CHAPTER 2

THEORY

The decision for investment in any project is a main economic consideration. Investing in a community power plant should involve the decision from both economic and environmental impacts. A power plant affects the whole community. Economics analysis is used to analyze all of the expenses in the production of electricity. Usually, the main factors affecting to the cost will include the fuel, the location of the plant, the transportation, the technology cost, and operation cost. This research will utilize the economics of the Life Cycle Cost Analysis (LCCA), and the environmental impact analysis of the Life Cycle Assessment (LCA) to determine if it is feasible to build a small community power plant in Thailand. The results of this study are expected to apply designing a power plant for community's energy-independence and sustainability. The chapter is divided into 4main sections to elaborate later on the assessment of the potential fuel to be fed to the power plant, the biomass fuel-logistics, Life Cycle Costing Analysis (LCCA) and Life Cycle Assessment (LCA) in theory.

2.1 Assessment of the biomass feedstock potential

The design of a power plant must be balanced with the capacity of the biomass feedstock. To be sustainable, community power plant should be managed and operated by the community to maximize the benefit to its own. In general, the community should be able to provide local biomass to the locally-owner power plant. The fuel is possibly from agricultural residue from harvesting and processing of agricultural products such as rice husk, or corn cob, or from what is available as by-products from local industries, or from plantation of biomass crops. These can profit the community if all residues and plantation are prepared, shared and perhaps traded locally and accelerate the economics of the community.

- Biomass Selection

The type of agricultural crops to be planted depends on the environment and topography of the area. For example, the northern topography is mountainous with sufficient rainfall. The northern areas are suitable to grow rice and corn which also enlist various form of residues from which energy can be derived. The advantage of agricultural residues is to easily provide sustainable supply since agricultural crops are replanted continuously but it needs proper management in the agricultural sector. Biomass from plants is generated due to the reaction of photosynthesis from solar energy from which carbon-dioxide and water are used to form the elemental form of biomass as shown in this following reaction:

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Solar energy}} C_6H_{12}O_6 + 6O_2$$

where $C_6H_{12}O_6$ is a chemical element of biomass. The conversion of biomass into energy can be done through various kind of reactions, including a simple combustion where biomass energy stored is released in accordance with equations:

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Combustion}} 6CO_2 + 6H_2O + \text{Energy} + \text{Ash}$$

In spite of the fact that biomass burning releases CO_2 emission into the atmosphere, the growth of biomass crops absorbs CO_2 from the atmosphere and combines with solar energy for use in the process of photosynthesis for growth. The CO_2 emission from the burning is equal to the absorption of CO_2 for photosynthesis, so the burning process is basically carbon neutral (George et al., 2009). Wood-derived sources are superior in this regard to fossil fuels. The potential of agricultural residue in each location is depended on species of plant and the harvest seasons. For example, in the northern part of Thailand there are many species of crop including rice which is planted in October to December. More examples are shown in Table 2.1. The amount of the agricultural residue affects all decisions on the locations of the power plant, planning, logistics and other related systems. The main evaluation methods of agricultural residues are the area and the quantitative method shown below.

Table 2.1 Seasons of agricultural productivity and biomass of various types in the Northern region

Products	Biomass	Months											
		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Rice	husk		■	■	■								
	straw.		■	■	■								
Off-season rice	husk							■	■	■	■	■	
	straw							■	■	■	■	■	
Sugar cane	bagasse.				■	■	■	■	■				
	leaves and tops.				■	■	■	■	■				
Maize	cob	■	■	■	■	■							
	corn stalks.	■	■	■	■	■							
Cassava	root				■	■	■	■	■	■	■	■	■
	stalk.				■	■	■	■	■	■	■	■	■
Wood	lumber	■	■	■	■	■	■	■	■	■	■	■	■
	sawdust	■	■	■	■	■	■	■	■	■	■	■	■

Source: Energy for Environment Foundation (2012)

Biomass potential depends on its amount available and several factors. Some agricultural residues are needed for other benefit such as for feed mixing for livestock. Availability is then varied. So, the potential energy of the area is calculated as follows: (Ministry of Energy, 2009)

Potential energy (MJ) = Production (kg) x Residue per Production x Surplus availability factor x heating value (MJ/kg)

The surplus availability factor is based on survey data and research which is shown in Table 2.2. Also, when converted into energy, its heating value is different.

The result of biomass potential in the target area is developed by mathematical model which is part of the Thailand-energy database. The principle of mathematical modeling is based on knowledge, experience, and survey-data. The Energy Policy and Planning Office, Ministry of Energy of Thailand, offers the database for public use to promote the utilization of alternative energy.

Table 2.2 The factors used to evaluate the potential energy

Production	Residues	Moisture (%)	Residues/ Production (RPR)	Energy use factor	Surplus availability factor	LHV (MJ kg^{-1}) (as received)
Sugarcane	Bagasse	50.00	0.250	0.793	0.207	6.43
	Top & trash	50.00	0.302	0.000	0.986	6.82
Paddy	Husk	8.83	0.230	0.531	0.469	12.85
	Straw (top)	8.17	0.447	0.000	0.684	8.83
Oil palm	Empty bunches	8.81	0.428	0.030	0.584	16.44
	Fiber	10.11	0.147	0.858	0.134	16.19
	Shell	13.00	0.049	0.588	0.037	17.00
	Frond	48.34	2.604	0.000	1.000	7.97
	Male bunches	13.82	0.233	0.000	1.000	14.86
Coconut	Husk	12.53	0.362	0.289	0.595	14.71
	Shell	11.79	0.160	0.413	0.378	16.48
	Empty bunches	13.03	0.049	0.144	0.843	13.94
	Frond	11.21	0.225	0.159	0.809	14.55
Cassava	Stalk	—	0.088	0.000	0.407	16.99
Maize	Corn cob	8.65	0.250	0.193	0.670	16.63
Groundnut	Shell	—	0.323	0.000	1.000	11.23
Cotton	Stalk	9.33	3.232	0.000	1.000	13.07
Soybean	Stalk, leaves, shell	—	2.663	0.007	0.760	18.00
Sorghum	Leaves & stem	—	1.252	0.118	0.648	17.80

(source: Sajjakulnukit et al., 2005)

The mathematical model used to evaluate the potential of renewable energy was created with 10 sources which includes hydro, solar, biodiesel, biogas, bagasse, agricultural and wood residues, rice husk, sawdust and wood dust. All is available on www.thaienergydata.in.th. The example of data includes yield, the ratio of biomass residue and biomass utilization. The potential of agricultural residue is shown in the form of energy (MJ). The density of biomass fuel per area is one of the factors to determine the location of the power plant. If sources of fuel are concentrated or in the vicinity of selected area, these will result in a reasonable transportation costs and time required to transport.

2.2 Geographic Information System and its application on biomass logistic

Biomass potential varies to throughout the area. Geographic Information System (GIS) is a tool to analyze spatial data which can be data will be arranged in patterns of linking relationship to the coordinate system based on the location biomass potential, in this current work, example is shown as geo-reference (GISTHAI, 2008) in 2.1. GIS data is divided into two types that are spatial data and non spatial data. Spatial Data is data which is referred to the ground and geographic reference. Non spatial data is the detailed information of location, for example, the usage data, and economy data, etc. All data is collected and, it spatial, geographic information database is modified accordingly. Some of the GIS data is already available from a number of organizations. Data analysis is to overlay the spatial data under the conditions specified by the relationships of data to enable user to retrieves the information when need. The data or the results of the analysis are displayed in forms of numbers and graphics. This geo-spatial information is essential for systematic and efficient planning and decision making in resource and environmental management (Jirakajohnkool, 2009).

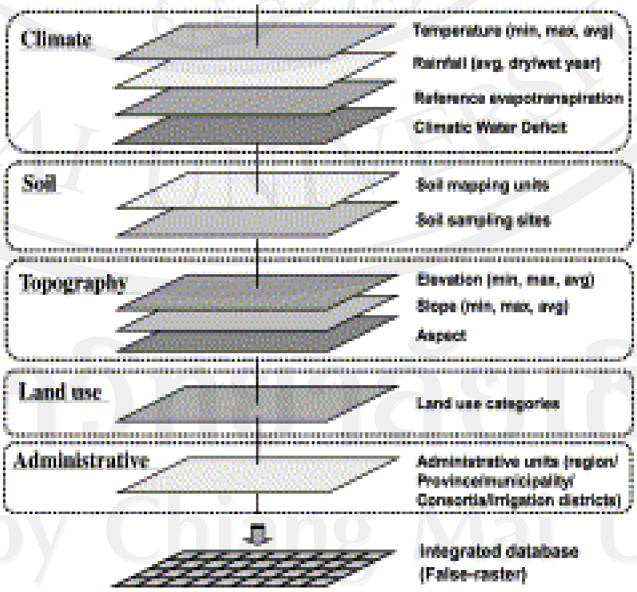

Figure 2.1 Principle of Geographic Information System

(Soure: Todorovic and Steduto, 2003)

Geographic information systems have become popular for various applications. For examples, in environmental aspect, GIS is used to collect spatial data of sources of toxic substances that are at risk for surface and underground water. In the management of emergencies and disasters, GIS is also used to collect routes to be avoided based on the prediction model on heavy traffic, or location of potential traffic blockage in transportation aspect, it is used to improve the efficiency of the transportation network by network analysis such as planning bus routes, and goods transportation (Junthon and YhouMeaung, 2002). For management of agricultural residues, GIS is applied to select biomass transport routes for reduction costs in relation with a location of power plant. Criteria for determining the position of the powerhouse is the least cost of collection and transportation of agricultural residues to the location where the power plant to be build. The transportation cost relates to the distance. This is shown in the form of the equation (Perpina et al., 2009)

$$CF=(FC_1+FC_2)NR_i + VC\sum_{i=1}^{n} d_i \quad (2.1)$$

CF = Collection and transportation costs (Baht)

FC_1 = fixed cost associated to loading/unloading operations where time, human resources and fuel are used

FC_2 = a fixed cost associated to biomass compacting, as well as the costs deriving from personnel and fuel involved in this process.

VC = a cost that depends on the total distance travelled ($\sum di$) to transport the total amount of biomass from the origin to destination

NRi = the number of trips needed to transport the biomass from the origins to one only destination (bioenergy plant)

The average cost of collecting and transporting biomass is calculated from the equation (Perpina et al., 2009).

$$\text{Average cost(Baht/ton)} = \frac{\text{CFi(Baht)}}{\text{Total biomass district (ton)}} \qquad (2.2)$$

2.3 Economic analysis

The assessment cost of electricity requires a basic knowledge of economics. Power plants will need to be provided with resources and materials for use in operations. These costs depends on several factors such direct and indirect costs involved, operating costs and maintenance, and the salvage value at the end of the life span as inflation, interest rates etc. The assessment of life cycle cost is to evaluate the cost of electricity production by biomass fuel throughout power plant's life cycle in present study. Economics of the project in terms of simple payback period, the net present value investment, and internal rate return and return on investment will be considered.

2.3.1 Life cycle cost analysis: LCCA

LCCA is used to predict the expenditures for the project, i.e. The power plant its electricity cost is associated with the costs of the initial investment, operation cost, maintenance costs, fuel costs, replacement costs, and costs of depreciation of equipment. The total cost is to evaluated against it unit of production (kWh). The cost expected in the future will be converted in reference with current value. The cost for the entire life cycle of electricity productions is based on the following equation (Blank and Tarquin, 1998):

$$LCC = C_{pw} + M_{pw} + F_{pw} + R_{pw} - S_{pw} \qquad (2.3)$$

where C = capital costs ($)

M = operating and maintenance costs ($)

F = fuel costs ($)

R = replacement costs ($)

S = salvage value ($)

subscript $_{pw}$ = present worth

Energy cost is usually displayed in terms of cost per unit (cost/kWh), calculated from the total expenditure based on the total of electricity produced. The unit cost of electricity is then calculated from the equation as

$$C_e = \frac{LCC}{E_t} \tag{2.4}$$

where C_e =Cost of electricity per unit (Baht/kWh)

LCC = Life cycle cost (Baht/year)

E_t = Energy produced throughout the project (kWh/year).

In the LCCA, the cost incurred during a different time. Any costs incurred will be adjusted into their present value through:

A. The equation of current and future value for the money.

$$P = \frac{F}{(1+i)^n} \tag{2.5}$$

where F is the value of money in the future(Baht)

P is the value of the current (Baht)

i is the interest rate per year

n is time period (year)

B. The equation of present value of income or expenses each year

$$P = A\left[\frac{(1+i)^n - 1)}{i(1+i)^n}\right] \tag{2.6}$$

where A is the value of income (annually uniform cost)

Costs of energy use, costs of operation, and maintenance expenses requires to pay annually and can be adjusted at any time. Changes in costs depend on escalation rate of energy and the rate of exchange rate of the country. The calculations must be adjusted to a value in the current year, which was calculated as the relationship.

$$P = A\left(\frac{1+e}{i-e}\right)\left(1-\left(\frac{1+e}{1+i}\right)^{n}\right) \tag{2.7}$$

where e is Escalation rate

2.3.2 Simple Payback Period (SPB)

Simple Payback Period is the length of time required for accumulate the incoming return to offset the cumulative costs of investment which is calculated from the equation.

$$SPB = \frac{Cost\ of\ \mathrm{Pr}oject}{Annual\ Cash\ Inflows} \tag{2.8}$$

2.3.3 Internal Rate of Return (IRR)

IRR is the discount rate that makes the net present value of all cash flow from a project equal to zero. IRR is considered interest rate which is equivalent with interest rate on the loan investment. IRR is the solution using trial and error method, which is calculated from the equation

$$\mathrm{NPV} = \sum_{n=1}^{n}\left(\frac{\mathrm{NCF_n}}{(1+\mathrm{i})^{n}} - \mathrm{TIC}\right) = 0 \tag{2.9}$$

where NPV is net present value (Baht)

NCF is net cash flow

TIC is total investment (Baht)

i is discount rate

n is time period (year)

In general, the project will be beneficial when its IRR is higher than the present interest rate of bank. Currently, the interest rate of 8.70% is for Minimum Retail Rate (MRR) (July 2012: BOT).

2.3.4 Externality

Power plant operation always affects the environment, for example, health problem, conflict of resources, and depletion resources. These problems may be solved by technology or process improvement, and also require more investment. Externality is the cost to solve for social and environmental impacts that occur from the products or projects. It is not directly from the system or the operation. It is typically exploited for governmental decision if the products or the projects should be supported. This research will assess externality cost of producing electricity from community-based power plant. Life cycle costing is adjusted to include this externality cost as the following:

$$LCC = C_{pw} + M_{pw} + F_{pw} + R_{pw} - S_{pw} + X_{pw} \quad (2.10)$$

where X_{pw} is the externality cost estimated from the quantity of emission or impact as :

$$X_{pw} = \sum (C_i x VED_i) \quad (2.11)$$

when C is amount of emission (kg) and

VED is Value of Environmental Damage of substance i (baht/kg)

Externality cost of electrification is derived from all energy and resources utilized during the course of electricity generation. There are several aspects of externality to be included in the analysis. If it is an assessment of public effect, theorem of welfare may be applied. This investigation focuses on the measurement of willingness to Pay (WTP) which describes the satisfaction level of consumers or value/benefit for the adoption of the changes. This might be called willingness to accept (WTA). Currently, this assessment has not widely utilized. It is one of objectives of this work to declare the life cycle costing which reflects the environmental impacts. However, the value of environmental damage used in this investigation will based on previously published data from variety of references, mostly from western countries. The external cost per ton of pollutant taken from those studies should be adjusted for Thailand. It can be accomplished by

$$VED_{(\mathrm{Thailand})} = VED_{(\mathrm{Reference})} \times \left(\frac{\mathrm{PPP_{Thailand}}}{\mathrm{PPP_{Refernce\ country}}}\right)^{\gamma} \quad (2.12)$$

where PPP = the gross national income (GNI) per capita for purchasing power parity.

γ = income elasticity.

There is several reports on how to designate income elasticity. Kanitpong and Promkutkeo (2010) reports the income elasticity of Thailand as 0.97 while Pearce (2003) suggests the elasticity for any country normally falls the range of 0.3-0.7. To range these suggestions, the income elasticity of this work is taken to be 0.5-1.

2.4 Life Cycle Assessment (LCA)

LCA is a method assessing the environmental effects related with the product or service during life cycle (ISO, 2006). The analyzed data includes the quantity of energy, raw material, all related wastes which are released to the environment. These discharges are classified and categorized as the environmental impact in the form of indicators based on equivalent or characterization factors. The equivalent unit is set from ability to cause environmental impacts of substances on the basis of reference. For example, global warming is measured in the form of $CO_{2\text{-}eq}$ and acidification is measured in the form of $SO_{2\text{-}eq}$. One kilogram of methane (CH_4) poses an impact to the environmental as much as what 25 kg of carbon dioxide can. Therefore, releasing one kilogram of methane is equal to 25 kg of CO_2; 1 g CH_4 is 25 g $CO_{2\text{-}eq}$.

LCA according to ISO14040 standard consists of 4 phases (ISO, 2006): (1) Goal & Scope Definition (2) Life Cycle Inventory (3) Impact Assessment, and (4) Interpretation. All phase are shown in Figure 2.2

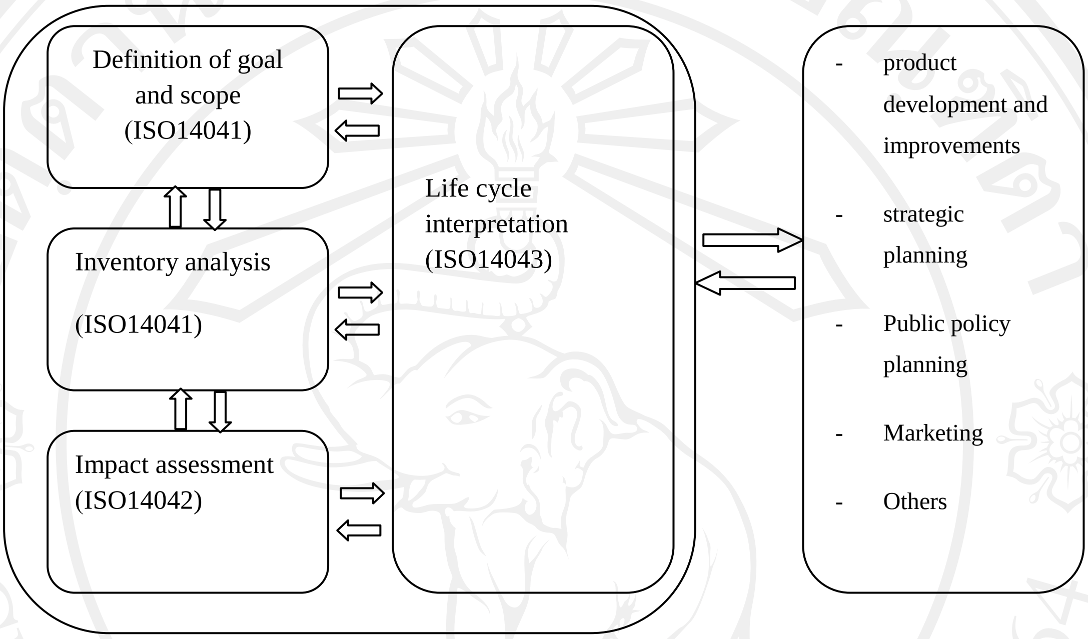

Figure 2.2 Phases in a Life Cycle Assessment of ISO 14040:2006.

2.4.1 Goal and scope of the analysis

The study of LCA must show the purpose of the study and how to study. LCA of electricity production is usually defined as kilowatt-hour (kWh) to allow the comparison among electrification from various source of fuel to compare to electricity.

2.4.2. Life Cycle Inventory Analysis (LCI)

Life cycle assessment depends on the items in inventory. The inventory consists of data collection of raw materials, energy, waste and pollution from the all processes from the cycle of project. Inputs substance is raw material and energy requirements of system. Discharge substance is atmospheric emission, waterborne emission, solid wastes and other releases for the entire life of all process as shown in Figure 2.3. LCI should be in a format that is easy to understand and should contain details of the process such as the quality and limitations. All processes related to the production of the goal and scope have to be refined and boundary has to be drawn to exclude all other processes. Current standardization of data collection methods is uncertain. However, it should adhere to the requirements of the LCI series. Sources of data are typical used data as follows: Electronic non-bibliographic databases (government and industrial), Electronic bibliographic databases, Electronic databases clearinghouses, Facility-specific industrial data, laboratory test data and Study-specific data. Steps to make inventory are as follows. Data from all processes needs to be validated. Verification of information will show the consistency of the data in each sub-process. Standardization of data collection methods can be bases on ISO14041 information related to the various processes studied.

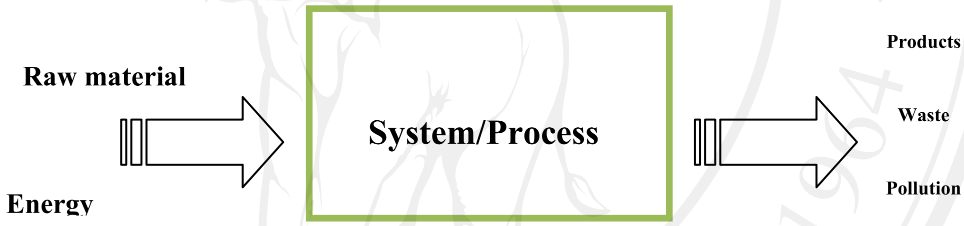

Figure 2.3 The diagram shown items in standard ISO 14040:2006

2.4.3 Life Cycle Impact Assessment (LCIA)

LCIA is to evaluate of life cycle inventory in terms of the potential environmental impacts on each side, including life stages and life cycle throughout of the product. Standard of LCIA has been defined by the ISO 14042. LCIA involves with are classification and characterization of environment impacts (Sadamichi, 2006). Figure 2.4 shows characterization, conversion and environmental mechanism in LCIA process.

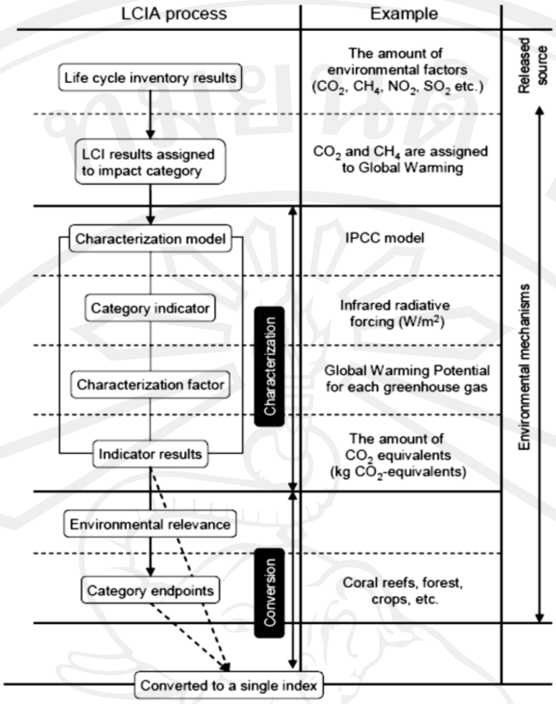

Figure 2.4 Characterization, conversion and environmental mechanism in LCIA process (source: Sadamichi, 2006).

The impact from the inventory is classified into group due to its effects such as global warming. This particular inventory includes Carbon Dioxide (CO_2), Methane (CH_4), NitrousOxide (NO_2), Hydroflurocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur Hexafluoride (SF_6). Then, potential of environmental impacts is evaluated from quantity of pollution that causes those effects. The standard unit of indicators is “Equivalent or Characterization Factors” that calculated by comparing the ability of environmental impact with a reference substances. Equivalents are calculated by models described in sequel physics - chemical mechanism of pollutants in the environment. Each environmental impact will specify the different indicators as a base unit such as the substances causing global warming will be calculated in unit of CO_{2-eq} and Acidification is calculated in the units of SO_{2-eq} etc. The value of potential to environmental impact is calculated from the equation as

$$EP_j = \sum (Q_i x EF_{ij}) \tag{2.13}$$

where

EP_j is Environmental Impact Potential

Q_i is Quantity of Substances

EF_{ij} is Equivalency Factor, as shows Equivalency Factor of global warming Table 2.3

Table 2.3 Example of Equivalency Factor: EF_{ij} for Global warming

Substance	**Formula**	**GWP (100 years)** $\mathbf{g\ CO_{2-eq}\ /\ g}$ **substance**
Carbon Dioxide	CO_2	1
Methane	CH_4	25
CFC_{11}	$CFCl_3$	4000
CFC_{12}	CF_2Cl_2	8500
CFC_{113}	$CF_2ClCFCl_2$	5000
CFC_{114}	CF_2ClCF_2Cl	9300
CFC_{115}	CF_2ClCF_3	9300
Tetrachloromethane	CCl_4	1400
$HCFC_{22}$	CHF_2Cl	1700
$HFC1_{23}$	CF_3CHCl_2	93
$HFC1_{24}$	$CF_3CHCFCl$	480
$HFC134_a$	CH_2FCF_3	1300
$HFC152_a$	CHF_2CH_3	140
Carbon Monoxide	CO	2

(Souse: Henrik et al., 1997)

The Normalizations compared of potential environmental impact of products with the acceptable environmental impact in the area. The procedure of the potential impacts associated with the impact of the social activities as a whole can be determined from

$$\text{Normalization} = \frac{\text{size of environmetal impacts of products studied}}{\text{size of environmental impact in national, regional or global level}}$$

All summation of environmental impact depends on the weighting of the severity of the impact on the environment. Weighting Factor is the weight of the severity of the impact analysis based on a custom WF assigned to the objectives set. However, the comparison of the different groups will be compared with the medium or reference value in the same unit in the form of Pt.

Standard Guidelines of LCA has only two parts. They are classification and characterization. The results of LCA as standard guidelines can be used to compare the environmental impacts of products. However, it depends on the scope of the study. The optional of LCA analysis is normalization and weighting based on the different reference value in each local area and it cannot be compared.

Now the concept of LCA has been interested widely and is well developed as software package and database. Programs are easy to operate, not complicated, and reduce the cost of data collection. These programs are linked to databases available in the world. The program has been used in many applications such as GaBi, TEAM and SimaPro.

SimaPro software program is one of popular program developed by researches in Netherlands. The program consists of two major parts: (1) the life cycle inventory and (2) data to assess the environmental impact. Both components are linked to databases. This program is applied in many fields and will be used to evaluate the environmental impact in the study.

2.4.4 Life Cycle Improvement Analysis (LCIA)

Interpretation and evaluation the assessment of the environmental impacts of products give the knowledge of the severity of the impact on the environment in each life cycle of product including the most significant environmental aspects, the sources of the problem and its potential impact on the environment. Analysis of environmental impact is to analysis to improve environmental aspect in the most efficient and effective way. Interpretation and evaluation should be carefully done and based on the scope of the study, and the intended objective. An analyst who will apply the information should be knowledgeable about the product and environmental management.

Improving the environmental performance of products should be identified alternative ways to improve the environment. LCIA is divided into 3 main steps. They are identification of possible options to improve the environment, analysis of alternatives to improve the environment, and selection of appropriate options to improve the environment. In this study, LCA is used to evaluate the environmental impacts expected to occur and to analyze and improve the environment.

To construct a power plant, the economic value or unit cost of produced electricity has to be lower than the selling price. The government has been promoting the usage of renewable energy by setting of high purchase price for electricity produced from renewable energy. The rate is called “adder cost”. Adder cost is different depending on the sources renewable. For example, adder cost of electricity produced from wind power with less than 50 kW capacity is 4.5 baht/kWh. Adder are shown in detail in Table 2.4

Table 2.4 Adder cost to support the production of electricity from renewable sources

Types of fuel	**Adder (Baht/kWh)**	**Compulsory duration(Year)**
Biomass		
Installed capacity <= 1 M	0.5	7
Installed capacity >1 M	0.3	7
Biogas (from all sources)		
Installed capacity <= 1 M	0.5	7
Installed capacity >1 M	0.3	7
Waste (municipal solid waste and industrial waste other than hazardous waste)		
landfill	2.5	7
Thermal Process	3.5	7
Wind Power		
Installed capacity <= 50 kW	4.5	10
Installed capacity > 50 kW	3.5	10
Small hydro		
Installed capacity <= 50 kW	0.8	7
Installed capacity > 50 kW	1.5	7
Solar	6.5	10

Source: prepared new measures to support the FIT system and NEPC. Approved June 28, 2010.

This study propose that agricultural residues and fast-growing tree are viable as the renewable source for electrification which can be sold to grid. Adder is 0.5 baht/kWh. The economic analysis is a based on the benefit from this purchasing rate and Simple Payback Period (SPB), Net Present Value (NPV), and also Internal Rate of Return (IRR) has to be reasonable.