waste Heat System	
5	Wet-Type Spray Scrubber	25	Waste Heat Boiler for Engine
6	Wet-Type Dust Catcher	26	Water Treatment System for Boiler
7	Alkali Water Washer G/W Separator	27	Layout service charge
8	Biomass Tar Filter	28	Pipe Between Waste System
9	Wet-type Pressure Adjustable Gas Tank	29	Conveying Pipe of Steam
10	Safety Water Seal for Over-Pressure	30	Gas Fuel Generator Set
11	Surplus Gas Burner	31	Water Cooling Pond
12	Ash Conveyer System by Water		
13	Cooling Settling Treatment Unit		
14	Gas Pipe And Accessory		
15	Water Pipe And Accessory		
16	Force Fan Unit		
17	Vacuum Blower Unit		
18	Feed Water Pump Unit		
19	Circulation Return Water Pump Unit		
20	Gasification Control Desk		
21	Material for Installing Gasification System		

Table 3.7 Performances of Gasifier Technology Power Generation

Power capacity (kW)	**100**	**50**
Technology	Downdraft	Rankine
Fuel Type	Wood	Wood
Ratio Fuel/power (kg/kWh)	2.27	4.78
Efficiency system	11.34	7.20%
Data reference	Center of Excellence in Biomass, SUT	Department of Mechanical Engineering, Chiang Mai University

The power plant in the first year invested heavily on all equipments and machineries including the power plant building, technology for power generation, trucks and grid-line connection system. The initial costs are showed in Table 3.9. After the total expenditure calculation, each cost item is converted to present value. Unit cost of electricity generation could be calculated for total cost per summation of electricity which is based on the following conditions:

- 100 kWe Downdraft gasifier and 50 kWe rankine steam power are installed at the community-owned power plant.
- The biomass fuel power plant with a capacity of less than 100 kW has the plant factor of 0.8 or approximately 7,008 hours per year, excluding the annual time for checking and maintenance.
- The generated electricity is sold to the Provincial Electricity Authority of Thailand. Estimated benefit from selling the electricity is 3.82 Bath/kWhr. It is calculated from the regulation issued by the Electricity Generating Authority of Thailand, (EGAT) which gives incentives in a form of adder (see Table 2.4). Buying price is derived as follows;

Table 3.8 Costs of each phase of power plant.

Phase	Item	Cost	Unit	Out put
Plantation	Seedling price	2	Baht/plant	Log of Fast -grow tree @ 60%MC
	Labors for planting	1,250	Baht/ha (200 Baht/rai)	
	watering	1,250	Baht/ha (200 Baht/rai)	
	field plugging	800-850	Baht/ha (800-850 Baht/rai)	
	Fertilizer (15-15-15)	690	Baht/ 50 kg	
	Weed control	937.5	Baht/ha (150 baht/rai)	
	Cutting and landing	937.5	Baht/ha (150 baht/rai)	
Transport	fuel	29.83	Baht/Liter	Log of Fast -grow tree @ 60%MC
	Labors cost for driver	237	Bath/Day	
	Truck	1,600,000	Baht	
Wood preparation	Reducing size	120	Baht/Ton	Fast -grow wood of 5 cm. x 15 cm. @15%MC
	Reducing moisture	73.67	Baht/Ton	
Electrification	Power generation system Connection grid-line system Labors cost Cost of production management Cost of sale management	see Table 3.9 Initial cost expense for equipment of electricity each system		Electricity (kWh)

Buying price (Baht/kWh) = Electricity energy price(Baht/kWh) + FT (Baht/kWh) + Adder (Baht/kWh)

Where;

Average electricity energy price = 3.02 Baht/kWh

FT = 0.30 Baht/kWh (reference data in July, 2012)

Adder = 0.5 Baht/kWh (see Table 2.4 in case biomass power plant capacity <= 1 MW)

Table 3.9 Initial costs of equipment for electricity generation system.

Equipment	Capacity	Cost of Unit (baht)
Steam generation system	1,000 kg/hr, 22 bar g,	2,800,000
Turbine generation system	45±5% kW out power, 0.278 kg_{steam}/s	170,000
Gasification system	100 kW out power	6,500,000
Connection Gird-line equipment		700,000

3.3.1 Assumptions on capital costs of the power plant system installation

The investment costs of the community power plant depend on the methodology and technology which is chosen by the community. The details are shown in Table 3.8 For example, the investment cost for plantation of fuel wood would be spent for seedling, labor for planting the tree, land preparation, fertilizer, weed control, cutting and transportations. Technology investment is costly and the cost also depend on the selected technology, for example the steam generation system cost is approximately 2,800,000 Baht. For other technologies, the details are shown in Table 3.9. Therefore the economic determination could be considered from the following scenarios;

- Interest rate and inflation rate 8.7%
- Escalation rates of electricity sell price 5%
- annual routine maintenance cost 5% of capital
- Escalation rates of maintenance cost 3%
- The fuel supply distance within 20 km of radius.

- Diesel fuel cost — 29.83 baht/liter (July,2012)
- Escalation rates of fuel cost — 5%
- Escalation rates of carbon credit cost — 2.5%
- Reservations of fuel for production of 30 days
- Electricity cost (for machinery and systems) — 3.32 baht/kWh
- Salvage of the system — 10% of capital cost
- Economic life time of the system is 30 years and the life time of each replacement component is shown in Appendix A

3.3.2 Assumptions on electricity generation costing

The expenses for electricity generated processes mainly consist of initial costs of system installation, grid connection or electricity distribution system, including costs of project management. These costs depend on many relevant factors all of which is listed as the followings:

- **Labor Costs**

A community scale biomass power plant requires around 7 employees working in 3 shifts, 8 working hours each, excluding fuel prepared time. They could operate the power plant in a range of 120-500 kW with based salary of 48,000 Baht/month or approximately 576,000 Baht/year. Table 3.10 shows the details of labor cost consideration.

Table 3.10 Labor cost consideration

Position	Duty /Qualification	Monthly Salary (Baht)
1. Engineer or Technician (1)	- Operate, Control the System	12,000
2. General laborers (6)	- Assistance in running the plant system	6,000

- **Power Plant Operating Costs**

Costs of the power plant operation results from operation of the electricity generating system which consist of some indirect expenses such as utility and facility costs (i.e. electricity and water consumption), and other material costs (i.e. chemicals, lubricants, filters, etc.). The cost content is approximated to be 5% of the total cost of the power plant. Examples of indirect expenses of the 100kW gasification power plant is shown in Table 3.11 which is reported about 5% as expected.

Table 3.11 Power plant operating costs of the gasification system.

Position	Duty / Qualification	cost (baht)	Monthly Salary (baht)
1.Indirect cost (laborers)	Quality control and maintenance	30,000.00	0.3%
2. Electricity	Operating 7,008 hrs. ×18 kW × 3.32 baht/kWh	399,876.48	4.0%
3. Water	Operating 7,008 hrs × 10 m^3/300 hrs × rate of 20 baht/m^3	5,840.00	0.1%
4. Catalytic substance	Operating 7,008 hrs. × rating 1 L/24 hrs. × 40 baht/L	11,680.00	0.1%
5. Filter bags	Operating 7,008 hrs. × 8 bags/ 200 hrs. × price @ 200 baht/bag	56,064.00	0.6%
6. Lubrication	Operating 7,008 hrs. × 50 L/ 1,000 hrs. × price @ 100 baht/L	35,040.00	0.4%
	TOTAL	558,500.48	5.4%

(Source: Khompis et al., 2009)

- **Related Project Management Costs**

This expense relates to managerial activities such as salary, welfare, personnel travel and also activity to interact with the community. It is approximated to be 3% of the total profit from the total cost of electricity sale. The main management cost is employee salary which is set to increase 1% every year and a welfare cost of 0.5% of the salary. The detail is shown in Table 3.12

To calculated for unit cost of electricity generated from wood fuel, above-mentioned costs are combined throughout the power plant life cycle as seen in Eq. 2.8. Main profit of the power plant is from electricity sold to the government-owned national grid where regulated “adder” incentives are applied

Table 3.12 The Marketing Management Costs.

Description	% of total marketing cost
Utility cost	1
Consumables material	0.12
Repair and replacement parts	1
Transportation & Travel	0.3
Others	0.5
Total	2.92

(Source: Khompis et al., 2009)

3.4 Results in life cycle cost

The feasibility of community-scaled biomass power plant is evaluated in terms of life cycle cost when all conditions and assumption previously described are applied along with all principles and designed processes from section 2.3 and section 3.3. It can be described by equation (3.5). The cost calculation is adjusted from the referenced values to present value. The detail of the results is shown in the followings:

Life cycle cost (LCC) = Fixed cost + Operation cost (3.5)

= (Seedling cost (C_s) + field plugging cost (C_{FP}) +Truck cost (C_{TG}) + Power generation system cost) + (Labors for planting cost (C_{LP}) + watering cost (C_W)+ Fertilizer cost (C_{FL}) +Weed control cost (C_{WC}) +Cutting and landing cost (C_{CL})]+ [Fuel cost of logistic (C_{FG})+Labors cost of logistic (C_{LG})] +[Reducing size cost (C_{RS})+Reducing moisture cost (C_{RM})]+ [Labors cost of electrification (C_{EL})+ production cost of electrification (C_{PC})+ Sale management cost (C_{PS})])

3.4.1 Phase Cost

Unit cost of generated electricity of each phase are shown in Table 3.13. It is shown that cost of the plantation phase and transportation are at 237.48 and 204.12 Baht/ton, respectively which bring to the total of 441.60 Baht/ton. For the sake of comparison, wood timber is sold in the market with the cost of 600-1,250 Baht/ton (EforE, 2012). It is therefore imperative that the community-owned power plant should operate its own wood plantation to ensure the feedstock and control the relevant expenses. Cost of wood preparation is 213.57 Baht/ton resulting from size and moisture reduction which results from the use of relatively small dryer and solar drying in the open field during summer. At present, woodchip available in the market is sold about 1,180 Baht/ton (EforE, 2012). Cost of producing woodchip from community-owned power plant is 44.48% lower than that traded in the market. This emphasizes that the community should invest in its own plantation. All activities should be well planned and restricted. Furthermore, if there are some excess wood, this can be extra revenue for the power plant. Thus, investment of fast-growing wood plantation could be an alternative way for the income of the farmer and the community in overall.

Costs of electricity generation from system's fixed and operational costs are 2.62 Baht/kWh and 2.55 Baht/kWh for the Rankine technology steam power and downdraft gasification, respectively. These costs seem to be very close although their efficiencies are different. This results from the fact that the fixed and operation costs are close.

Table 3.13 Comparison of Electricity Generation Costs.

Process	Rankine steam power	Downdraft gasification	Unit
Plantation phase	237.48	237.48	Baht/ton of fast-growing woods
Transportation phase	204.12	204.12	Baht/ton of fast-growing woods
Preparation phase	213.57	213.57	Baht/ton of fast-growing woods
Electrification phase	2.62	2.55	Baht/kWh

3.4.2. Unit Costs of the Rankine steam system

In case of using 50 kW Rankine steam system as a community electricity generation system, it needs 57.43 ha (358.91 rai) for wood plantation. Installation (Fixed) costs and operation at the first year would be approximately 6.9 Million Baht.

Table 3.14 and Figure 3.5 summarize the LCC results of the system. It is found that cost throughout the life cycle of Rankine steam system is 5.78 Baht/kWh which is higher than the selling rate issued by EGAT. The cost of electrification phase shows the highest value of 35.10% of the total cost due to the cost of technology. It also result from the fact that the smaller the system is, the smaller efficiency the system will provide. This system requires special small equipment used to produce high pressure steam which causes the high costs. In case of transportation cost, it is 16.04% of the overall cost as the radius of plantation site is in the coverage of 20 km from the power plant station. The cost of fuel preparation phase is represented as 17.66% of the overall cost. It is noted that it is very close to the cost of transportation phase, due to technology and labor costs. Cost of plantation phase is ranked the second at 31.21% due to fixed costs on seeding embryo, fertilizers, etc.

The 50 kW rankine system is thus not feasible as it cannot pay back to the community within its life time unless other source of profit are proposed.

Table 3.14 Breakdown of economic for power plant community during system's lifetime

Capital item	Rankine steam power	Downdraft gasification	Unit
Installed capacity	50	100	kW
Plant net efficiency (%)	7.2	17.72	%
Fuel consumption rates	4.78	2.27	kg/kWh
Plant Factor	80		%
Electricity generation of life cycle	350,400.00	700,800.00	kWh/Y
Spacing	2 x 2		m
Cultivation area	57.43	54.54	ha
	358.91	340.89	rai
Life time of system	30		Years
Fuel wood	1,674.91	1,591	(ton/year)
Process			
Plantation phase	18,964,714.84	18,012,511.59	Baht
Transportation phase	9,745,131.34	7,430,354.13	Baht
Preparation phase	10,731,208.22	10,192,402.79	Baht
Electrification phase	21,330,493.33	52,517,781.25	Baht
Total	60,771,547.73	88,153,049.75	Baht
Electricity breakeven price	**5.78**	**4.19**	**Baht/kWh**
Plantation phase	1.80	0.86	Baht/kWh
Transportation phase	0.93	0.35	Baht/kWh
Preparation phase	1.02	0.48	Baht/kWh
Electrification phase	2.03	2.50	Baht/kWh
Payback period	**Not worth investment**	**17.19**	**Years**
NPV	**Not worth investment**	**-**	**Baht**
IRR	**Not worth investment**	**4.55**	**%**

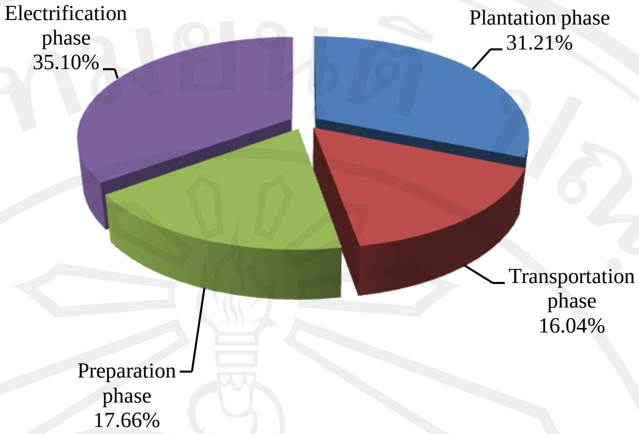

Figure 3.5 Life cycle cost analytical result of the Rankine steam power plant.

3.4.3 Costs of electricity generation of downdraft gasification system

The electricity generation by The 100 kW downdraft gasification with system efficiency of 17.72% consumes 2.27 kg of wood fuel/kWh or, by average, 1,674 ton/year. Plantation requires 54.54 ha (340.89 rai). Investment cost at the first year is 11.96 Million Baht. Figure 3.6 and Table 3.15 show the results of LCC analysis. It is found that cost throughout the life cycle of downdraft gasification system is 4.19 Baht/kWh. The electricity generation phase gives the highest cost of 59.58% of the unit cost due to expenditures for technology installation and operation cost. Similarly, the least cost is transportation cost of 8.43%. Costs of plantation phase and preparation phase are 20.43% and 11.56% respectively. This represents similar trends with those of the rankine system. Total investment cost for the whole project is approximately 88.2 Million Baht.

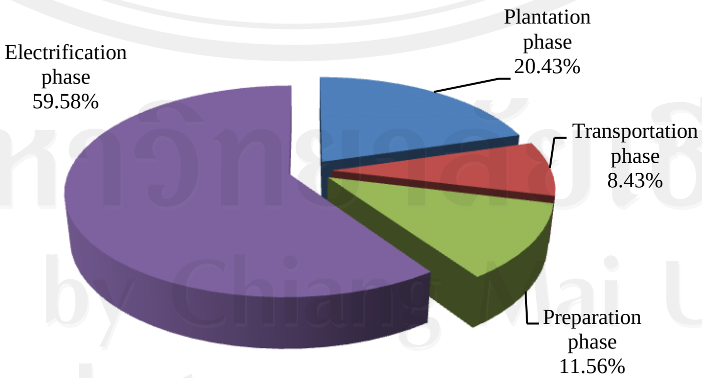

Figure 3.6 Life cycle cost analysis of the downdraft gasification system power plant.

3.4.4 Comparison of Life Cycle Cost

In general, LCC unit cost comparison in Baht per kWh for rankine and downdraft gasification system are analyzed and compared for a small community-scaled power plant. The results are found that the unit cost from 50 kW Rankine system is 5.78 Baht/kWh which is 38.88% higher than that of the Downdraft gasification which is at 4.19 Baht/kWh. The production processes of the both systems are divided in the same fashion into 4 main phases which are plantation phase, transportation phase, preparation phase and electrification phase. Costing ratio of all phases is similar for both systems, i.e. electrification is the highest cost and it is followed by plantation phase, preparation phase and transportation phase respectively. Cost of the Rankine steam technology is more expensive by 2.21 times than that of the Downdraft gasification technology. Furthermore, the Rankine system shows the overall efficiency only 7.2% while the Downdraft system plays the value of 17.72% or 2.4 times higher. This is why the fuel consumption of the downdraft gasification is half of what Rankine has to consume. Thus it leads less cost as shown in Figure 3.7.

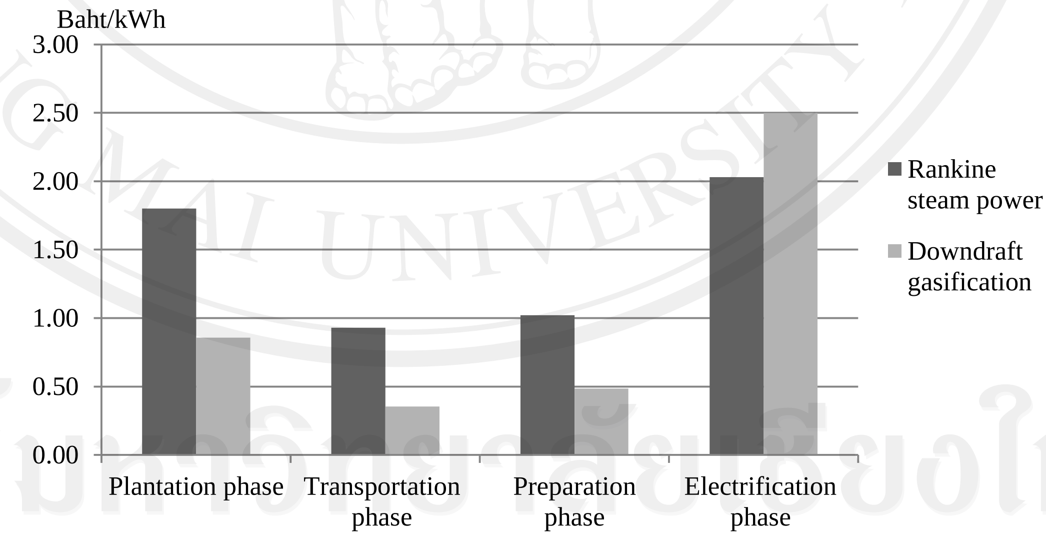

Figure 3.7 Cost analysis of the electricity generation phase.

According to their rated sizes, these two systems are classified as the very-small Power Producer: (VSPP) according to the Provincial Electricity

Authority (PAE); however, due to its small size and small efficiency the results show that both unit costs are still high and higher than price that PAE can afford according to its adder regulation. Figure 3.8 shows the price comparison among the electricity generation technologies

In spite of the fact that the current price of electric power from the grid is at in an average of 3.82 Baht/kWh, this price is very sensitive to the quantity of reserved fossil fuel. Within a few years (decades), price of electricity might be increased according to lower reserve. At that time, the community-scaled power plant might catch national attention as the price might becomes more economical and project might become feasible.

Cost analysis of electrification by Downdraft gasification with a capacity of 100 kW studied by Mahapatra and Dasappa (2012), reveals the value of 2.98 Baht/kWh due to lower system's fixed cost and higher efficiency. The capital (fixed) cost of the afore-mentioned biomass gasification system is reported to be 51,550 – 44,390 Baht/kWh while biomass consumption is reported at 1.4 kg/kWh which is lower than our current 2.27 kg/kWh. Therefore if the current system is replaced by this system, the unit costs will be down to 3.47 Baht/kWh which is lower than the purchasing price designated by the government sector, consistent with the result of Mahapatra and Dasappa (2012). Additional, Cost analysis of electrification by Downdraft gasification with a capacity of 100 kW from fast-growing wood also studied by Dwivedi and Alavalapati 2009, shows the value of 4.58 Baht/kWh ($0.15/kWh), which was greater than the price of electricity supplied from their grid 2.44 baht/kWh ($0.08/kWh) due to scale of operations. It could be found that unit cost electricity analyses are very close and same reason to generate high cost. It is clear that costs of energy from biomass are lower than those of other alternative energy sources, such as photovoltaic. In addition, incomes of the power plant do not come from electricity trade but also from other by-product sale, such as the tops and leaves tree, charcoal, and waste heat recovery which will be presented in the next section.

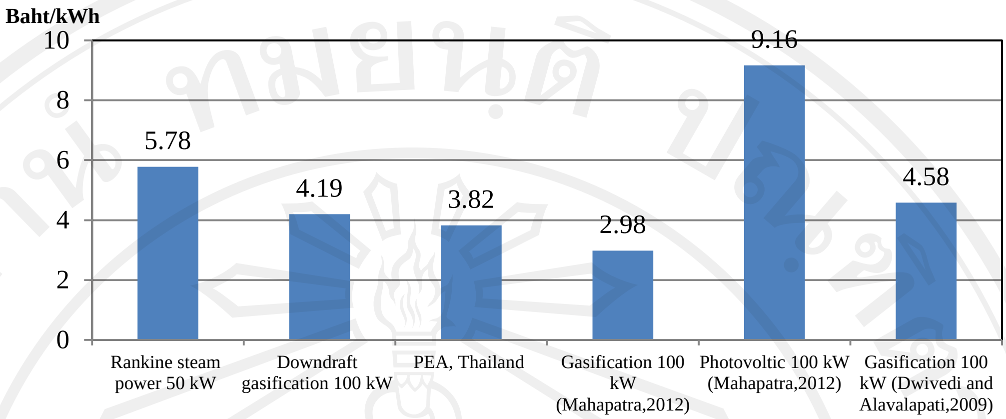

Figure 3.8 LCC comparisons of others alternative technologies.

3.5 Extra benefit from co-products, by products, and process waste

Unit cost of electricity generated from both systems can be reduced from the beneficial products from all production activities. Co-products and waste from power plant is possibly valuable. For example tops and leaves of the fast-growing fuel woods, can be used as parts of animal feed. Waste as charcoal from the gasification reactor could be processed and used for cooking or waste heat from the reactor or condenser can be recovered and make use in drying process of agricultural products, such as longan, tobacco and etc. All these can create more monetary benefit to the powerplant.

3.5.1 Community Power Plant System Improvement.

- **Sale of tops and leaves of the *Leucaena Leucocephala*, as livestock feed**

One of the by-products from this process is tops and leaves of the fast-growing plant which could be used for animal food productions. The productivity of tops and leaves is 425 kg/ha (68 kg/rai) of Leucaena *Leucocephala* plantation area. Tops and leaves of the *Leucaena Leucocephala* contain 24.4% of protein nutrient; therefore, it is suitable for feeding animals such as cattle and duck (Tudsri et al., 2008). The tops and leaves could be used to mix with others ingredients for livestock fed of which its commercial value depends on the detail of modified ingredients. For example, while the price of cost of dried leaves is about 1.9 – 3.5 Baht/kg, its processing cost can be controlled and varied between 1.20 – 3.40 Baht/kg. Cost control can be implemented from labors cost (400 Baht/day for 2-man labored), fuel cost (35 Baht/Liter) and other expenses as shown in Table 3.15 from which it agrees reasonably with Charunroch et al., (2011). For providing 400-500 kg/day dried tops and leaves, these co-products can provide additional benefit of 500-750 baht/day.

Table 3.15 Producing cost of the chopped-dried tops and leaves process.

Items	**Quantity**	**Cost (Baht)**
Cost for labor to tops and leaves (200 Baht/labor/day)	2 labors	400
Fuel oil	2.0-2.5 liter/day	70
Other costs	-	30
Total cost (bath/day)		500-600
Productivity of chopped-dried (kg/day)		400-500
Unit cost of chopped-dried (Baht/kg)		1.25-1.35
The net profit (bath/day)		500-750

Source: Charunroch et al., (2011)

- **Sale of Charcoal or Char Carbons**

While, it should be noted that ash from combustion in rankine system could be used to mix with fertilizer but the beneficial by-product will rest on the gasification system. By-product from the Downdraft gasifier is normally charcoal or char carbons which can be used for cooking purpose. 9.28% Charcoal can be retrieved from the fuel-woods (Khompis et al., 2009). Process of the carbon bar production is shown in Figure 3.9. Firstly, the process starts with collecting charcoal and filter ash before reducing its moisture to 30%. Binders as cassava starch is then added for 4 – 5% (by weight) after which it is compressed in the mold to resume its bar shape until it is completely dried. The corresponding costs are as follows: Fixed cost of mixer and compressing machine is 1,200,000 Baht and annual operational cost is 384,389 Baht. The total production cost for 1000 kg of charcoal bar is

3,732 baht as the detail shown in Table 3.16 while the market price of the charcoal bar is 12 Baht/kg.

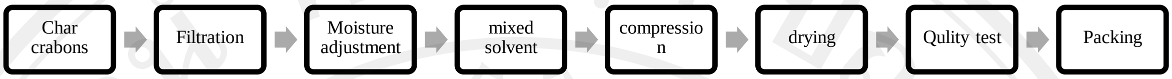

Figure 3.9 Process of carbon bar production.

Table 3.16 Production costs of carbon bar 1,000 kg

Cost	amount	Unit	unit cost	Unit	Total(Baht)
cassava starch	50	kg	12	Baht/kg	600
Electricity for compress	38.54	kWh	3.5	Baht/kWh	135
Electricity for mixture	3.2	kWh	3.5	Baht/kWh	11
Electricity for packaging	4.5	kWh	3.5	Baht/kWh	16
Labors for production	24	hrs	30	Baht/kWh	720
Labors for packaging	1,000	Bags	0.25	Baht/bag	250
package	500	Bags	4	Baht/bag	2,000
Total (Baht)				**3,732**	

Source: Khompis et al., 2009

- **Waste Heat Recovery System.**

In spite of its simplicity and low maintenance, the efficiency of small Rankin power system is relatively low. The possibility of introducing the system as combine heat and power (CHP) to improve its overall efficiency by waste heat recovery is worth mentioning as hot gas or steam can be a heat source for drying agricultural products to preserve most of its quantity especially for local products as longan, lychee, chili and tobacco. Typical drying process uses conventional fuels such as LPG, fuel woods and etc. Nuntaphan et al., (2006) illustrated the use hot steam for drying, replacing the use of LPG. The unit cost is found to be 1.67 Baht/kg of fresh longan fruit. There is also flue gas from rankin system from which simple heat exchange can produce 80^{o}C hot air to dry local agriculture product as longran.

In this study, there is 0.85 kW exhaust gas per 1 kW of the electrical generated energy (Khompis et al., 2009). The Rankine steam power system has waste heat recovery inform of hot steam at its condenser is 608.58 kW (Vorayos et al., 2008).

These are alternative methods to bring extra benefit for the community-based power plant. The economical analysis with all above-mentioned cases is shown for the following cases:

Rankine Steam Power System

Case. 1 The community power plant with extra benefit from tops and leaves products.

Case. 2 The community power plant with extra benefit from waste heat recovery 50% of the total waste heat for drying the agricultural products.

Case. 3 The community power plant with extra benefit from tops and leaves products and waste heat recovery 50% of the total waste heat for drying the agricultural products.

Downdraft gasifications system

Case.1 The community power plant with extra benefit from tops and leaves products.

Case.2 The community power plant with extra benefit from charcoal.

Case. 3 The community power plant with extra benefit from tops and leaves products and charcoal products.

3.5.2 Economical Results of the Rankine steam power system improvement.

Cost reduction resulting from extra benefit are summarized below as economic analytical results of the 50 kW rankine steam power system improvement are reported as shown in Table 3.17 Extra income from tops and leaves products from the *Leucaena Leucocephala* is not attractive as additional benefit is not high enough.

Table 3.17 Economical analysis of investment cost reduction of the Rankine system.

Rankine steam power	Base	Case.1	Case.2	Case.3
NPV(Baht)	(6,682,139)	(6,311,533)	9,817,081	10,188,124
IRR	NA	NA	24.36%	24.91%
Pay Back Period (Yrs)	NA	NA	4.02	3.93

(The cash flow statement available in APPENDIX B)

However, waste heat energy can dry fresh longan of 16.2 ton/ 4 days. Total agriculture product drying period is about 120 days annual (July-September). There are 30 possible batches (lots) to produce 484.5 ton dried longan in a year. Outside this duration, there is a possibility to dry other agricultural products as well, such as tobacco. For possible 180-day duration, the capacity for tobacco drying can reach 14 ton/5 days which heat system requirement of 320 kW. The tobacco leaves are dried within 36 times/year and equivalent to 239.6 ton of dried tobacco leaves per year. Price of dried longan and dried tobacco leaves are 2.5 Baht/kg and 2 Baht/kg respectively. Income from these processes about 1.7 million Baht/year or 4.82 Baht/kWh. However, 2 drying chambers with investment cost of 1.4 million Baht (700,000 Baht/chamber, 10 years lifetime, and 3.73 kWe) have to be added. The power plant could have net profit from drying process of 4.43 Baht/kWh, plus selling electricity to the PAE of 3.82 Baht/kWh. Thereby, the power plant could get total income of 8.25 Baht/kWh. It would bring more income at NPV of 9.8 million Baht and IRR value of 24.4% and the payback period of 4 years. It is considered to be worth investment because the NPV indicates in a positive value and the IRR shows value of the rate of return higher than that at the present time (8.7%). However, the waste heat recovery maybe is not utilized fully. This current work also analyse the unit cost of production electricity at various percentage of heat recovery utilization as shown in term of the relation of IRR in Figure 3.10. To gain attractive IRR, waste heat has to be recovered at least approximately 27%. The fresh longan and tobacco products should be dried at least 296 ton/year and 143.7 ton/year, respectively. In the same way, the downdraft gasification power plant can gain extra benefit from waste heat recovery as well but the extra benefit low such that IRR is not attractive at all.

Hence, the economic rate of return will be higher if tops and leaves are sold together with heat recovery.

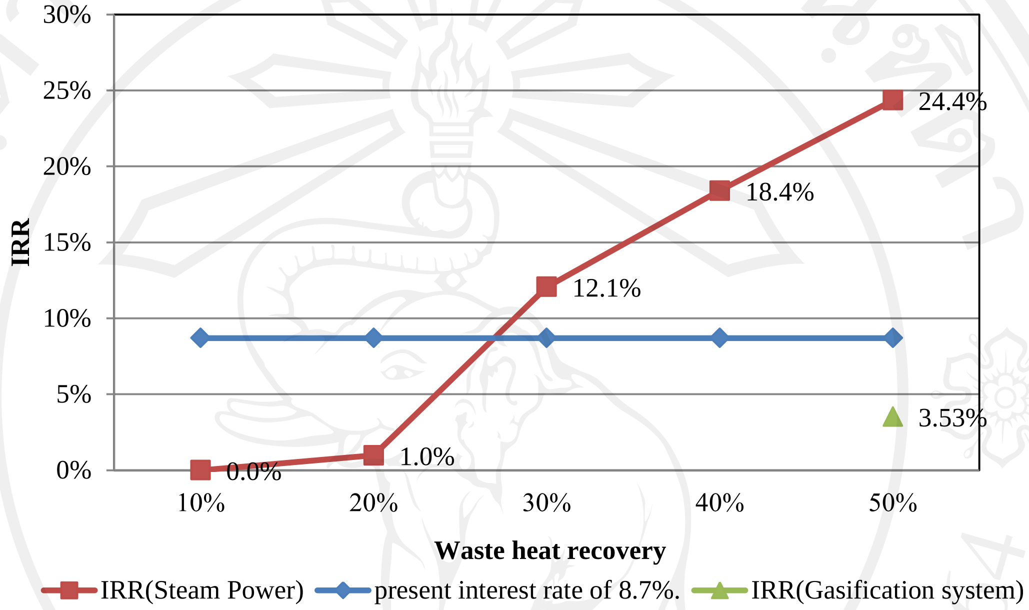

Figure 3.10 The relation between the ratio of waste heat recovery with IRR

3.5.3 Economical results of the Downdraft gasification system improvement.

Cost of electrical generation of the downdraft gasification system is 4.19 Baht/kWh which slightly higher than the value of electricity purchasing price of PEA. The economical results of the system improvement of the 3 case studies are shown in Table 3.18

Table 3.18 Economical results of the downdraft gasification system improvement.

Downdraft gasification	Base	Case.1	Case.2	Case.3
NPV(Baht)	(3,199,398)	(2,846,985)	3,009,205	3,361,617
IRR	4.55%	5.06%	11.72%	12.05%
Pay Back Period (Yrs)	17.19	16.20	7.79	7.59

(The cash flow statement available in APPENDIX B)

Only selling tops and leaves products (case 1) is unable to recover the investment cost as it is shown from the low IRR value.

However, the Downdraft gasification system with char carbon as a by-product. Its producing quantity of char is around 86 ton /year with price of 12 Baht/kg. Thus the extra benefit should be 1.48 Baht/kWh. Nevertheless, there is additional investment on pressing machine and managerial costs for carbon bars process at 1,200,000 baht (10 years lifetime, and 22 kWe) and the operating cost is 324,177.05 baht/year. As shown in case.2 in the Table 3.19, this is worth investment because the power plant could gain the NPV of 3,009,205 Baht and IRR of 11.72%.

Alternative technique to reduce the capital cost turns attractive in case 3. It is suggested that tops and leaves and charcoal product should be well managed simultaneously. This will increase NPV to 3,009,205 Baht/year and bring the IRR rate to 12.05%. It also offers higher income if charcoal management is integrated with waste heat recovery. The increase of NPV is reported to 4,903,110 Baht and the IRR is also levitated to 13.25%.

From Figure 3.11 it is clear that the Rankine steam power system should be operation with waste heat recovery system (Case. 2) or integrated that with the management of tops and leaves of plantation phase (Case. 3)

The Downdraft gasification power plant should be operated with the management of charcoal bar (Case.2) and combined with selling by-products from tops and leaves (Case.3).

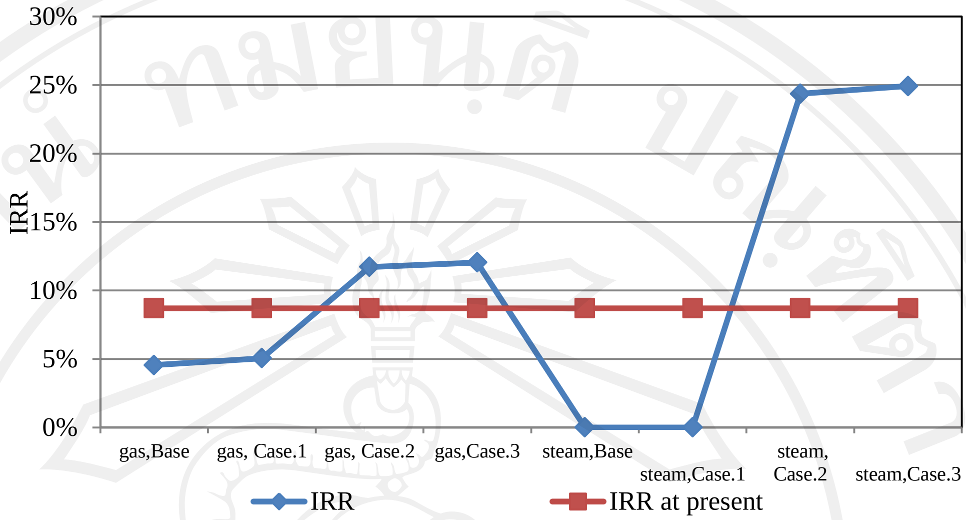

Figure 3.11 Comparisons of IRR value of the case studies, at the present interest rate of 8.7%.

3.6 Life Cycle Assessment of the Electrification from the fast-growth wood-fuel.

In spite of the fact that the community-based biomass power plant is economically feasible but the concerns on environmental issues has to be evaluated. That environment impact has to be determined since it directly affects the quality of living of the community. In this work, Life Cycle Assessment or LCA is deployed and four main steps introduced in section 2.4 are carried out.

3.6.1 Goal and Scope Definition

LCA's goal is to determine the environmental impacts from the production of 1 kWh electricity from community-based biomass power plants. Two different technologies, i.e. 100 kW downdraft gasification and 50 kW rankine steam power are studied and in comparison.

Environmental impacts starting from a biomass plantation to and biomass-fueled electrification (from cradle to gate) are primarily focused. *Leacocaena Leucocephala* is suggested as selected species. An assumption of community-owned plantation and electrification is applied such that the entire processes are to be well managed by the community. Wooden fuel is in three-year rotation and prepared within the area corresponding to power plant's capacity. Transportation of wood stems from plantation to the storage near power plant location is preferred where size and moisture reduction is achieved. Waste heat recovery system is utilized to dry the woodchips. All materials and energy input into entire processes along with corresponding gas emission are analyzed. Environmental impacts from infrastructure assumingly yield less impact as electricity generation is far more affecting the environment (Varela et al., 1999). All environmental impacts are based on 1 kWh of electrification and to be referenced those generated from national grid.

3.6.2 Life Cycle Inventory (LCI)

All relevant quantity of natural resources, energy, materials used as the input of the whole system is listed and collected against the output in terms of pollutant emission as Life Cycle Inventory (LCI). Some figures are to be found in recorded documents and some others are to be measured on site. Inventory of electricity consumption from national grid is analyzed separately as shown in Table 3.19

(i) LCI of national grid.

In 2010, The Electricity Generating Authority of Thailand (EGAT) generated the net electricity of 74,328.0 M kWh/year from difference sources comprising of 2.27 M kWh from solar power plant, 3.38 M kWh from wind turbine, 5,345.58 M kWh from hydro power plant, 1.64 M kWh from geothermal, and 68,975.15 M kWh from fossil-fueled power plant. These are accounted for the several pollutants, i.e. 4.16×10^7 Tons of CO_2/year , 2.5127 Tons of SO_2 /year, 33182 Tons of NO_x/year, and 1935 Tons of dust particle/year. Details are shown in Figure 3.12. Based on collected data from power plants across Europe, America, and Asia, SimaPro, a dedicated commercial LCA software, is used to assess the environmental impacts for this investigation.

Table 3.19 Inventory of electricity generation in Thailand in 2010

Input		**Output**	
Resource (kg/kWh)		Production : Electricity 1 kWh	
Fuel oil	1.67E-01	Emission	to air (kg/kWh)
Diesel oil	1.55E-04	CO_2	5.59E-01
Coal and Lignite	1.37E-01	SO_2	3.38E-04
Natural GAS	1.41E-01	No_x	1.12E-03
		Dust	2.60E-05

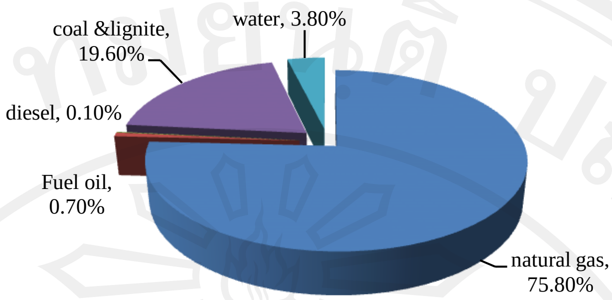

Figure 3.12 Fuel sources for generated electricity in Thailand
Source: EGAT, 2010

(ii) LCI of electrification from fasting-growth wood

Life cycle inventory is achieved in this work for the simple rankine steam-powered cycle and the gasification system according section 3.2. The details of energy, raw material, chemical substances and natural resources consumed for the production along with the resulting pollutants and wastes from each process are shown in Table 3.20 and 3.21.

Table 3.20 LCI of the stream-powered system

Input				Output		
Plantation	Soil, unspecified, in ground	5.83E-02	kg/kWh	**Product** Electricity	1.00	kWh
	Fertilizer (N)	2.50E-02	kg/kWh	**Emission to Air**		
	Fertilizer ($P_2 0_5$)	2.50E-02	kg/kWh	Carbon dioxide (CO_2)	2.67E+02	kg/kWh
	Fertilizer (K_2O)	2.50E-02	kg/kWh	Carbon monoxide (CO)	2.95E+00	kg/kWh
	Diesel	8.55E-03	kg/kWh	Nitrogen oxides (NO_x)	2.59E-01	kg/kWh
	electricity -grid line	1.54E-01	kWh/kWh	Particulate matter (PM)	1.60E-04	kg/kWh
Transportation	water	1.86E+01	kg/kWh	Hydrocarbons (HC)	3.73E-04	kg/kWh
Wood preparation	Phosphate (PO_{43-})	3.75E-04	kg/kWh	Methane (CH_4)	8.98E-06	kg/kWh
Electricification	electricity -grid line	7.50E-02	kWh/kWh	Benzene (C_2H_6)	7.06E-06	kg/kWh
	water	18.6	kg/kWh	Toluene (C_7H_8)	2.99E-06	kg/kWh
	Phosphate (PO_{43-})	0.000375	kg/kWh	Xylene (C_8H_{10})	2.99E-06	kg/kWh
				Non – methane volatile organic compounds (NMVOCs)	1.23E-03	kg/kWh
				Sulfur oxides (SO_x)	1.78E-04	kg/kWh
				Nitrous Oxide (N_2O)	3.20E-05	kg/kWh

Table 3.20 LCI of the stream-powered system (Cont.)

Input	Output		
	Cadmium	2.54E-09	kg/kWh
	Copper	4.32E-07	kg/kWh
	Chromium	1.27E-08	kg/kWh
	Nickel	1.78E-08	kg/kWh
	Selenium	2.54E-09	kg/kWh
	Zinc	2.54E-07	kg/kWh
	Lead	2.80E-11	kg/kWh
	Mercury	5.09E-12	kg/kWh
	N-Nitrrosodipropylamine	5.28E-09	kg/kWh

Table 3.21 LCI of the gasification system

Input				Output		
Plantation	Soil, unspecified, in ground	2.77E-02	kg/kWh	**Product** Electricity	1.00	kWh
	Fertilizer (N)	1.19E-02	kg/kWh	**Emission to Air**		
	Fertilizer (P_20_5)	1.19E-02	kg/kWh	Carbon dioxide (CO_2)	2.08E+01	kg/kWh
	Fertilizer (K2O)	1.19E-02	kg/kWh	Carbon monoxide (CO)	4.52E-02	kg/kWh
	Diesel	4.61E-03	kg/kWh	Nitrogen oxides (NO_x)	8.31E-02	kg/kWh
	electricity -grid line	7.31E-02	kWh/kWh	Particulate matter (PM)	4.30E-03	kg/kWh
Transportation	Automotive Lubricant	1.98E-04	liter/kWh	Hydrocarbons (HC)	1.00E-02	kg/kWh
Wood preparation	Polyester Needle felt	8.29E-04	kg/kWh	Methane (CH4)	2.41E-04	kg/kWh
Electricification	electricity -grid line	8.50E-02	kWh/kWh	Benzene (C_2H_6)	1.90E-04	kg/kWh
	Poly Aluminum Chloride: PAC	5.00E-05	liter/kWh	Toluene (C_7H_8)	8.05E-05	kg/kWh
				Xylene (C_8H_{10})	8.05E-05	kg/kWh
				Non – methane volatile organic compounds (NMVOCs)	3.32E-02	kg/kWh
				Sulfur oxides (SO_x)	4.78E-03	kg/kWh
				Nitrous Oxide (N_2O)	1.17E-03	kg/kWh
				Cadmium	6.83E-08	kg/kWh
				Copper	1.16E-05	kg/kWh
				Chromium	3.42E-07	kg/kWh
				Nickel	4.80E-07	kg/kWh
				Selenium	6.83E-08	kg/kWh
				Zinc	6.83E-06	kg/kWh
				Lead	7.52E-10	kg/kWh
				Mercury	1.37E-10	kg/kWh
				N-Nitrrosodipropylamine	5.28E-09	kg/kWh

3.6.3 Life Cycle Impact Assessment (LCIA)

The environment impact is assessed for the net pollutants emission to environment for the production of electricity 1 kWh based on EDIP/UMIP 97 method in SimaPro software program. The EDIP/UMIP method (Environmental Design of Industrial Products, in Danish UMIP) was developed in 1996. The weighting factors were set based on the politically set target emissions per person in the year 2000, the weighted results were expressed except for resources which was based on the proven reserves per person in 1990. The impacts categories have been classified into 16 categories as follows:

(1) Global Warming (GW)
(2) Ozone Depletion (OD):
(3) Acidification (Ac)
(4) Eutrophication (Eu)
(5) Photochemical Smog (PS)
(6) Ecotoxicity to Water Chronic (EWC)
(7) Ecotoxicity to Water Acute (EWA)
(8) Ecotoxicity to Soil Chronic (ESC)
(9) Human Toxicity to Air (HTA)
(10) Human Toxicity to Water (HTW)
(11) Human Toxicity to Soil: HTS
(12) Bulk Waste (BW)
(13) Hazardous Waste (HW)
(14) Radioactive Waste (RW)
(15) Slag/Ashes (S/A)
(16) Resources (all)

The environmental impacts are measured as direct and indirect effects from which the degrees of the effects are also differences. The direct effects are the impacts that can be measured on site while the indirect effects occur during the production process or other relevant processing, for example, fossil fuel is used in an engine which the direct effect is an exhaust gas from the engine combustion and the indirect effect is the pollution that occurred during fuel production process. In case of electricity, the direct effects are less as fossil fuel are consumed more efficiently but the indirect effects may be more as they arise from more transportations, more construction materials and more wastes.

As the environmental impacts of each category are described in term of kg substance/equivalent, comparison of impacts in among categories is not advised. However, for comparison the effect of each category, it can be converting into the same unit in term of Point or Pt by the factor of normalization and weighing as show in Table 3.22.

Table 3.22 Normalization and Weighting Factor of EDIP/UMIP 97 method.

Impact categories	Unit (ER_j)	Normalization	Weighting
Global warming (GWP 100)	ton CO_2-eq./capita/year	1.15E-07	1.1
Ozone depletion	kg CFC-11-eq./capita/year	9.71E-03	63
Acidification	kg SO_2-eq./capita/year	1.35E-05	1.3
Eutrophication	kg NO_3-eq./capita/year	8.40E-06	1.2
Photochemical smog	kg ethene-eq./capita/year	4.00E-05	1.3
Ecotoxicity water chronic	m^3air/capita/year	2.84E-06	1.2
Ecotoxicity water acute	m^3water/capita/year	3.44E-05	1.1
Ecotoxicity soil chronic	m^3soil/capita/year	1.04E-06	1.0
Human toxicity air	m^3water/capita/year	3.27E-10	1.1
Human toxicity water	m^3water/capita/year	1.92E-05	1.3
Human toxicity soil	m^3soil/capita/year	7.87E-03	1.2
Bulk waste	kg SO_2-eq./capita/year	7.41E-04	1.1
Hazardous waste	kg NO_3-eq./capita/year	4.83E-02	1.1
Radioactive waste	m^3air/capita/year	2.86E+01	1.1
Slags/ashes	m^3water/capita/year	2.86E-03	1.1

Source: EDIP/UMIP method, SimaPro software (November 2009, v 2.05)

Both technologies, the steam power system and the gasification system, are based on fast-growth wood. The environmental impacts of relating processes are reported from which those from plantation, transportation, wood preparation, and electrification are included:

- **Plantation Phase**

For the fast-growing tree plantation phase, the environmental impacts of pollutant per ton of fast growing tree are shown in Table 3.23 .

Table 3.23 The environmental impacts of the fast-growing tree plantation.

Impact category	Unit	Total	Fertilizer (N)	Fertilizer (P_2O_5)	Fertilizer (K_2O)	Polyvinylchloride	Diesel (kg)	grid-line nation
Global warming (GWP 100)	g CO_2	6.28E+04	5.03E+04	6.20E+03	3.49E+03	6.19E+01	1.36E+01	2.77E+03
Ozone depletion	g CFC11	3.20E-03	0.00E+00	0.00E+00	0.00E+00	2.02E-08	2.59E-08	3.20E-03
Acidification	g SO_2	2.73E+02	1.65E+02	9.44E+01	5.98E+00	1.71E-01	1.05E-01	7.99E+00
Eutrophication	g NO_3	3.24E+02	2.45E+02	6.08E+01	8.15E+00	2.39E-01	2.01E-01	9.31E+00
Photochemical smog	g ethene	6.52E+00	2.14E+00	1.48E+00	4.08E-01	7.04E-02	7.13E-03	2.41E+00
Ecotoxicity water chronic	m^3	2.14E+03	4.88E+00	4.89E+00	1.79E+00	1.39E+01	1.71E-02	2.12E+03
Ecotoxicity water acute	m^3	2.13E+02	0.00E+00	0.00E+00	0.00E+00	1.40E+00	1.71E-03	2.12E+02
Ecotoxicity soil chronic	m^3	5.26E+01	6.65E+00	3.36E+01	8.51E+00	5.05E-01	2.64E-05	3.32E+00
Human toxicity air	m^3	5.72E+06	1.70E+06	3.08E+06	7.22E+05	5.25E+03	1.32E+03	2.02E+05
Human toxicity water	m^3	5.57E+00	1.63E+00	3.76E-01	3.14E-01	1.42E+00	8.11E-06	1.84E+00
Human toxicity soil	m^3	1.39E+00	3.48E-01	6.09E-01	1.61E-01	1.39E-02	1.88E-06	2.60E-01
Bulk waste	kg	1.18E-03	0.00E+00	0.00E+00	0.00E+00	1.18E-03	0.00E+00	0.00E+00
Hazardous waste	kg	5.40E-09	0.00E+00	0.00E+00	0.00E+00	5.40E-09	0.00E+00	0.00E+00
Radioactive waste	kg	5.44E-09	0.00E+00	0.00E+00	0.00E+00	5.44E-09	0.00E+00	0.00E+00
Slags/ashes	kg	7.70E-05	0.00E+00	0.00E+00	0.00E+00	7.70E-05	0.00E+00	0.00E+00

The corresponding conversion of these impacts into Pt by the normalization and weighting factor to the unit of Pt is then shown in Table 3.24. and Figure 3.13

Table 3.24 The environmental impacts of plantation phase (Pt/ton of Fast-growing tree)

Impact category	Unit	Total	Fertilizer (N)	Fertilizer (P205)	Fertilizer (K2O)	Polyvinylchloride	Diesel (kg)	grid-line nation
Total	**Pt**	**4.91E-02**	**1.58E-02**	**1.00E-02**	**2.46E-03**	**2.88E-04**	**6.58E-06**	**2.05E-02**
Global warming (GWP 100)	Pt	7.95E-03	6.36E-03	7.84E-04	4.42E-04	7.84E-06	1.72E-06	3.51E-04
Ozone depletion	Pt	1.96E-03	0.00E+00	0.00E+00	0.00E+00	1.24E-08	1.59E-08	1.96E-03
Acidification	Pt	4.80E-03	2.89E-03	1.66E-03	1.05E-04	3.01E-06	1.83E-06	1.40E-04
Eutrophication	Pt	3.27E-03	2.47E-03	6.13E-04	8.22E-05	2.41E-06	2.03E-06	9.39E-05
Photochemical smog	Pt	3.39E-04	1.11E-04	7.71E-05	2.12E-05	3.66E-06	3.71E-07	1.26E-04
Ecotoxicity water chronic	Pt	7.31E-03	1.66E-05	1.67E-05	6.12E-06	4.73E-05	5.83E-08	7.22E-03
Ecotoxicity water acute	Pt	8.06E-03	0.00E+00	0.00E+00	0.00E+00	5.30E-05	6.47E-08	8.01E-03
Ecotoxicity soil chronic	Pt	5.47E-05	6.91E-06	3.50E-05	8.85E-06	5.25E-07	2.74E-11	3.45E-06
Human toxicity air	Pt	2.06E-03	6.13E-04	1.11E-03	2.60E-04	1.89E-06	4.75E-07	7.28E-05
Human toxicity water	Pt	1.39E-04	4.06E-05	9.38E-06	7.84E-06	3.54E-05	2.02E-10	4.59E-05
Human toxicity soil	Pt	1.31E-02	3.29E-03	5.75E-03	1.52E-03	1.31E-04	1.77E-08	2.45E-03
Bulk waste	Pt	9.62E-07	0.00E+00	0.00E+00	0.00E+00	9.62E-07	0.00E+00	0.00E+00
Hazardous waste	Pt	2.87E-10	0.00E+00	0.00E+00	0.00E+00	2.87E-10	0.00E+00	0.00E+00

Table 3.24 The environmental impacts of plantation phase (Pt/ton of Fast-growing tree) (Cont.)

Impact category	Unit	Total	Fertilizer (N)	Fertilizer (P205)	Fertilizer (K2O)	Polyvinylchloride	Diesel (kg)	grid-line nation
Radioactive waste	Pt	1.71E-07	0.00E+00	0.00E+00	0.00E+00	1.71E-07	0.00E+00	0.00E+00
Slags/ashes	Pt	2.42E-07	0.00E+00	0.00E+00	0.00E+00	2.42E-07	0.00E+00	0.00E+00

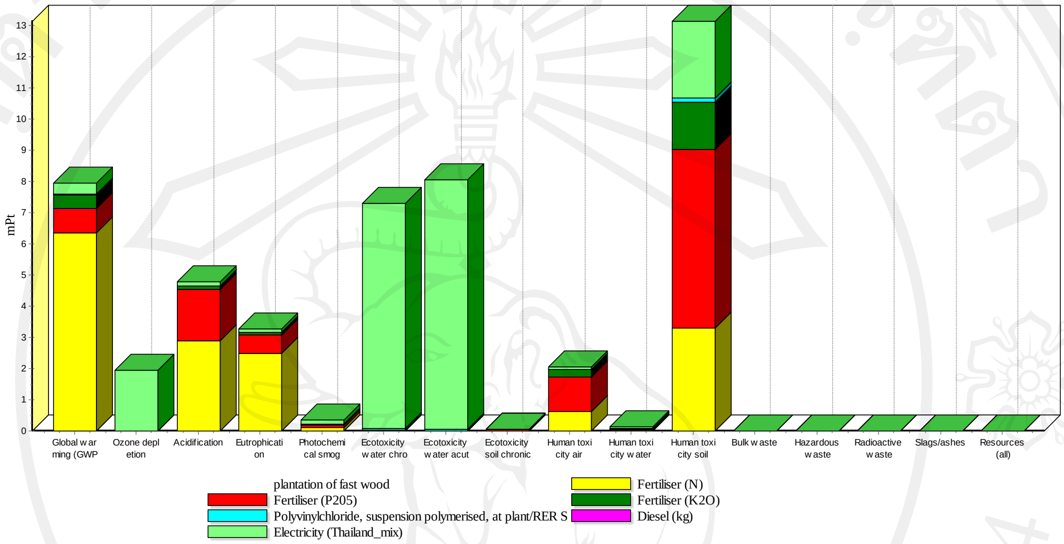

Figure 3.13 The environmental impacts of plantation phase (Pt/ton of Fast-growing tree)

Utilization of materials and energy consumed i.e., Fertilizer(N), (P_2O_5), (K_2O), Polyvinyl/chloride, diesel and electricity from nation grid, displays a number of impacts. Main impacts are Human toxicity soil and Global warming (GWP 100) which are equivalent to 1.31E-02 Pt and 7.95E-03 Pt, respectively. The impacts are directly from the utilization of fertilizer in plantation, especially from Nitrate and Phosphate. The other important environmental impacts are Ecotoxicity water chronic, Ecotoxicity water acute and Acidification. It is observed that the impact of the electricity from national grid-line nation causes similar effects from fossil fuel for electricity generation.

- **Transportation Phase**

For Transportation phase, the environmental impacts are shown in Table 3.25 in term of pollutant per km and Table 3.26 in term of pollutant Pt/km.

Table 3.25 The environmental impacts of transportation phase.

Impact category	Unit	Total	Diesel
Global warming (GWP 100)	g CO_2	1.20E+04	1.20E+04
Ozone depletion	g CFC11	1.70E-03	1.70E-03
Acidification	g SO_2	3.71E+01	3.71E+01
Eutrophication	g NO_3	6.73E+01	6.73E+01
Photochemical smog	g ethene	1.07E+01	1.07E+01
Ecotoxicity water chronic	m^3	2.51E+03	2.51E+03
Ecotoxicity water acute	m^3	2.49E+02	2.49E+02
Ecotoxicity soil chronic	m^3	6.69E+00	6.69E+00
Human toxicity air	m^3	1.66E+06	1.66E+06
Human toxicity water	m^3	1.37E+01	1.37E+01
Human toxicity soil	m^3	1.74E+00	1.74E+00
Bulk waste	kg	9.63E-03	9.63E-03
Hazardous waste	kg	8.15E-06	8.15E-06
Radioactive waste	kg	1.61E-05	1.61E-05
Slags/ashes	kg	1.14E-04	1.14E-04

Table 3.26 The environmental Impacts of Transportation phase (Pt/ km)

Impact category	**Unit**	**Total**	**Diesel**
Total	Pt	0.04031	0.04031
Global warming (GWP 100)	Pt	0.001521	0.001521
Ozone depletion	Pt	0.001042	0.001042
Acidification	Pt	0.00065	0.00065
Eutrophication	Pt	0.000679	0.000679
Photochemical smog	Pt	0.000558	0.000558
Ecotoxicity water chronic	Pt	0.008558	0.008558
Ecotoxicity water acute	Pt	0.009419	0.009419
Ecotoxicity soil chronic	Pt	6.96E-06	6.96E-06
Human toxicity air	Pt	0.000598	0.000598
Human toxicity water	Pt	0.000342	0.000342
Human toxicity soil	Pt	0.016423	0.016423
Bulk waste	Pt	7.85E-06	7.85E-06
Hazardous waste	Pt	4.33E-07	4.33E-07
Radioactive waste	Pt	0.000505	0.000505
Slags/ashes	Pt	3.58E-07	3.58E-07

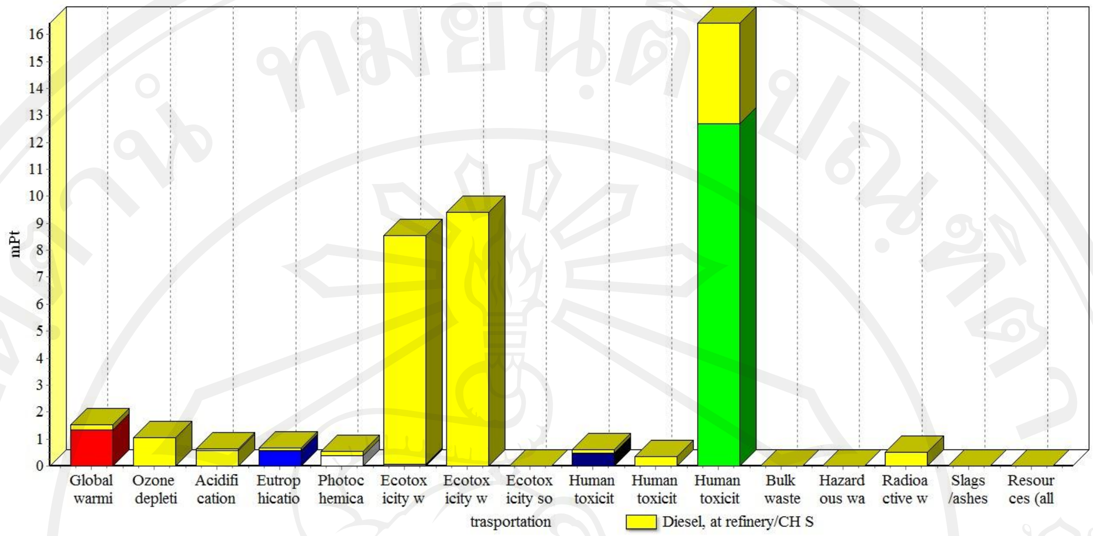

Figure 3.14 The environmental Impacts of transport phase (Pt/ km)

This impact results from the utilization of diesel in community vehicles which give the impact value of 0.04031 Pt. This number is accumulated from the drilling for crude oil to the emission of the pollutants from vehicle's engine into the environment. The main impact effects are on human toxicity, soil toxicity, ecotoxicity water acute, ecotoxicity water chronic.

- **Preparation Phase**

The environmental impacts of the preparation phase are shown in Table 3.27. Results are in term of pollutant per ton of fast-growing tree. Table 3.28 also shows the same results in term of pollutant Pt per fast-growing tree used.

Table 3.27 The environmental impacts of preparation phase

Impact category	Unit	Total	grid-line nation
Global warming (GWP 100)	g CO_2	3.40E+03	3.40E+03
Ozone depletion	g CFC11	3.93E-03	3.93E-03
Acidification	g SO_2	9.80E+00	9.80E+00
Eutrophication	g NO_3	1.14E+01	1.14E+01
Photochemical smog	g ethene	2.96E+00	2.96E+00

Table 3.27 The environmental impacts of preparation phase (Cont.)

Impact category	**Unit**	**Total**	**grid-line nation**
Ecotoxicity water chronic	m^3	2.60E+03	2.60E+03
Ecotoxicity water acute	m^3	2.60E+02	2.60E+02
Ecotoxicity soil chronic	m^3	4.07E+00	4.07E+00
Human toxicity air	m^3	2.48E+05	2.48E+05
Human toxicity water	m^3	2.26E+00	2.26E+00
Human toxicity soil	m^3	3.19E-01	3.19E-01
Bulk waste	kg	0.00E+00	0.00E+00
Hazardous waste	kg	0.00E+00	0.00E+00
Radioactive waste	kg	0.00E+00	0.00E+00
Slags/ashes	kg	0.00E+00	0.00E+00

Table 3.28 The environmental impacts of preparation phase (Pt/ton of fast-growing tree).

Impact category	Unit	Total	grid-line nation
Total	**Pt**	**2.51E-02**	**2.51E-02**
Global warming (GWP 100)	Pt	4.30E-04	4.30E-04
Ozone depletion	Pt	2.40E-03	2.40E-03
Acidification	Pt	1.72E-04	1.72E-04
Eutrophication	Pt	1.15E-04	1.15E-04
Photochemical smog	Pt	1.54E-04	1.54E-04
Ecotoxicity water chronic	Pt	8.85E-03	8.85E-03
Ecotoxicity water acute	Pt	9.82E-03	9.82E-03
Ecotoxicity soil chronic	Pt	4.23E-06	4.23E-06
Human toxicity air	Pt	8.93E-05	8.93E-05
Human toxicity water	Pt	5.63E-05	5.63E-05
Human toxicity soil	Pt	3.01E-03	3.01E-03
Bulk waste	Pt	0.00E+00	0.00E+00
Hazardous waste	Pt	0.00E+00	0.00E+00
Radioactive waste	Pt	0.00E+00	0.00E+00
Slags/ashes	Pt	0.00E+00	0.00E+00

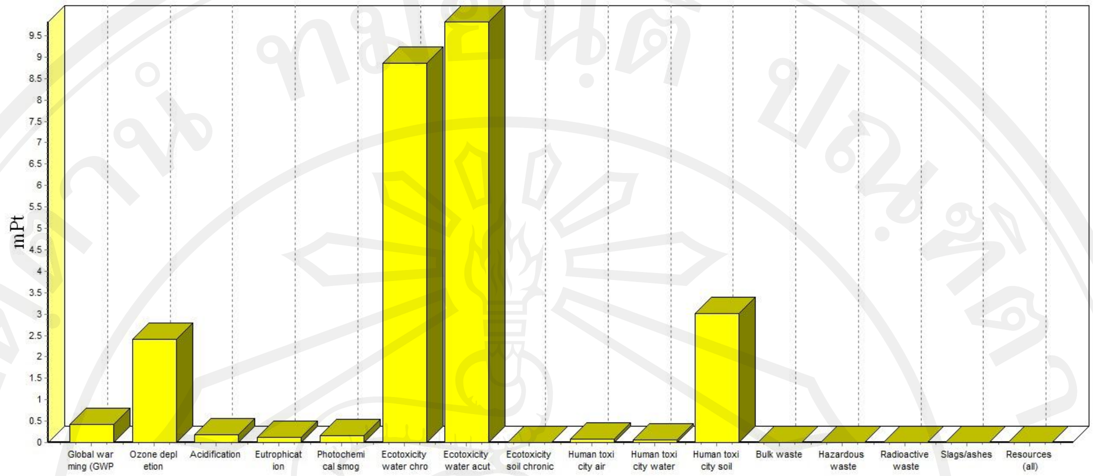

Figure 3.15 The environmental impacts of preparation phase (Pt/ ton of fast-growing tree)

In preparation phase chipping machines are only equipment being used. Other than that, it is complimented by the workers of the power plant. Therefore, pollutants from the Electricity grid-line is only at the probable 2.51E-02 Pt. It is found that the main impacts are Ecotoxicity water acute and Ecotoxicity water chronic equivalent for 9.82E-03 Pt/ton and 8.85E-03 Pt/ton, respectively. This is mainly caused from utilization of the fossil fuel for machinery which is accounted for all exploration and production activities needed prior to this work which include surveying, drilling, refining and transporting.

- **Electrification phase**

i. Steam power system.

The environmental impacts in the Electrification phase of the steam power system are shown in Table 3.29 in the unit of the pollutant per kWh and Table 3.30 in term of the pollutant Pt/kWh.

Table 3.29 The environmental impacts from electrification phase of the steam power system**.**

Impact category	Unit	Total	combustion	grid-line nation
Global warming (GWP 100)	g CO2	3.15E+02	2.72E+02	4.34E+01
Ozone depletion	g CFC11	5.01E-05	0.00E+00	5.01E-05
Acidification	g SO2	4.71E-01	3.46E-01	1.25E-01
Eutrophication	g NO3	4.91E-01	3.46E-01	1.46E-01

Table 3.29 The environmental impacts from electrification phase of the steam power system (Cont.)

Impact category	Unit	Total	combustion	grid-line nation
Photochemical smog	g ethene	1.26E-01	8.85E-02	3.78E-02
Ecotoxicity water chronic	m3	3.31E+01	0.00E+00	3.31E+01
Ecotoxicity water acute	m3	3.31E+00	0.00E+00	3.31E+00
Ecotoxicity soil chronic	m3	5.19E-02	0.00E+00	5.19E-02
Human toxicity air	m3	8.03E+03	4.87E+03	3.17E+03
Human toxicity water	m3	2.88E-02	0.00E+00	2.88E-02
Human toxicity soil	m3	4.07E-03	0.00E+00	4.07E-03
Bulk waste	kg	0.00E+00	0.00E+00	0.00E+00
Hazardous waste	kg	0.00E+00	0.00E+00	0.00E+00
Radioactive waste	kg	0.00E+00	0.00E+00	0.00E+00
Slags/ashes	kg	0.00E+00	0.00E+00	0.00E+00
Resources (all)	g CO2	1.83E-06	0.00E+00	1.83E-06

Table 3.30 The environmental impacts from electrification phase of the steam power system (Pt/kWh)

Impact category	**Unit**	**Total**	**combustion**	**grid-line nation**
Total	Pt	3.71E-04	5.03E-05	3.20E-04
Global warming (GWP 100)	Pt	3.99E-05	3.44E-05	5.48E-06
Ozone depletion	Pt	3.07E-05	0.00E+00	3.07E-05
Acidification	Pt	8.27E-06	6.08E-06	2.19E-06
Eutrophication	Pt	4.95E-06	3.48E-06	1.47E-06
Photochemical smog	Pt	6.57E-06	4.60E-06	1.96E-06
Ecotoxicity water chronic	Pt	1.13E-04	0.00E+00	1.13E-04
Ecotoxicity water acute	Pt	1.25E-04	0.00E+00	1.25E-04
Ecotoxicity soil chronic	Pt	5.40E-08	0.00E+00	5.40E-08
Human toxicity air	Pt	2.89E-06	1.75E-06	1.14E-06
Human toxicity water	Pt	7.18E-07	0.00E+00	7.18E-07
Human toxicity soil	Pt	3.84E-05	0.00E+00	3.84E-05
Bulk waste	Pt	0.00E+00	0.00E+00	0.00E+00
Hazardous waste	Pt	0.00E+00	0.00E+00	0.00E+00
Radioactive waste	Pt	0.00E+00	0.00E+00	0.00E+00
Slags/ashes	Pt	0.00E+00	0.00E+00	0.00E+00
Resources (all)	Pt	0.00E+00	0.00E+00	0.00E+00

The environmental impacts are from utilization of material and energy as their impacts are 3.71E-04 Pt/kWh. Main impacts are Ecotoxicity water acute and Ecotoxicity water chronic. The impacts primarily are from the utilization of electricity from national grid from which the effects are on Global warming, Acidification, Eutrophication, and Photochemical smog. They are direct impact caused by fuel gas.

When the results are presented according to the 4 phases of processing, they can be shown in Table 3.31 and 3.32.

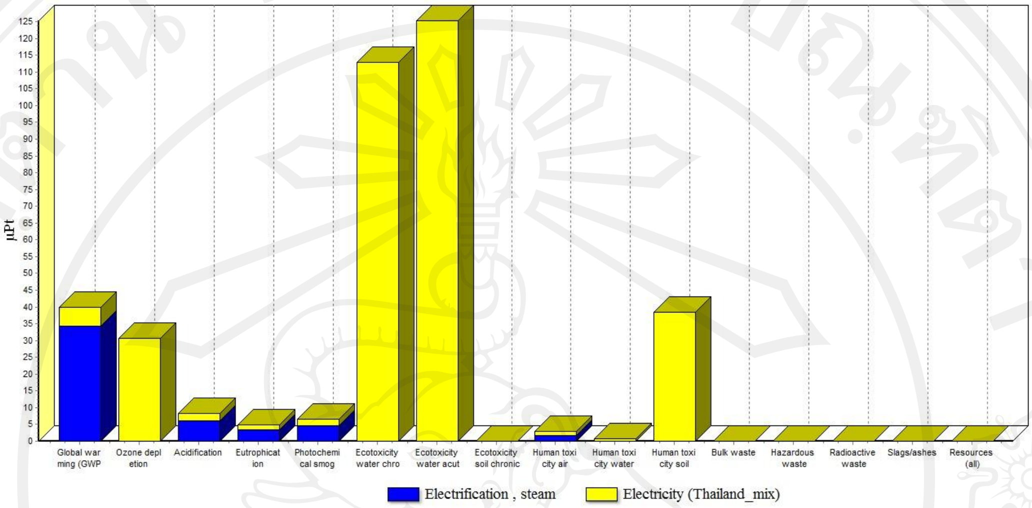

Figure 3.16 Environmental impact from electrification phase of the steam power system (Pt/kWh)

Table 3.31 Environmental impact the steam power system in term of impact per kWh.

Impact category	Unit	Total	plantation	Preparation	Transportation	Electrification
Global warming (GWP 100)	g CO_2	6.90E+02	3.01E+02	1.63E+01	5.76E+01	3.15E+02
Ozone depletion	g CFC11	9.24E-05	1.53E-05	1.88E-05	8.16E-06	5.01E-05
Acidification	g SO_2	2.01E+00	1.31E+00	4.69E-02	1.78E-01	4.71E-01
Eutrophication	g NO_3	2.42E+00	1.55E+00	5.47E-02	3.22E-01	4.91E-01
Photochemical smog	g ethene	2.23E-01	3.12E-02	1.42E-02	5.14E-02	1.26E-01
Ecotoxicity water chronic	m^3	6.79E+01	1.03E+01	1.24E+01	1.20E+01	3.31E+01
Ecotoxicity water acute	m^3	6.77E+00	1.02E+00	1.24E+00	1.19E+00	3.31E+00
Ecotoxicity soil chronic	m^3	3.55E-01	2.52E-01	1.95E-02	3.21E-02	5.19E-02
Human toxicity air	m^3	4.46E+04	2.74E+04	1.19E+03	7.96E+03	8.03E+03
Human toxicity water	m^3	1.32E-01	2.67E-02	1.08E-02	6.57E-02	2.88E-02
Human toxicity soil	m^3	2.06E-02	6.67E-03	1.53E-03	8.33E-03	4.07E-03
Bulk waste	kg	5.18E-05	5.65E-06	0.00E+00	4.61E-05	0.00E+00
Hazardous waste	kg	3.91E-08	2.59E-11	0.00E+00	3.90E-08	0.00E+00
Radioactive waste	kg	7.70E-08	2.61E-11	0.00E+00	7.70E-08	0.00E+00
Slags/ashes	kg	9.14E-07	3.69E-07	0.00E+00	5.45E-07	0.00E+00
Resources (all)	g CO_2	5.98E-06	2.84E-06	6.87E-07	6.29E-07	1.83E-06

Table 3.32 Environmental impact the steam power system in term of Pt per kWh.

Impact category	Unit	Total	plantation of fast wood	Preparation	transportation	Electrification , steam
Total	Pt	0.000919	0.000235	0.00012	0.000193	0.000371
Global warming (GWP 100)	Pt	8.73E-05	3.81E-05	2.06E-06	7.29E-06	3.99E-05
Ozone depletion	Pt	5.65E-05	9.39E-06	1.15E-05	4.99E-06	3.07E-05
Acidification	Pt	3.52E-05	2.3E-05	8.24E-07	3.12E-06	8.27E-06

Table 3.32 Environmental impact the steam power system in term of Pt per kWh (Cont.)

Impact category	Unit	Total	plantation of fast wood	Preparation	transportation	Electrification , steam
Eutrophication	Pt	2.44E-05	1.56E-05	5.52E-07	3.25E-06	4.95E-06
Photochemical smog	Pt	1.16E-05	1.62E-06	7.38E-07	2.67E-06	6.57E-06
Ecotoxicity water chronic	Pt	0.000231	3.5E-05	4.24E-05	4.1E-05	0.000113
Ecotoxicity water acute	Pt	0.000256	3.86E-05	4.7E-05	4.51E-05	0.000125
Ecotoxicity soil chronic	Pt	3.7E-07	2.62E-07	2.03E-08	3.34E-08	5.4E-08
Human toxicity air	Pt	1.6E-05	9.85E-06	4.28E-07	2.86E-06	2.89E-06
Human toxicity water	Pt	3.29E-06	6.66E-07	2.7E-07	1.64E-06	7.18E-07
Human toxicity soil	Pt	0.000194	6.3E-05	1.44E-05	7.87E-05	3.84E-05
Bulk waste	Pt	4.22E-08	4.61E-09	0	3.76E-08	0
Hazardous waste	Pt	2.08E-09	1.38E-12	0	2.07E-09	0
Radioactive waste	Pt	2.42E-06	8.2E-10	0	2.42E-06	0
Slags/ashes	Pt	2.88E-09	1.16E-09	0	1.72E-09	0

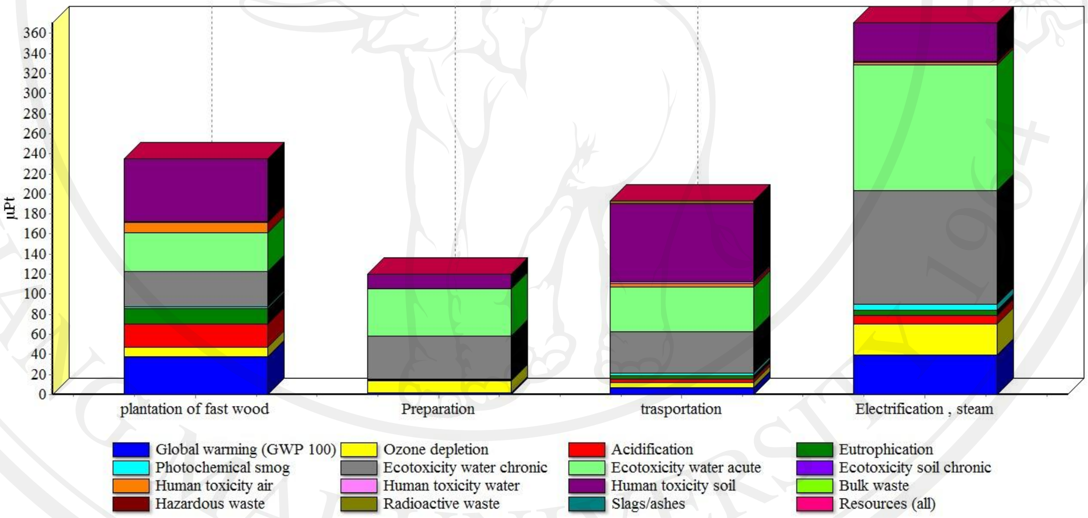

Figure 3.17 The comparison results of electricity generation using the steam power system (Pt/kWh).

Electrification yields highest environmental impact and is accounted for 40% of the total impacts that is primarily from the national-grid electricity. Plantation phase follows with 25% of the total environmental impact from the utilization of fertilizer and electricity used from national grid. The impact of transportation phase is ranked third of 21%. This is due to utilization of diesel in vehicle which results to the direct pollution from engine combustion. As expected, the preparation phase is found to yield relatively least environmental impact as minimum use of machinery is proposed and solar drying is preferred and carefully plan with minimum auxiliary system.

ii. Gasification system

SimaPro shows the resulting environmental impact from gasification system in Table 3.33 and Table. 3.34.

Table 3.33 The environmental impacts from gasification system.

Impact category	Unit	Total	Electrification	Lubricant oil	Polyester resin	Allyl chloride,	grid-line nation
Global warming (GWP 100)	g CO_2	2.47E+02	1.90E+02	6.43E-01	6.39E+00	1.14E-01	4.91E+01
Ozone depletion	g CFC11	5.79E-05	0.00E+00	1.10E-07	8.95E-07	1.43E-07	5.68E-05
Acidification	g SO_2	1.63E-01	2.20E-04	5.46E-03	1.52E-02	4.35E-04	1.42E-01
Eutrophication	g NO_3	2.99E-01	4.24E-04	7.44E-02	5.66E-02	2.30E-03	1.65E-01
Photochemical smog	g ethane	4.65E-02	5.31E-05	3.26E-04	3.22E-03	3.97E-05	4.28E-02
Ecotoxicity water chronic	m^3	4.49E+01	0.00E+00	1.39E-01	6.92E+00	2.83E-01	3.76E+01
Ecotoxicity water acute	m^3	4.48E+00	0.00E+00	7.09E-03	6.96E-01	2.83E-02	3.75E+00
Ecotoxicity soil chronic	m^3	1.39E-01	0.00E+00	3.96E-03	7.41E-02	2.19E-03	5.88E-02
Human toxicity air	m^3	1.06E+04	1.50E+00	3.54E+01	7.01E+03	1.60E+01	3.59E+03
Human toxicity water	m^3	1.72E-01	0.00E+00	2.30E-04	1.32E-01	7.35E-03	3.26E-02
Human toxicity soil	m^3	1.39E-02	0.00E+00	1.33E-05	9.28E-03	1.69E-05	4.61E-03
Bulk waste	Kg	2.76E-04	0.00E+00	0.00E+00	2.66E-04	1.04E-05	0.00E+00
Hazardous waste	Kg	1.11E-07	0.00E+00	0.00E+00	1.04E-07	6.40E-09	0.00E+00
Radioactive waste	Kg	1.39E-07	0.00E+00	0.00E+00	1.33E-07	6.30E-09	0.00E+00
Slags/ashes	Kg	6.58E-07	0.00E+00	0.00E+00	6.33E-07	2.46E-08	0.00E+00
Resources (all)	g CO_2	2.70E-06	0.00E+00	7.74E-09	6.00E-07	2.36E-08	2.07E-06

Table 3.34 The environmental impacts from gasification system (Pt/kWh)

Impact category	Unit	Total	Electrification	Lubricant oil	Polyester resin	Allyl chloride	grid-line nation
Total	Pt	5.42E-04	2.41E-05	1.90E-06	1.50E-04	2.73E-06	3.63E-04
Global warming (GWP 100)	Pt	3.12E-05	2.41E-05	8.13E-08	8.08E-07	1.45E-08	6.21E-06
Ozone depletion	Pt	3.54E-05	0.00E+00	6.74E-08	5.48E-07	8.74E-08	3.47E-05
Acidification	Pt	2.86E-06	3.86E-09	9.58E-08	2.67E-07	7.63E-09	2.49E-06
Eutrophication	Pt	3.01E-06	4.27E-09	7.50E-07	5.70E-07	2.32E-08	1.66E-06
Photochemical smog	Pt	2.42E-06	2.76E-09	1.69E-08	1.68E-07	2.07E-09	2.23E-06
Ecotoxicity water chronic	Pt	1.53E-04	0.00E+00	4.73E-07	2.36E-05	9.66E-07	1.28E-04
Ecotoxicity water acute	Pt	1.70E-04	0.00E+00	2.68E-07	2.63E-05	1.07E-06	1.42E-04
Ecotoxicity soil chronic	Pt	1.45E-07	0.00E+00	4.12E-09	7.71E-08	2.28E-09	6.12E-08
Human toxicity air	Pt	3.83E-06	5.41E-10	1.27E-08	2.52E-06	5.75E-09	1.29E-06
Human toxicity water	Pt	4.30E-06	0.00E+00	5.74E-09	3.30E-06	1.83E-07	8.14E-07
Human toxicity soil	Pt	1.31E-04	0.00E+00	1.26E-07	8.77E-05	1.59E-07	4.35E-05
Bulk waste	Pt	2.25E-07	0.00E+00	0.00E+00	2.17E-07	8.47E-09	0.00E+00
Hazardous waste	Pt	5.89E-09	0.00E+00	0.00E+00	5.55E-09	3.40E-10	0.00E+00
Radioactive waste	Pt	4.39E-06	0.00E+00	0.00E+00	4.19E-06	1.98E-07	0.00E+00
Slags/ashes	Pt	2.07E-09	0.00E+00	0.00E+00	1.99E-09	7.75E-11	0.00E+00
Resources (all)	Pt	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

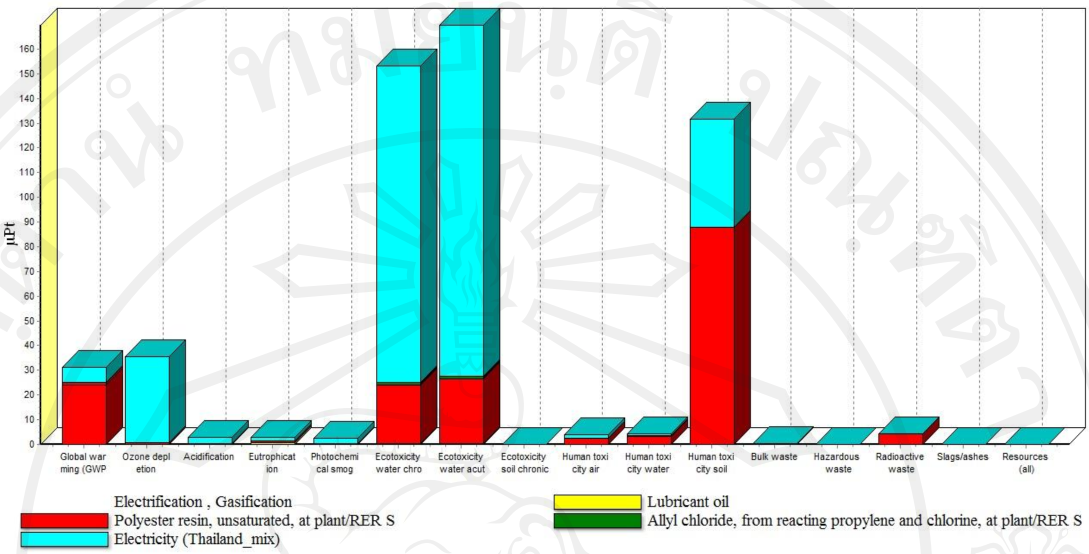

Figure 3.18 Environmental impact from gasification system (Pt/kWh)

It can be determined that the environmental impacts occurs from the utilization of material and energy in 4 categories which are lubricant oil, polyester resin, Allychloride and grid-line nation. The direct pollutants emission from reactor gives the impact value of 5.42E-04 Pt. It could be found that the main impacts are Ecotoxicity water acute, Ecotoxicity water chronic and Human toxicity soil from which the corresponding numbers are 1.53E-04 Pt, 1.70E-04 Pt and 1.31E-04 Pt, respectively. The impacts are primarily caused from the utilization of clean produced gas and electricity from national grid. The results can be shown regarding to the 4 phases of processing as in Table 3.35 and Figure 3.19.

Table 3.35 Environmental impact of electricity generation from the Gasification system in term of impact per kWh.

Impact category	Unit	Total	plantation	Preparation	Transportation	Electrification
Global warming (GWP 100)	g CO_2	4.24E+02	1.43E+02	7.71E+00	2.73E+01	2.47E+02
Ozone depletion	g CFC11	7.80E-05	7.27E-06	8.92E-06	3.87E-06	5.79E-05
Acidification	g SO_2	8.90E-01	6.21E-01	2.22E-02	8.41E-02	1.63E-01
Eutrophication	g NO_3	1.21E+00	7.36E-01	2.59E-02	1.53E-01	2.99E-01
Photochemical smog	g ethene	9.23E-02	1.48E-02	6.72E-03	2.43E-02	4.65E-02
Ecotoxicity water chronic	m^3	6.14E+01	4.87E+00	5.90E+00	5.70E+00	4.49E+01
Ecotoxicity water acute	m^3	6.12E+00	4.83E-01	5.89E-01	5.65E-01	4.48E+00
Ecotoxicity soil chronic	m^3	2.83E-01	1.19E-01	9.23E-03	1.52E-02	1.39E-01

Table 3.35 Environmental impact of electricity generation from the Gasification system in term of impact per kWh (Cont.)

Impact category	Unit	Total	plantation	Preparation	Transportation	Electrification
Human toxicity air	m^3	2.80E+04	1.30E+04	5.64E+02	3.77E+03	1.06E+04
Human toxicity water	m^3	2.21E-01	1.27E-02	5.12E-03	3.11E-02	1.72E-01
Human toxicity soil	m^3	2.18E-02	3.16E-03	7.24E-04	3.95E-03	1.39E-02
Bulk waste	kg	3.01E-04	2.68E-06	0.00E+00	2.19E-05	2.76E-04
Hazardous waste	kg	1.29E-07	1.23E-11	0.00E+00	1.85E-08	1.11E-07
Radioactive waste	kg	1.76E-07	1.23E-11	0.00E+00	3.65E-08	1.39E-07
Slags/ashes	kg	1.09E-06	1.75E-07	0.00E+00	2.58E-07	6.58E-07
Resources (all)	g CO_2	4.67E-06	1.34E-06	3.25E-07	2.98E-07	2.70E-06

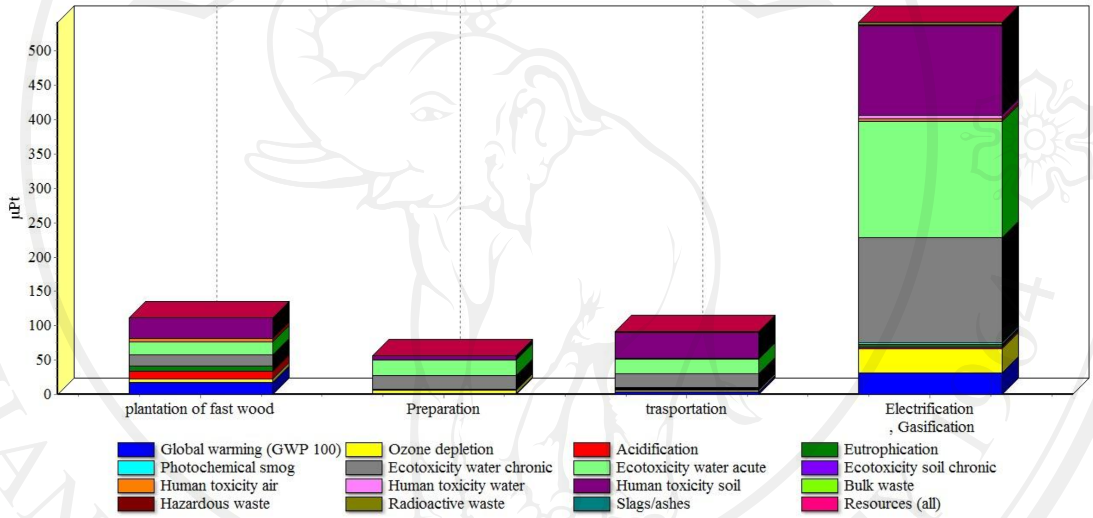

Figure 3.19 Comparison results of 4 phase of electricity generation by the gasification system (Pt/kWh)

The results show similar trend to those of the steam-powered system. The electrification phase yields the highest impact on the environment at 67%. This results from the utilization of the electricity from national grid, chemical substance used for gas purification, and the gas leakage from the gasification reactor. Impacts from the plantation are found at 13.9% due to using fertilizer from which it causes the ecotoxicity to the soil. The impacts from transportation phase and preparation phase are found to be 6.46% and 1.82%, respectively.

3.6.4 The environmental impact of generated electricity from national grid line (impact/kWh)

As the produced electricity is planned to be sold and sent back to the national grid to maximize the benefit. Auxiliary electricity for the machineries is still pertinent and power from national grid is still needed. Originated from variety of sources, environmental impacts of the grid line have to be found as it will contribute to the total impact from the power plants. Using SimaPro, environmental impacts from national grid is shown in Table 3.36 and Fig 3.20.

Table 3.36 Environmental impact of generated electricity from grid-line nation system in term of kg substance equivalent/kWh

Impact category	Unit	impact	combustion	Diesel	Natural gas	lignite	Fuel oil
Global warming (GWP 100)	g CO^2/kWh	5.78E+02	4.47E+02	7.88E-02	3.64E+01	9.72E+00	8.46E+01
Ozone depletion	g CFC11/kWh	6.68E-04	0.00E+00	6.18E-07	1.88E-06	0.00E+00	6.66E-04
Acidification	g SO_2/kWh	1.67E+00	8.97E-01	5.60E-04	1.46E-01	2.06E-02	6.02E-01
Eutrophication	g NO_3/kWh	1.94E+00	1.21E+00	5.71E-04	1.09E-01	1.07E-02	6.14E-01
Photochemical smog	g ethene/kWh	5.04E-01	0.00E+00	4.34E-04	3.33E-02	2.50E-03	4.67E-01
Ecotoxicity water chronic	m^3/kWh	4.42E+02	0.00E+00	4.08E-01	1.90E+00	0.00E+00	4.40E+02
Ecotoxicity water acute	m^3/kWh	4.41E+01	0.00E+00	4.07E-02	1.92E-01	0.00E+00	4.39E+01
Ecotoxicity soil chronic	m^3/kWh	6.92E-01	0.00E+00	6.28E-04	4.13E-02	0.00E+00	6.50E-01
Human toxicity air	m^3/kWh	4.22E+04	8.05E+03	2.82E+01	3.83E+03	2.72E+01	3.03E+04
Human toxicity water	m^3/kWh	3.84E-01	0.00E+00	1.93E-04	1.76E-01	0.00E+00	2.08E-01
Human toxicity soil	m^3/kWh	5.42E-02	0.00E+00	4.48E-05	5.98E-03	0.00E+00	4.82E-02
Bulk waste	kg/kWh	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hazardous waste	kg/kWh	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Radioactive waste	kg/kWh	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Slags/ashes	kg/kWh	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Heat rate	MJ/kWh	13.00	0.00E+00	1.70E-08	4.38E-06	1.73E-06	1.83E-05

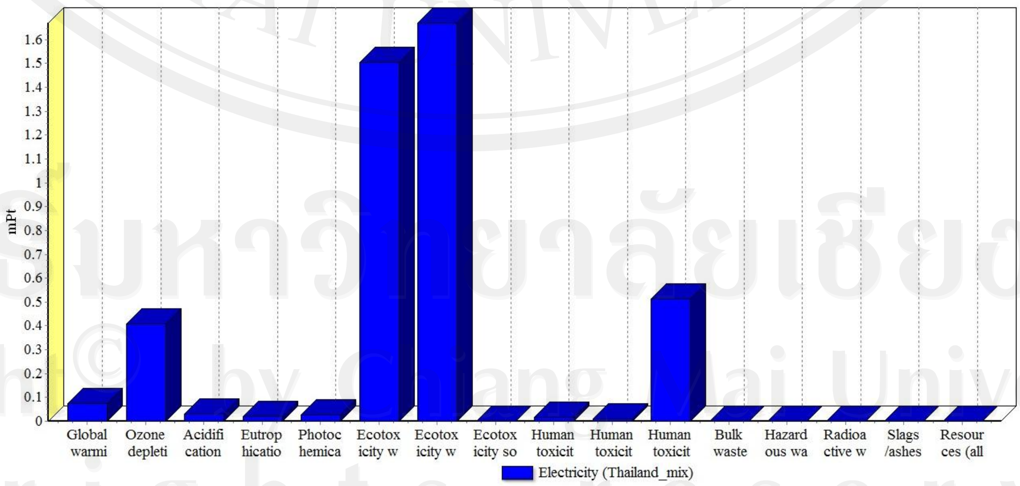

Figure 3.20 The comparison of 4 phase of electricity generated by grid-line nation.

It could found that environmental impacts relate largely on Ecotoxicity water acute (4.41E+01Pt) and Ecotoxicity water chronic (4.42E+02Pt). Human toxicity soil effect is at 5.42E-02Pt. The impacts are from the fact that most of the fuel used in national grid is fossil-based. Therefore, exploration and fuel production are majoring factors releasing pollutant into soil and underground water.

3.6.5 The Comparison of environmental impact from electrification from community-based steam-powered system, gasification system, and national grid.

The LCA result of the generated electricity from grid-line nation and community-based power plant are compared in Table 3.37-3.38 and Fig 3.21

Table 3.37 The Comparison of environmental impact from national grid and community-based power plants (unit of pollutants per kWh)

Impact category	Unit	Gasification system base	grid-line nation	Rankine steam power system base
Global warming (GWP 100)	g CO_2/kWh	4.24E+02	5.78E+02	6.90E+02
Ozone depletion	g CFC11/kWh	7.80E-05	6.68E-04	9.24E-05
Acidification	g SO_2/kWh	8.90E-01	1.67E+00	2.01E+00
Eutrophication	g NO_3/kWh	1.21E+00	1.94E+00	2.42E+00
Photochemical smog	g ethene/kWh	9.23E-02	5.04E-01	2.23E-01
Ecotoxicity water chronic	m^3/kWh	6.14E+01	4.42E+02	6.79E+01
Ecotoxicity water acute	m^3/kWh	6.12E+00	4.41E+01	6.77E+00
Ecotoxicity soil chronic	m^3/kWh	2.83E-01	6.92E-01	3.55E-01
Human toxicity air	m^3/kWh	2.80E+04	4.22E+04	4.46E+04
Human toxicity water	m^3/kWh	2.21E-01	3.84E-01	1.32E-01
Human toxicity soil	m^3/kWh	2.18E-02	5.42E-02	2.06E-02
Bulk waste	kg/kWh	3.01E-04	0.00E+00	5.18E-05
Hazardous waste	kg/kWh	1.29E-07	0.00E+00	3.91E-08
Radioactive waste	kg/kWh	1.76E-07	0.00E+00	7.70E-08
Slags/ashes	kg/kWh	1.09E-06	0.00E+00	9.14E-07
Resources (all)	kg/kWh	4.67E-06	2.44E-05	5.98E-06
Energy rate	MJ/kWh	2.73E+00	1.30E+01	4.19E+00

As the proposed systems are biomass-based, Analysis by SimaPro shows the advantage of community-based steam power system and Gasification System. More subtle aspects remains to be incorporated as plantation absorbs carbon dioxide for their photosynthesis such that carbon dioxide generated from the latter processes are, in fact, recycled.

Table 3.38 The Comparison of environmental impact from national grid and community-based power plants (Pt per kWh)

Impact category	Unit	Gasification system base	grid-line nation	Rankine steam power system base
Total	Pt	8.02E-04	4.27E-03	9.19E-04
Global warming (GWP 100)	Pt	5.37E-05	7.31E-05	8.73E-05
Ozone depletion	Pt	4.77E-05	4.09E-04	5.65E-05
Acidification	Pt	1.56E-05	2.93E-05	3.52E-05
Eutrophication	Pt	1.22E-05	1.96E-05	2.44E-05
Photochemical smog	Pt	4.80E-06	2.62E-05	1.16E-05
Ecotoxicity water chronic	Pt	2.09E-04	1.51E-03	2.31E-04
Ecotoxicity water acute	Pt	2.32E-04	1.67E-03	2.56E-04
Ecotoxicity soil chronic	Pt	2.94E-07	7.19E-07	3.70E-07
Human toxicity air	Pt	1.01E-05	1.52E-05	1.60E-05
Human toxicity water	Pt	5.52E-06	9.58E-06	3.29E-06
Human toxicity soil	Pt	2.05E-04	5.12E-04	1.94E-04
Bulk waste	Pt	2.45E-07	0.00E+00	4.22E-08
Hazardous waste	Pt	6.87E-09	0.00E+00	2.08E-09
Radioactive waste	Pt	5.53E-06	0.00E+00	2.42E-06
Slags/ashes	Pt	3.43E-09	0.00E+00	2.88E-09
Resources (all)	Pt	0.00E+00	0.00E+00	0.00E+00

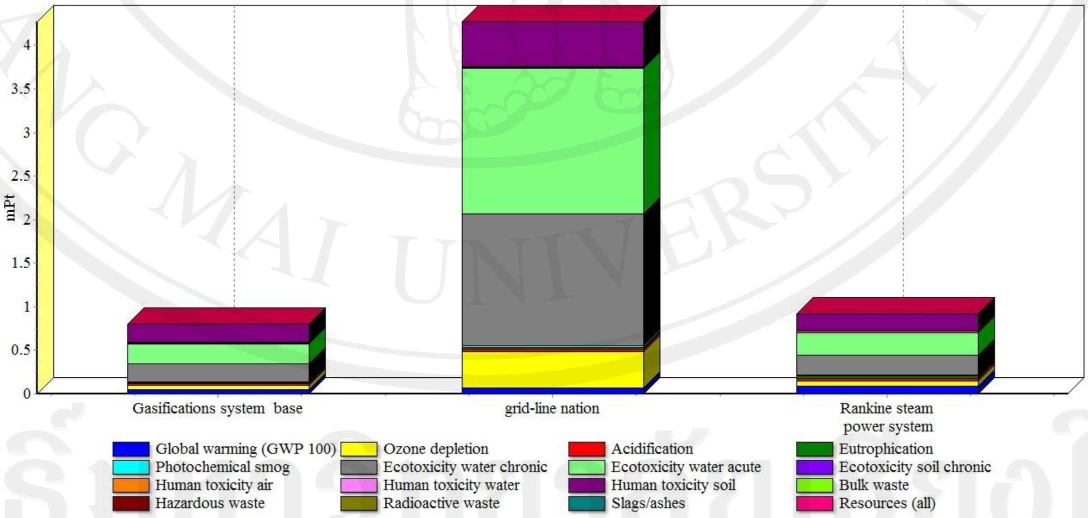

Figure 3.21 The Comparison of environmental impact from national grid and community-based power plants (Pt/kWh)

However, carbon recycling is not included or primarily focused in this work. The environmental impact of national grid line at 4.27E-03 Pt is found to be higher than that from steam-powered and gasification systems which are at 9.19E-04 Pt and 8.02E-04 Pt, respectively. The higher efficiency of the gasification system yields less environmental impact as it consumes fewer resources. There is also fewer use of the chemical substance energy for the relevant phases especially in providing wood fuel. However, the using organic or fermented fertilizer instead of chemical fertilizer is still viable. As the plantation is planned such that the power plant is just at the center, logistic route and corresponding fuel use can still be improved. Additionally, the exploitation of sophisticating technologies into community-based system such as low No_x Burner, Electrostatic Precitator (ESP), and Flue Gas Desulfurization (FGD) is viable option but, for the sake of simplicity to the community to operate, it is not incorporated into this work.

Even with just simple installation, the community-based power plant is environmental friendly and, seems to be suitable for agriculture communities where plantation is possible. It also promotes decentralization and energy independency which play significant role in sustainability and, hence, supports national energy policies. However, operating the power plant is not simple so that any communities, especially those in the rural areas, can invest on it without proper planning, training, and management, for the least. Plantation can provide the community not just only the wooden biomass but also other resource for monetary gain. The systems either simple rankine system or gasification is costly in spite of the fact that they can be simple; therefore, it needs benefits to offset the cost. In addition to that, efficiency improvement becomes more important if issues on environmental impact are factored in. Several options are proposed in the following sections.

3.6.6 Environmental impacts of cost improvement.

As seen in section 3.4, it could found that the unit cost of electricity generated by a rankine steam-powered system and downdraft gasification system are 5.78 Baht/kWh and 4.17 Baht/kWh, Respectively. With adder incentive, if this electricity is sold to EPA, the community will be paid at approximately 3.82 Baht/kWh. This is due to its small size and relatively low efficiency. Plantation for benefit from electrification alone is obviously not feasible so several improvements have to be done.

Supplement income from the by-products from plantation and simple addition of heat recovery system are proposed to offset the cost. Selected species, *Leucaena Lecocephala*, offers its tops and leaves as animal supplement feedstock. These can become beneficial to community-based power plant around the power plant facilities.

For Thai agricultural communities, their local products can be traded when they are fresh or can be preserved for later trade which, for some cases, is preferred. Drying is a simple process which communities usually practice. Most of the times, it is rare for communities to own and operate post harvesting facilities as they usually rely on the local private investment where some fees are applied and dried products are traded to the private traders afterward. This work proposes that possibility of small dryer is installed from which 50% of waste heat is recovered. It certainly adds some cost to the system but it will generate incomes to the community as well. Additionally, as the proposed dryer is operated with the heat recovery from the system, it will replace the need to use fossil-based fuel from which diesel or Liquefied Petroleum Gas (LPG) is used with additional emissions; hence, environmental impacts are reduced. However, small fan for hot air circulation in drying compartment is needed and grid electricity consumption is still presented.

Heat recovery system for the gasification system might not be that simple in comparison with Rankine's steam-powered system, as the main source of waste heat is from the gas engine. However, gasification system also offers charcoal as a by-product which can be additional improvement to the environment. Community can replace biomass use in the household with this charcoal. Biomass resources are rather preserved and the alternative can be considered environmental friendly. Binding and pressing have to be done to form the charcoal briquette. Most of the time simple binding material made from corn or cassava starch is possible. As the briquettes can be sold, additional income for the community-based power plant is then possible to offset the system cost.

Corresponding LCI's is reported in this Table 3.39-3.41. The following cases are explored:

Table 3.39 LCI of the chopped-dried tops and leaves process.

Input			Output		
Diesel	1.70E+00	kg	**Product** chopped-dried tops and leaves	500	kg
			Emission to Air		
			Carbon dioxide	5.4	kg
			Carbon monoxide	37.14	g
			Nitrogen oxides	0.14	g
			Nitrogen dioxide	73.56	g
			NMVOC, non-methane volatile organic compounds, unspecified origin	13.12	g
			Methane	0.72	g

Table 3.40 LCI of the Char carbon process.

Input			Output		
Modified starch	50	kg	Product Char carbon	1,000	kg
Electricity nation-grid	46.24	kWh	**Emission to Air**		
Polyethylene low	5	kg	Carbon dioxide	20.68	kg
			Sulfur dioxide	9.25	kg
			Nitrogen oxides	4.14	kg
			Particulates, unspecified	1.85	kg

Table 3.41 LCI of the waste heat recovery for drying the agricultural process.

Input			Output		
Electricity nation-grid	268.56	kWh	Product agricultural dried	1,000	kg
			Emission to Air		
			Carbon dioxide	128.15	kg
			Sulfur dioxide	57.31	kg
			Nitrogen oxides	25.63	kg
			Particulates, unspecified	11.46	kg

The environmental impacts for each improvement case in the unit of kg substance equivalent/kWh are shown in Table 3.42 and those in the Unit of Pt/kWh are shown in Table 3.43. Additional environmental impact of produced charcoal is at 1.47×10^{-3} Pt/kg of charcoal resulting from the use of machinery powered by fossil based fuel. Using machinery to collect tops and leaves from plantations also raises additional environmental impact at 4.13 x

10^{-5} Pt/kg of dried leave. The environmental impacts of waste heat recovery system for steam-powered is at 2.38 x 10^{-4} Pt/ kg of agricultural products. The best case which put the least burden to the environment is case 3 for the gasification system where three improvements are incorporated where 9.8 x 10^{-4} Pt/kWh is imposed. For steam-powered system, case 3 is at the best there the burden is suggested at 2.10 x 10^{-3} Pt/kWh.

Table 3.42 The environmental impacts for all scenarios (kg substance equivalent/kWh)

Impact category	Unit	Gasifications system base	Gasifications system Case.1	Gasifications system Case.2	Gasifications system Case.3	Rankine steam power system base	Rankine steam power system Case.1	Rankine steam power system Case.2	Rankine steam power system Case.3
Global warming (GWP 100)	g CO2	424.221	424.659	440.896	441.334	689.996	690.918	849.476	850.398
Ozone depletion	g CFC11	7.8E-05	7.8E-05	8.3E-05	8.3E-05	9.2E-05	9.3E-05	0.00028	0.00028
Acidification	g SO2	0.88993	0.8936	0.96567	0.96933	2.00511	2.01283	2.46499	2.47271
Eutrophication	g NO3	1.21316	1.22026	1.50497	1.51207	2.42069	2.43563	2.95669	2.97163
Photochemical smog	g ethene	0.09231	0.09289	0.10188	0.10246	0.22305	0.22427	0.36201	0.36323
Ecotoxicity water chronic	m3	61.3625	61.4831	80.3519	80.4725	67.878	68.1319	189.788	190.042
Ecotoxicity water acute	m3	6.12041	6.13244	8.01407	8.02611	6.76548	6.79082	18.9425	18.9678
Ecotoxicity soil chronic	m3	0.28291	0.28322	0.5939	0.59421	0.35539	0.35603	0.54625	0.54689
Human toxicity air	m3	27963.6	27981.1	30509.2	30526.7	44570.1	44607	56220.7	56257.6
Human toxicity water	m3	0.22112	0.22177	0.48716	0.4878	0.13193	0.1333	0.23779	0.23915
Human toxicity soil	m3	0.02175	0.02177	0.02357	0.02359	0.02059	0.02063	0.03555	0.03559
Bulk waste	kg	0.0003	0.0003	0.0011	0.0011	5.2E-05	5.3E-05	5.2E-05	5.3E-05
Hazardous waste	kg	1.3E-07	1.3E-07	3.5E-06	3.5E-06	3.9E-08	4E-08	3.9E-08	4E-08
Radioactive waste	kg	1.8E-07	1.8E-07	3.2E-07	3.2E-07	7.7E-08	7.9E-08	7.7E-08	7.9E-08
Slags/ashes	kg	1.1E-06	1.1E-06	3E-06	3E-06	9.1E-07	9.3E-07	9.1E-07	9.3E-07
Resources (all)	kg	4.7E-06	4.7E-06	6.5E-06	6.5E-06	6E-06	6E-06	1.3E-05	1.3E-05

Table 3.43 The environmental impact for all scenarios (Pt/kWh)

Impact category	Unit	Gasifications system base	Gasifications system Case.1	Gasifications system Case.2	Gasifications system Case.3	Rankine steam power system base	Rankine steam power system Case.1	Rankine steam power system Case.2	Rankine steam power system Case.3
Total	Pt	8.02E-04	8.03E-04	9.79E-04	9.80E-04	9.19E-04	9.22E-04	2.10E-03	2.10E-03
Global warming (GWP 100)	Pt	5.37E-05	5.37E-05	5.58E-05	5.58E-05	8.73E-05	8.74E-05	1.08E-04	1.08E-04
Ozone depletion	Pt	4.77E-05	4.78E-05	5.08E-05	5.08E-05	5.66E-05	5.67E-05	1.69E-04	1.69E-04
Acidification	Pt	1.56E-05	1.57E-05	1.70E-05	1.70E-05	3.52E-05	3.53E-05	4.33E-05	4.34E-05

Table 3.43 The environmental impact for all scenarios (Pt/kWh) (Cont.)

Impact category	Unit	Gasifications system base	Gasifications system Case.1	Gasifications system Case.2	Gasifications system Case.3	Rankine steam power system base	Rankine steam power system Case.1	Rankine steam power system Case.2	Rankine steam power system Case.3
Eutrophication	Pt	1.22E-05	1.23E-05	1.52E-05	1.52E-05	2.44E-05	2.46E-05	2.98E-05	3.00E-05
Photochemical smog	Pt	4.80E-06	4.83E-06	5.30E-06	5.33E-06	1.16E-05	1.17E-05	1.88E-05	1.89E-05
Ecotoxicity water chronic	Pt	2.09E-04	2.10E-04	2.74E-04	2.74E-04	2.31E-04	2.32E-04	6.47E-04	6.48E-04
Ecotoxicity water acute	Pt	2.32E-04	2.32E-04	3.03E-04	3.04E-04	2.56E-04	2.57E-04	7.17E-04	7.18E-04
Ecotoxicity soil chronic	Pt	2.94E-07	2.95E-07	6.18E-07	6.18E-07	3.70E-07	3.70E-07	5.68E-07	5.69E-07
Human toxicity air	Pt	1.01E-05	1.01E-05	1.10E-05	1.10E-05	1.60E-05	1.61E-05	2.02E-05	2.02E-05
Human toxicity water	Pt	5.52E-06	5.54E-06	1.22E-05	1.22E-05	3.29E-06	3.33E-06	5.94E-06	5.97E-06
Human toxicity soil	Pt	2.05E-04	2.06E-04	2.23E-04	2.23E-04	1.95E-04	1.95E-04	3.36E-04	3.36E-04
Bulk waste	Pt	2.45E-07	2.46E-07	8.93E-07	8.93E-07	4.22E-08	4.30E-08	4.22E-08	4.30E-08
Hazardous waste	Pt	6.87E-09	6.89E-09	1.88E-07	1.89E-07	2.08E-09	2.12E-09	2.08E-09	2.12E-09
Radioactive waste	Pt	5.53E-06	5.56E-06	1.01E-05	1.01E-05	2.42E-06	2.47E-06	2.42E-06	2.47E-06
Slags/ashes	Pt	3.43E-09	3.45E-09	9.42E-09	9.44E-09	2.88E-09	2.91E-09	2.88E-09	2.91E-09

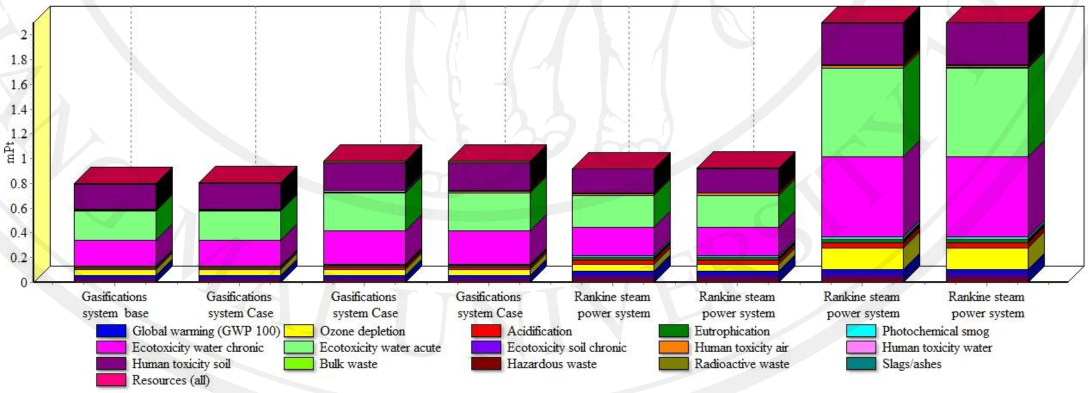

Figure 3.22 The environmental impacts for all scenarios (Pt/kWh)

3.7 Externality Cost

Externality cost is a price to be paid to cover the environmental impacts from the products. It is necessary to add the externality cost to the actual cost of generating electricity to reflect the economic and environmental effects. Externality is determined using existing data records, mostly, from developed countries. As the externality cost is accessed from Value of Environmental Damage (VED) which is generated from consumer satisfaction and acceptance to pay (willingness to pay, WTP). To be able to use this numbers for Thailand, benefit transfer method has to be used as referred in section 2.3.4. Referenced VED values from several publications are used and adjusted as shown in Table 3.44[1]. Having the amounts of all emissions and other pollutants, each corresponding externality cost is adjusted and shown in Table 3.45.

Table 3.44 VED for impacts

Impact category	Reference Substance	Reference Source	VED_{ref} ($/ton)		VED_{Thai} (Baht/ton)	
			Min	**Max**	**Min**	**Max**
Global warming (GWP 100)	CO_2	CO2 damage cost for rural area (State of Minnesota Public Utilities Commission, 2011)	0.3	3.1	0.06	94.55
Ozone depletion	CFC-11	GWP_{CFC-11} x $VED_{CO2\ Minnesota,\ USA\ 2011}$	1,200	12,400	236.40	378,200.00
Acidification	SO_2	SO2 damage cost for rural area (State of Minnesota Public Utilities Commission, 2011)	10	25	1.97	762.5
Eutrophication	NO_3	NO3 damage cost for rural area (State of Minnesota Public Utilities Commission, 2011)	18	102	3.55	3,111.00
Photochemical smog	Ethene	GWP_{ethene} x $VED_{CO2,\ Minnesota,\ USA\ 2011}$	0.9	9.3	0.18	283.65
Ecotoxicity water chronic	Lead	Lead damage cost for rural area (State of Minnesota Public Utilities Commission, 2011)	402	448	79.19	13,664.00
Ecotoxicity water acute	Lead	Lead damage cost for rural area (State of Minnesota Public Utilities Commission, 2011)	402	448	79.19	13,664.00
Ecotoxicity soil chronic	Lead	Lead damage cost for rural area (State of Minnesota Public Utilities Commission, 2011)	402	448	79.19	13,664.00
Human toxicity air	CO	CO damage cost for rural area (State of Minnesota Public Utilities Commission, 2011)	0.21	0.41	6.41	12.51
Human toxicity water	Hg	Hg damage cost (Walter, 2000)	0.12		3.6	
Human toxicity soil	Lead	Lead damage cost for rural area (State of Minnesota Public Utilities Commission, 2011)	402	448	12,261.00	13,664.00
Bulk waste	waste	Bulk waste cost (Phuket City, 2010)	17.31		528	
Hazardous waste	Toxic waste	The economics of waste (Richard, 2002)	0.16		4.82	
Radioactive waste	Nuclear waste	The economics of waste (Richard, 2002)	396		12,078.00	
Slags/ashes	Coal ash	Combustion science and engineering (Annamalai and Puri, 2007)	7.50E-03		2.29E-01	

[1] In this case 1 USD = 30.5 Baht (BOT,2011) , 1 USD = 19.16 baht (The Big Mac Index, 2011), GDP Per Capita (PPP) for Thailand = US$ 9598.01, and GDP Per Capita (PPP) for the US = US$48665.81

The externality cost of the rankine steam-powered system is between 0.003 to 0.565 Baht/kWh. It could be found that the main costs are Human toxicity soil, Eutrophication, Global warming, and Ecotoxicity soil chronic, respectively. Similarly, the externality cost of the gasification system is in a range from 0.002 - 0.436 Baht/kWh which is lower than that of steam system due to its higher efficiency. This resulting externality cost is in the same trend as what is reported by Energy for Environment Foundation (EforE, 2004) as shown in Table 3.46. For the improvement cases discussed in the earlier section, the real cost, where externality cost, is reported for each case and the results are shown in Table 3.47. The externality does not affect much on the cost of each case so that the decision to select the system out of these cases will depend on the economic analysis only.

Table 3.45 The externality costs of both of power plant community.

Impact category	Rankine steam power system			Gasification system		
	Pt/kWh	Externality (baht/kWh)		Pt/kWh	Externality (baht/kWh)	
		Min	Max		Min	Max
Global warming (GWP 100)	8.73E-05	4.08E-05	6.52E-02	5.37E-05	2.51E-05	4.01E-02
Ozone depletion	5.65E-05	2.19E-08	3.50E-05	4.77E-05	1.84E-08	2.95E-05
Acidification	3.52E-05	3.95E-06	1.53E-03	1.56E-05	1.75E-06	6.79E-04
Eutrophication	2.44E-05	8.58E-06	7.53E-03	1.22E-05	4.30E-06	3.77E-03
Photochemical smog	1.16E-05	3.95E-08	6.33E-05	4.80E-06	1.64E-08	2.62E-05
Ecotoxicity water chronic	2.31E-04	2.69E-06	4.64E-04	2.09E-04	2.43E-06	4.19E-04
Ecotoxicity water acute	2.56E-04	2.68E-06	4.62E-04	2.32E-04	2.42E-06	4.18E-04
Ecotoxicity soil chronic	3.70E-07	2.81E-03	4.86E-01	2.94E-07	2.24E-03	3.87E-01
Human toxicity air	1.60E-05	2.22E-06	6.72E-04	1.01E-05	1.39E-06	4.21E-04
Human toxicity water	3.29E-06	1.18E-11	1.83E-09	5.52E-06	1.98E-11	3.06E-09
Human toxicity soil	1.94E-04	1.96E-05	3.39E-03	2.05E-04	2.08E-05	3.58E-03
Bulk waste	4.22E-08	2.73E-05	2.73E-05	2.45E-07	1.59E-04	1.59E-04
Hazardous waste	2.08E-09	1.22E-12	1.88E-10	6.87E-09	4.03E-12	6.23E-10
Radioactive waste	2.42E-06	6.01E-09	9.30E-07	5.53E-06	1.37E-08	2.12E-06
Slags/ashes	2.88E-09	3.04E-12	2.09E-10	3.43E-09	3.63E-12	2.50E-10
Total	**9.19E-04**	**0.003**	**0.565**	**8.02E-04**	**0.002**	**0.436**

Table 3.46 The environmental costs of electricity generation, classified by fuel types

Source	Generation Cost (Baht/kWh)	Externality Cost (Baht/kWh)
Coal	1.45	2.76
Oil	2.02	2.67
Natural Gas	1.36	0.79
Biomass	1.57	0.63
Hydro	1.76	0.39
Solar	9.07	0.14
Wind	3.98	0.05

Source : EforE, 2004

Table 3.47 summary of economic and environment analysis.

System	Life cycle cost (baht/ kWh)	Payback period (Yrs)	NPV (Baht)	IRR (%)	Impact (Pt/kWh)	Externality cost (baht/kWh)		Life cycle cost Including Externality (baht/kWh)	
						Min	Max	Min	Max
steam, base	5.78	(35.58)	(6,682,139)	NA	9.19E-04	0.003	0.565	5.783	6.345
steam, Case.1	5.78	(47.67)	(6,311,533)	NA	9.22E-04	0.003	0.566	5.783	6.346
steam, Case.2	5.78	4.23	9,817,081	24.36%	2.10E-03	0.004	0.706	5.784	6.486
steam, Case.3	5.78	3.42	10,188,124	24.91%	2.10E-03	0.004	0.707	5.784	6.487
Gasification, base	5.78	17.19	(3,199,398)	4.55%	8.02E-04	0.002	0.436	5.782	6.216
Gasification, Case.1	4.17	16.20	(2,846,985)	5.06%	8.03E-04	0.002	0.437	4.172	4.607
Gasification, Case.2	4.17	7.79	3,009,205	11.72%	9.79E-04	0.005	0.865	4.175	5.035
Gasification, Case.3	4.17	7.59	3,361,617	12.05%	9.80E-04	0.005	0.865	4.175	5.035

3.8 Conclusions

The feasibility study of small community-based biomass power plant (100 kW_e and below) is reported in this chapter. Powered by biomass from plantation, economic and environment analyses of systems powered by two different technologies: Rankine steam-powered system and gasification system are compared. Set up of analyses is kept simple to avoid complexity so that and power plant is community-owned.

Corresponding life cycle costing for both systems is calculated and reported as 5.78 Baht/kWh for rankine steam-powered system and 4.17 Baht/kWh for gasification system due to its lower efficiency at such small scale. Profit from electrification alone is not feasible since, even with adder, biomass-based power price is not competitive enough unless additional profit from co-products, by-products, and waste-heat recovery system is exploited.

One possibility is that electrification from Rankine steam-powered system should be incorporated with managing the livestock feed from the plantation of wood fuel where *Leucaena Leucocephala* is selected and servicing drying unit.

Another possibility for electrification from the downdraft gasification power plant is to incorporating the system with managing livestock feed from biomass plantation, managing charcoal briquettes, and servicing drying unit.

Life cycle assessment for producing 1 kWh electricity from two different community-based biomass power plants is also investigated. Fueled by biomass from community plantation, electricity generated from these two systems shows lower environmental impacts than that from national grid. As expected, with higher efficiency, the gasification system yields less environmental impacts. Analysis reveals that externality costs will not affect much on the cost of the system.