# System Design and Analysis of Biomass Energy Utilization for Sustainability in Rural Areas

**January 2014**

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# System Design and Analysis of Biomass Energy Utilization for Sustainability in Rural Areas

A Dissertation Submitted to

the Graduate School of Life and Environmental Sciences,

the University of Tsukuba

in Partial Fulfillment of the Requirements

for the Degree of Doctor of Philosophy in Biotechnology

(Doctoral Program in Bioindustrial Sciences)

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# Abbreviation

| | |
|---|---|
| AHP | Analytic Hierarchy Process |
| ANP | Analytic Network Process |
| BOCR | Benefits, Opportunities, Costs and Risks |
| COCN | Council on Competitiveness-Nippon |
| CRR | Crop-to-Residue Ratios |
| DEDE | Department of Alternative Energy Development and Efficiency |
| EGAT | Electricity Generating Authority of Thailand |
| EFB | Empty Fruit Bunches |
| ENCON | Energy Conservation |
| EPR | Energy Profit Ratio |
| ExPR | Exergy Profit Ratio |
| GHG | Green House Gas |
| GIS | Geographical information system |
| IUFoST | International Union of Food Science and Technology |
| NEC | National Energy Committee |
| OECD | Organization for Economic Cooperation and Development |
| PDP | Power Development Plan |
| SPP | Small Power Producer |
| VSPP | very small power producer |

# Nomenclature

| | |
|---|---|
| $DC$ | Direct combustion |
| $GS$ | Gasification |
| $S_{in}$ | Industrial scenario |
| $S_{co}$ | Cooperative scenario |
| $B$ | Benefits |

| | |
|---|---|
| $O$ | Opportunities |
| $R$ | Risks |
| $C$ | Costs |
| $B_c$ | Capacity of energy production |
| $B_e$ | Employment |
| $B_g$ | GHG Reduction |
| $R_a$ | Material availability |
| $R_e$ | Environmental risk |
| $R_r$ | Technology reliability |
| $O_e$ | Participation of entrepreneur |
| $O_f$ | Participation of farmer |
| $C_i$ | Initial cost |
| $C_r$ | Running cost |
| $u_{ij}$ | weight comparison between the criteria and alternatives |
| $w_{ij}$ | weight comparison between alternatives and criteria |
| $v_i$ | converged value as final weight of each matrix |
| $\lambda_{max}$ | a maximum eigen value |
| n | number of row or column of the matrix |
| $E_{BBF}$ | liquid fossil fuels used for biomass production including transportation |
| $E_{BEL}$ | electricity used for biomass production including transportation |
| $e_{BF}$ | lower quantity of heat for biofuel |
| $E_{BF}$ | amount of biofuel expected from the final benefit |
| $E_{BFtoE}$ | amount of electricity produced from biofuel |
| $E_{EL}$ | amount of electricity expected from the final benefit |
| $e_{EL}$ | conversion efficiency from electricity to heat |
| $E^j_{cons}$ | energy consumption of j |
| $E^j_{pro}$ | energy production of j |
| $e_k$ | conversion factor of heat |
| $E_X{}^j_{cons}$ | exergy consumption of j |

| | |
|---|---|
| $E_{X\,pro}^{j}$ | exergy production of j |
| $E_{system}$ | Energy system |
| $E_{system}^{\mathrm{EX}}$ | Exergy system |
| $F_j$ | amount of final benefit per unit for type of energy j |
| $H$ | annual heating per household |
| $H_0$ | total amount of heat |
| $i$ | variety of energy conversion equipment |
| $k$ | type of energy produced in the plant |
| $M$ | Annual mileage per household |
| $M_0$ | total amount of mileage for final benefit in society |
| $n_{BL}$ | number of households with boilers (heating equipment by combustion) |
| $n_{EV}$ | number of households with electric vehicles |
| $n_{GV}$ | number of households with gasoline vehicles |
| $n_{HP}$ | number of households with heat pumps |
| $n_i$ | number of i |
| $\eta_{\mathrm{BF}}$ | efficiency from biomass to biofuel in the plant |
| $\eta_{BL}$ | amount of heat energy produced by boilers using biofuel |
| $\eta_{\mathrm{EL}}$ | conversion efficiency from biomass to electricity |
| $\eta_{EV}$ | mileage from electric vehicles |
| $\eta_{GN}$ | efficiency of power generator |
| $\eta_{GV}$ | mileage from gasoline vehicles using biofuel |
| $\eta_{HP}$ | amount of heat energy produced by heat pumps |
| $\eta_{\mathrm{i}}$ | efficiency of i |
| | |
| C.I. | Consistency Index |
| C.R. | Consistency ratio |
| R.I. | Random index |

# Units

| | |
|---|---|
| 10a | 1,000 Square meter |
| EJ | Exa joule |
| GJ | Gigajoule |
| ha | Hectare |
| J | Joule |
| kg | Kilogram |
| km | kilo meter |
| kW | kilo Watt |
| kWh | Kilo watt hour |
| L | Littre |
| MJ | Mega joule |
| MTtoe | Million tons of oil equivalent |
| MW | Mega watt |
| PJ | Pica joule |
| t | Ton |
| TOE | Ton of Oil Equivalent |
| ° C | Degree Celsius |

Abstract

Due to a significant increase in the cost of fossil fuel, biomass has begun to gain acceptance as a viable resource of alternative energy. Fossil fuel is valuable because it can produce significant amounts of energy per unit weight, it is abundant, and it is easy to transport, extract and process as a liquid. However, some uncertainty exists regarding its availability, effect on the environment, cost in the world market and the shortage of existing supplies. The substitution of fossil fuel with biomass aims to reduce environmental impacts and the cost of imported fossil fuels, such as coal, petroleum and natural gas. Biomass energy utilization is considered a feasible approach for reducing fossil fuel consumption and $CO_2$ emissions. However, biomass resource, field area of biomass production, variety of biomass, conversion efficiency of biomass plants and suitable conversion system should be evaluate for the more effective production of biomass energy and rural areas development.

The objective of this study was to evaluate the conversion technology by using energy and exergy analysis, and decision support system to aid in the decision to introduce a biomass power plant using rice husk for rural areas in Thailand. The evaluation functions using energy and exergy analysis were proposed to analyze the consistency between energy production and energy consumption for final benefit. The evaluation functions aim to minimize the difference between energy production and energy consumption, and field area of biomass production to provide the system design. The evaluation was proposed to measure quality and availability of energy. The result of trial calculation for Utsunomiya city in Tochigi Prefecture, Japan, as an example of the rural area, was discussed was to clarify the credibility of evaluation functions.

Then the measurement was applied to evaluate two conversion systems between direct combustion and gasification in order to choose the best system. The measurement to choose for the best technology was made for introducing the suitable energy plants and measure field area that satisfy energy demand in rural areas of Thailand. In order to validate the system, Suphanburi province, Thailand was selected to investigate in this study. An evaluation for choosing the best biomass conversion system by decision support system was also proposed to identify suitable options for biomass energy plants using rice

husk in rural areas of Thailand. Not only the efficiency of conversion process, minimum field areas and quality of energy were analyzed but decision support system on benefits and opportunities should be focused as well.  Risk assessment is also a major consideration, including environmental and GHG risks. A decision support system with an Analytical Network Process (ANP) would aid in determining the best biomass conversion method from the different alternatives. Considering the various analytical hierarchies, ANP theory can include different criteria, sub-criteria, and alternatives for judging the best conversion method from rice husk in rural areas considering environmental and social problems for the rural areas. Therefore, the research herein was aimed at proposing for introducing the most suitable rice husk energy plant in rural areas of Thailand. The systematic approach and evaluation functions required to develop and provide the guideline to support the utilization of biomass energy resource.

Two studies were conducted to suggest the most suitable energy technology and scenario for the desired future of biomass utilization;

(1) The Evaluation functions for minimizing the disparity between energy supply and demand and reducing the field area for biomass production, which are based on energy benefits, were proposed in a system design for biomass production. An Exergy Profit Ratio (ExPR) and Energy Profit Ratio (EPR) were also proposed to measure the quality and availability of energy for the biomass plant in Utsunomiya city in Tochigi Prefecture, Japan. For the minimum field area of biomass production based on societal demand in household of Utsunomiya city, 17,500 ha was the minimum value by the evaluation function of energy and 29,500 ha was the minimum value by evaluation function of exergy under the case of lighting: 100% electricity; heating: 89% electricity and 11% of vapor. On the other hand, 17,000 ha was the minimum value by and 29,000 ha was the minimum value by exergy under the case of lighting:100% electricity; heating: 100% electricity and 100% of vapor. Thus, if EPR and evaluation function by energy of bio-ethanol & electricity production were underestimated for a minimum field area, then ExPR and evaluation function by exergy could be used to maintain the results of introducing biomass production to prevent field area shortages for biomass production.

Then, the measurement was applied to evaluated two conversion systems between direct combustion and gasification systems to choose the best system for introducing in rural areas of Thailand. The suitable energy plants and minimum field area that satisfy energy demand were measured for the introducing. Direct combustion and gasification systems were evaluated by EPR and ExPR were made to assess the credibility of the evaluation functions for the desired future of rural areas. The evaluation method of total energy efficiency can lead to a more effective production of biomass energy. Suphanburi province, Thailand was selected as an investigated area in this study. The result of EPR and ExPR analysis demonstrated that the direct combustion system had a higher advantage than the gasification system. For the minimum field area of rice production based on energy demand, the results indicated that in case of similarity energy demand for final benefit and energy demand for production, the minimum field area of energy demand for 100%, 25% and 8% of direct combustion system were below the current rice field area. In addition, the results of minimum field area of energy demand for 100% of gasification system significantly exceed the current rice field area while the energy demand for 8% and 25% were below the current rice field area. If the energy demand for 8% and 25% were propose to measurement, both direct combustion system and gasification system can satisfy the energy demand. Therefore, energy demand in the rural area by the different energy resources should be concerned to provide the satisfy energy supply and demand.

(2) Analytic Network Process (ANP) modeling for a decision support system was proposed to identify suitable options for biomass energy plants using rice husk in rural areas of Thailand. The efficiency of conversion process, minimum field areas and quality of energy were analyzed to select the most suitable energy system biomass by the viewpoint of the biomass energy production and utilization in the first research study. However, a decision support system considering benefits, opportunities, risk and cost should be focused as well. In this attempt, direct combustion and gasification systems for a biomass energy plant were evaluated. An ANP-based model was used to consider criteria, sub-criteria, and alternatives. Environmental and social problems were considered to construct the model. The ANP model results showed that the gasification system was likely a better alternative than the direct combustion system in a cooperative scenario considering environmental and social concerns. In contrast, direct combustion was likely a suitable energy plant in an industrial scenario considering the benefits and economic issues.

According to the results of the two research studies, in case of the selection based on the evaluation to select the most suitable energy generated system, the decision was decided base on two aspects. Firstly, the evaluation function by energy and exergy were

proposed to analyze the consistency between energy production and energy consumption, to achieve final benefits in specific area. And the second, the evaluation base on rural area benefits was study. A decision support system with an ANP results provided the suggestion and guideline to the government of Thailand to select the most appropriate system with the environmental and social problems consideration. The result shows that direct combustion system was a suitable plant for large scale of energy production by its high efficiency for its economy. The direct combustion plant had high reliability of its technology, more energy efficiency as EPR and ExPR and lower field area production required. The direct combustion system was more suitable energy plant from the benefit and economy advantage to introduce in the rural areas of Thailand. However, the advantage of a gasification system is the energy source which has small-scale located near energy consumers with a short transmission. Moreover, this system is considered as an energy source that will increase rural development. Therefore, So Gasification plant may use as an additional support energy plant fluctuated voltage areas or established the transmission grid areas in order to support the power for direct combustion plant. At the conclusion, direct combustion plant had an advantage compared with the gasification system by the benefit and economic concerned. The both two evaluation results herein provided important information for policy management for introducing not only choice between alternatives but also the new alternatives according to mixed rate between two different types of energy plants in rural areas of Thailand.

# CHAPTER 1

# Introduction

### *1.1 Research Questions and Motivation*

Due to a significant increase in the cost of fossil fuels, biofuel has begun to gain acceptance as a viable resource of alternative energy. Fossil fuel is valuable because it can produce significant amounts of energy per unit weight, it is abundant, and it is easy to transport, extract and process as a liquid. However, some uncertainty exists regarding its availability, effect on the environment, cost in the world market and the shortage of existing supplies. The substitution of fossil fuel with biomass aims to reduce environmental impacts and the cost of imported fossil fuels, such as coal, petroleum and natural gas (Shen *et al* 2011; Sawangphol and Pharino, 2011).

Biomass is considered a feasible approach for reducing fossil fuel consumption and $CO_2$ emissions. Using biomass to produce energy is the benefits the nation, especially rural areas. Inaccessibility of electricity in rural areas reduces the quality of life such as poor infrastructure, less community development, higher the gap of living condition between rural and urban areas. Improving people's access to energy services can also contribute to quality of life improvements, and economic and social development. The supply of improved energy supply can productivity of agricultural product such as water pumps and mills and increase the time available to engage in agriculture, food processing, productive hours of a day, enabling processing activities in the industries. There are a number of technological options available to meet the energy needs in rural areas. The necessary factors that impact the decision for select the conversion processes are the type of the biomass, the available quantity of biomass, economic conditions; and project specific factors. The generation of electricity from biomass encompasses a wide range of different possible conversion processes.

In Thailand, although Electricity Generating Authority of Thailand (EGAT) was since 1969, but in some rural areas there were no access the transmission grid. In 2011, 2.9 million households in Thailand can not access to the electricity which equal to 15.3% from total households. Thai government promote for the using of renewable energy for energy generation to solve the problem. Biomass resource as agricultural wastes which are bagasse, rice husk, and oil palm waste have been considered as an energy generation in rural areas in Thailand.

Rice husk is one of the major agricultural residues produced in Thailand. In processing the rice at rice mills across the country, about $6.17 \times 10^6$ t/year of rice husk is produced as a by-product. About a half amount of rice husk is currently consumed for producing heat, electricity, soil conditioner (Kapur *et al*, 1998). Remaining rice husk is lost due to rot or burned in open air unless utilized. These managements cause environmental pollution and skin irritations for local residents (Ueda 2007). On the other hand, $3.05 \times 10^6$ t/year of available rice husk of remaining produces 2,500 GWh/year based on a heating value of 14.7 MJ/kg and standard efficiency for electricity generating (Srisovanna, 2004; Witichakorn, 2004; Ueda, 2007; Utistham, 2007).

Therefore, the government has been promoting rice husk energy to support the energy demand. One of the primary objectives of the government is to motivate renewable energy use at 25% consumption by 2022 (Sawangphol and Pharino, 2011). This policy will help to reduce energy imports, encourage use of domestic energy supplies for sustainable economic growth and reduce greenhouse gas emissions. The potential for rice husk energy in rural areas has been studied. The conversion of biomass is an issue that also must be considered for use in electricity generation.

There are two systems which have been wide progressed in Thailand which are direct combustion and gasification systems. A direct combustion system is the most common plant type for producing thermal energy and generates electricity. This system produces a large portion of the electricity. A gasification system is considered as a decentralized biomass electricity system due to its small scale that can access easily to any area. The gasification system was considered as an adequate technology for distributing electricity through a transmission grid in rural areas. However, gasification technology is not used widespread (Kumar *et al,* 2010) because its technology is still not established for stable operation by many factors which are occurred by the characteristics of biomass material.

No clear guidelines from the government for neither small-scale energy plant nor large scale plant must be decided on the best choice between direct and gasification systems. Moreover, biomass resource, field area of biomass production, variety of biomass, conversion efficiency of biofuel plants and suitable system should be evaluate for the more effective production of biomass energy and rural areas development.

### *1.2 Objective and Organization of Thesis*

In order to make a clear guideline to support the introduction of biomass energy plant and its utilization for the policy maker and government, it is necessary to propose the decision support system and system design concept. The success of supported policy can be reached by well planning and obvious guideline.

This research studied reported in this thesis were conducted with the main objective of evaluate between two systems between direct combustion and gasification systems. The evaluation can be helpful to choose best system for introducing energy plants in rural areas. Then systematic approach and evaluation functions required to develop and provide the guideline to support the utilization of biomass energy resource. The research was carried out the outlined below;

1. Evaluation functions, which are based on energy benefits, were developed in this research to minimize the disparity between energy supply and demand and to reduce the field area of biomass production in biofuel production. The evaluation function also aids to construct the system design model for rural areas in Thailand. The measurement of precise physical quantities of energy for rice husk energy production is indispensable for determining the total amount of social benefit for rural areas in Thailand. An and Energy Profit Ratio (EPR) and Exergy Profit Ratio (ExPR) were also proposed to measure the quality and availability of energy. From the viewpoint of quality of life, environmental protection, and sustainable development, forecasting which an estimation of future impact is should be considered. Future target goals and an evaluation were required to make the suitable policies. To validate the system design model, Utsunomiya City in the Tochigi Prefecture of Japan and Suphanburi province, Thailand were selected as an example and studied to assess the credibility of the evaluation functions.

2. ANP evaluation was aimed for choosing the best biomass conversion system should focus on benefits and opportunities. Risk assessment is also a major consideration, including environmental and GHG risks. A decision support system with an analytical hierarchy would aid in determining the best biomass conversion method from the different alternatives. Considering the various analytical hierarchies, ANP theory can include

different criteria, sub-criteria, and alternatives for judging the best conversion method from rice husk in rural areas considering environmental and social problems for the rural areas. The evaluating on direct combustion and gasification systems can be helpful in choosing the best system for introducing energy plants in rural areas.

Therefore, the research herein was aimed at proposing a decision support system by using ANP theory and system design for biomass energy resources utilization for introducing the most suitable rice husk energy plant in rural areas of Thailand. This research was expected that the result would be useful for the following;

1. Energy policy planner of Thailand,
2. Local administration in rural area,
3. Private Entrepreneur and local cooperative,
4. Farmer and local people in rural areas.

# CHAPTER 2

## System Design and Analysis

## (Basic Description of Systems Tools: Energy, Exergy, AHP and ANP Analysis)

### *2.1 Exergy and Energy*

Energy is a key element of the interactions between nature and society. It is also considered a key input for economic development and as everyone knows, there is no source of energy which is absolutely neutral with respect to the environment. The use of energy as a measure for identifying and measuring the benefits of energy systems can be misleading and confusing (Dincer, 2002). Energy consumption is one of the most important indicator showing the development stages of countries and living standards of communities. Efficiency is one of the most frequently used terms in thermodynamics, and it indicates how well an energy conversion or process is accomplished (Kanoglu *et al*, 2007). Generally, the performance of energy power plants is evaluated through energy efficiency based on first law of thermodynamics, including electrical power and thermal efficiency.

In a broader perspective (except for the zero and third law of thermodynamics), the thermodynamics can be defined as the science of energy and exergy including a number of concepts of temperature, pressure, enthalpy, heat, work, energy, as well as entropy. Apparently, the first law of thermodynamics refers to the energy analysis which only identifies losses of work and potential improvements or the effective use of resources. Energy analysis has some limitations like not accounting for properties of the system environment, degradation of the energy quality through the processes and does not characterize the irreversibility of processes within the system.

The total energy *E* represents the sum of all forms of energy a system processes, and the change in the energy content of a system during a process is expressed as ∆Esystem (Dincer and Cengel, 2001). In the absence of electrical, magnetic, surface, etc effects, the total energy in that case can be expressed as the sum of the internal, kinetic, and potential energies as;

$$E = U + KE + PE \qquad \text{and} \qquad \Delta E_{system} = \Delta U + \Delta KE + \Delta PE \quad (2\text{-}1)$$

Energy can be transferred to or from a system in three forms: *heat Q*, *work W*, and *mass flow m*. Energy interactions are recognized at the system boundary as they cross it, and they represent the energy gained or lost by a system during a process. Then the energy balance for any system undergoing any kind of process can be expressed as;

$$E_{in} - E_{out} = \Delta E_{system} \qquad (2\text{-}2)$$

That is, the net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process. This relation can also be expressed per unit mass, differential, and rate forms as;

$$e_{in} - e_{out} = \Delta e_{system} \qquad (2\text{-}3)$$

$$\delta E_{in} - \delta E_{out} = dE_{system} \quad \text{or} \quad \delta e_{in} - \delta e_{out} = de_{system} \qquad (2\text{-}4)$$

In contrast, the exergy efficiency based on the second law of thermodynamics has found as useful method in the design, evaluation, optimization and improvement of energy power plants (Kaushik *et al*, 2011). Exergy analysis will characterize the work potential of a system. Exergy is the maximum work that can be obtained from the system, when its state is brought to the reference or standard atmospheric conditions (Regulagadda *et al*, 2010). Exergy is a measure of the potential of the system or flow to cause change, as a consequence of not being completely in equilibrium relative to the reference environment. Unlike energy, exergy is not subject to a conservation law (except for ideal processes). Rather exergy is consumed or destroyed, due to non-idealities or irreversibility in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibility associated with the process (Dincer, 2002). There are some illustrated meanings of exergy by the following example;

- A system in complete equilibrium with its environment does not have any exergy, and no difference appears in temperature, pressure, or concentration etc. for any of such processes.

- A system carries more exergy the more it deviates from the environment. Hot water has a higher content of exergy during the winter than it has on a hot summer day. A block of ice carries hardly any exergy in winter while it does so in summer.

- When the energy loses its quality, it results in the exergy being destroyed. The exergy is the part of the energy which is useful in the society and therefore has an economic value and is worth taking care of.

There are some key points to highlight the importance of the exergy and its essential utilization in numerous ways (Dincer, 1998):

- It is a primary tool in best addressing the impact of energy resource utilization on the environment.

- It is an effective method using the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the design and analysis of energy systems.

- It is a suitable technique for furthering the goal of more efficient energy resource use, for it enables the locations, types, and true magnitudes of wastes and losses to be determined.

- It is an efficient technique revealing whether or not and by how much it is possible to design more efficient energy systems by reducing the inefficiencies in existing systems.

- Finally, it is a key component in obtaining sustainable development.

Furthermore, almost all energy was converted in the thin layer on the earth's surface, where life can be found, derives from the sun. Sunlight, rich in exergy, reaches the earth. A lot of it is reflected but the energy absorbed on the earth is converted and finally leaves the earth as heat radiation with no exergy relative to the earth. The net exergy absorbed by the earth is consequently gradually destroyed, but during this destruction it manages to drive the water or wind system and the life on earth. Plants can absorb exergy from the sunlight and convert it via photosynthesis into chemical exergy. The chemical exergy then passes through different food chains in the ecosystems. On every tropical level, exergy is consumed and microorganisms live on the last level in this food chain. There exists no waste (Wall, 1995).

Exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. Exergy is a measure of the potential of the system or flow to cause change, as a consequence of not being completely in stable equilibrium relative to the reference environment. Unlike energy, exergy is not subject to a conservation law (except for ideal, or reversible, processes). Rather, exergy is consumed or destroyed, due to irreversibilities in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibility associated with the process.

For exergy analysis, the state of the reference environment, or the reference state, must be specified completely. This is commonly done by specifying the temperature, pressure and chemical composition of the reference environment. The results of exergy analyses, consequently, are relative to the specified reference environment, which in most applications is modeled after the actual local environment.

Exergy analysis is a method that uses the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the analysis, design and improvement of energy and other systems (Rosen and Dincer, 1999). The exergy method is useful for furthering the goal of more efficient energy-resource use, for it enables the locations, types, and true magnitudes of wastes and losses to be determined. In general, more meaningful efficiencies are evaluated with exergy analysis rather than energy analysis, since exergy efficiencies are always a measure of the approach to the ideal case. Therefore, exergy analysis can reveal whether or not and by how much it is possible to design more efficient energy systems by reducing the inefficiencies in existing systems. Many engineers and scientists suggest that the thermodynamic performance of a process is best evaluated by performing an exergy analysis in addition to or in place of conventional energy analysis because exergy analysis appears to provide more insights and to be more useful in efficiency improvement efforts than energy analysis. It is important to highlight that exergy analysis can lead to a substantially reduced rate in the use of natural resources and the environmental pollution by reducing the rate of discharge of waste products.

Exergy is a measure of how far a certain system deviates from equilibrium with its environment and therefore, the following expressions can be written for exergy contained in a system;

$$Ex = T_0(S_{t,eq} - S_t) \qquad (2\text{-}5)$$

where $T_0$ is the temperature of the environment and $(S_{t,eq} - S_t)$ is the deviation from equilibrium of the negentropy (= minus the entropy) of the system and its environment, i.e., the total system (Dincer and Cengel, 2001).

The performing of exergy and energy analyses together can give a complete depiction of system characteristics. Such a comprehensive analysis will be a more convenient approach for the performance evaluation and determination of the steps towards improvement. The considering both the energy and exergy analysis together can guide the ways of efficient and effective usage of fuel resources by taking into account the quality and quantity of the energy used in the generation of electric power in energy plants (Kaushik *et al*, 2011). The exergy can be used to help for the better understand the benefits of utilizing by providing more useful information than energy provides. Exergy clearly identifies efficiency improvements and reductions in thermodynamic losses. The difference between energy and exergy analysis may be explained considering an example. Consider a geothermal power plant using geothermal liquid water at 160 °C at a rate of 440 kg/s as the heat source, and producing 15 MW of net power in an environment at 25 °C. Energy analysis allows us to determine that this source has an energy value of 251 MW and the energy efficiency of the plant is 6% (15/251 MW). Exergy analysis shows that the source has a work potential (i.e., exergy) of 44.5 MW and the plant exergy efficiency is 34% (15/44.5 MW). Here, the exergy of geothermal water constitutes only 18% of its energy. The remaining 82% is not available for conversion to electricity, even with a reversible heat engine. Only 34% of the exergy entering the plant is converted to electricity and the remaining 66% is lost. An exergy analysis of this plant also identifies the sites of exergy losses in a quantitative manner and helps in prioritizing improvement efforts (Rosen *et al*, 2008).

***Exergy vs Energy***

The traditional method of assessing the energy disposition of an operation involving the physical or chemical processing of materials and products with accompanying transfer and/or transformation of energy is by the completion of an energy balance. This balance is apparently based on the first law of thermodynamics. In this balance, information on the system is employed to attempt to reduce heat losses or enhance heat recovery. However, from such a balance no information is available on the degradation of energy, occurring in the process and to quantify the usefulness or quality of the heat content in various streams leaving the process as products, wastes, or coolants. The exergy method of analysis overcomes the limitations of the first law of thermodynamics. The concept of exergy is based on both first law of thermodynamics and second law of thermodynamics. Exergy analysis can clearly indicate the locations of energy degradation in a process that may lead to improved operation or technology. It can also quantify the quality of heat in a reject stream. So, the main aim of exergy analysis is to identify the causes and to calculate the true magnitudes of exergy losses. In the Table 2.3, the comparison of the concepts of energy and exergy were illustrated.

To begin with, we must distinguish between exergy and energy in order to avoid any confusion with the traditional energy-based methods of thermal system analysis and design. Energy flows into and out of a system via mass flow, heat transfer, and work (e.g., shafts, piston rods). Energy is conserved, not destroyed: this is the statement made by the first law of thermodynamics. Exergy is an entirely different concept. It represents quantitatively the "useful" energy, or the ability to do work-the work content-of the great variety of streams (mass, heat, work) that flow through the system. The first attribute of the property "exergy" is that it makes it possible to compare on a common basis interactions (inputs, outputs) that are quite different in a physical sense. Another benefit is that by accounting for all the exergy streams of the system it is possible to determine the extent to which the system destroys exergy. The destroyed exergy is proportional to the generated entropy. In actual systems, exergy is always destroyed, partially or totally: this is the statement made by the second law of thermodynamic. The destroyed exergy or the generated entropy is responsible for the less-than-theoretical efficiency of the system.

## *2.2 Analytic Hierarchical Process (AHP) and Analytic Network Process (ANP)*

### Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) has been developed by Tomas Saaty. AHP is a well-known and widely used decision making approach. The AHP models presented in this study are qualitative methods which rely on the judgment and experience of decision makers to prioritize information for better decisions. Establishing criteria for decision-making is a necessary task. Therefore, this research was conducted to determine a decision support system using a multiple criteria analysis. Analytic Hierarchy Process (AHP) is focused on complex decisions based on mathematics and psychology (Alphonce, 1996). Each criterion was set to evaluate for small energy plant (Witichakorn, 2004). Using a decision-support system through a multiple criteria analysis Analytic Hierarchy Process (AHP) is focused on overcoming these drawbacks. The AHP will help to prioritize information for better decisions (Alphonce, 1997).

Then the researcher has to solve the problems various alternatives the decision - maker has to define the structure in order to making a criteria and/or sub-criteria of the objective. Analytic Hierarchy Process was mentioned that it can help to solve the problem when the human brain's reaction that the brain is able to compare elements. However, there are many subjectively rank with lots of objects. The problem occurs with how to solve the problem if there is more than one criterion. Human cannot make a choice from a set that is infinite. As a completely new approach to solving decision making problems, mathematician Saaty developed this new method.

Once Researcher built hierarchy, it will systematically evaluate its various elements by comparing or weighting the criteria and alternative at a time. It is conducted by concerns with the impact in the hierarchy.

As a time to making the comparisons, the decision makers will evaluate the data about criteria and alternative. The judgments about the elements' relative are very importance because it can be used in performing the evaluations such a numerical data. The AHP converts these evaluations to numerical data in order to process and compare over the entire hierarchy. The numerical data will be calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal. Finally, the result will show the priority which is derived from the weighted element of the hierarchy.

AHP can help to support for the decision making with regards to the complex issues. It is used to solve the complex decision problems and simplify it to get the best answer. It performs by the structured hierarchically. The pair wise comparison will help decision makers to consider each individual trade off in the decision problem. Finally, AHP can be used to provide the implementation and evaluation of policy planning as well.

AHP approached step can be divided in to four stages;

**Stage 1: Decomposition**

The first step, AHP will decompose the problem in order simplified and arrange the hierarchy as in the Fig. 2.1

From the Fig2.1. above as you can see, AHP will divide problem into three stratified components: goal, criteria (and sub-criteria) and the alternatives. The goal is located at the top. Goal is the vision of problem. Criteria and Sub – criteria are below which represents an aspect and control direct way to reach the goal. Levels are evaluated. The alternatives are the final level. In this level the solution will achieve the goal.

For the example of Analytic hierarchy model, the model for new automobile selection is shown in Fig.2.2 Goal is “new automobile selection”, criteria are “price”, “comfortable”, and “energy consumption”. The AHP is able to be used for selecting best alternative from three alternatives which are company A, B and C by weighting in hierarchy.

After get the AHP model, each level shows the components of the decision-making process. For the ranking of criteria, user of AHP method understands on the term fundamentally means. The elements value will explain by numerous in order to calculated and evaluate for the final result.

**Stage 2: Define perspective**

In this step, the prospective viewpoint will be identified. The priorities which are placed on every level will give the ranking of the alternatives.

**Stage 3: Weighting and Synthesis**

After the perspective is identified, the comparison in a three level hierarchy will be utilized by comparing from criteria to goal and inside each level. This stage will release the priority for each comparison. The simply numeric weights will be used to correspond to each component of comparison. For the prioritized, weighting of criteria, sub – criteria or alternatives is necessary. The methods are direct input and paired comparison. Direct input is easy and simple method but it is difficult to input the accurate value satisfied with consistency index of matrix for weighting. Paired comparison is easy method to input accurate value but take more time for weighting (Noguchi, 2007). It can help to compare one to one item by user feeling by using some language expression. This language expression can be used for making judgment as shown in Table 2.1.

A number in the matrix is a dominance judgment. A judgment of 1.0 means an equal, a judgment of 3.0 means moderately or three times as much and 5.0, 7.0, 9.0 means those number times as much.

For a determination of weight, geometry and eigenvectors methods are calculated in order to get priority. Eigenvectors is more accuracy of final conclusion than geometry method. Firstly, weight of criteria and sub - criteria will be calculated followed by weight of each alternative under criteria and sub – criteria. At this stage, each criterion has a priority value which is representing the importance or preferable of each alternative. The final answer will be in this stage. After got weight comparison, the additive formulation was used for synthesize the model result.

**Stage 4: Consistency test**

The purpose is to measure how consistent the judgments have been relative to large samples of purely random judgments (Coyle, 2004). Consistency ratio (C.R.) is used to verify the credibility and reasonability of evaluation. If the value of C.R. is below 0.1, weighting will be accepted. Errors are quite small. If the value is equal 0, it shows the perfect weight comparison.

$$\text{C.R.} = \frac{\text{Average} - \text{Number of criteria}}{\text{Number of criteria} - 1} \qquad (2\text{-}6)$$

In use of eigenvectors to weight, C.I. (Consistency Index) is expressed as follows.

($\lambda_{max}$= a maximum eigen value, n= number of row or column of the matrix)

$$\text{C.I.} = \frac{\lambda\max - n}{n-1} \qquad (2\text{-}7)$$

And

$$\text{C.R.} = \frac{\text{C.I.}}{\text{R.I.}} \qquad (2\text{-}8)$$

C.R. is expressed consistency index and R.I. represents the random index.

The value of R.I. is the average consistency index of randomly generated pairwise comparison matrix of similar size (Fu, 2009; Noguchi, 2007). Table 2.2 shows random index;

**Stage 5: Sensitivity analysis**

Sensitivity analysis is Necessary to explore the impact of alternative priority structures. It can help to check for changes in the weights given to the criteria even though the small changes to specific input parameters on evaluation outcomes (Chen, 2009).

**Analytic Network Process**

Analytic Network Process (ANP) is the new theory that extends AHP processes. The basic structure is quite same as AHP but more advance with the interaction and feedback within and between the clusters. ANP does not require the strictly hierarchy structure and allows inter – relationship among levels. Moreover, the influence does not require to flow only downward and AHP. It can help to get more sophisticated answer. The influence pattern of the network is essential. Identify clusters that influences some elements within network are considered for each control criteria and sub – criteria under goal. The scenarios are compared pairwise towards their control criteria and the criteria themselves are also compared pairwise with respect to their contribution to the scenario as well. Same as AHP, pairwise comparison of ANP is made in the framework of a matrix. Then limiting supermatrix was computed and global preferences of decision elements are obtained. These preferences serve as the best decision selection or for the purpose.

To understand the affects between the decisions parameters of ANP, the pairwise comparison is conventionally used. Fundamental scale for pairwise comparison matrix is given (Saaty 1999) by taking into account the 1–9, Saaty scale for determining the weight of each matrix element for super matrix. Evaluation matrix U, which shows Criteria ($C_1$, $C_2$) evaluates alternative ($A_1$, $A_2$, $A_3$), and can be expressed as:

$$U = \begin{matrix} & C_1 & C_2 \\ A_1 & u_{11} & u_{12} \\ A_2 & u_{21} & u_{22} \\ A_3 & u_{31} & u_{32} \end{matrix} \tag{2-9}$$

$u_{ij}$ is the weight comparison between the criteria and alternatives. i is the row and j is the column. Evaluation matrix $W$ which shows criteria ($A_1$, $A_2$, $A_3$) evaluates alternatives ($C_1$, $C_2$) can be expressed as:

$$W = \begin{matrix} & A_1 & A_2 & A_2 \\ C_1 & w_{11} & w_{12} & w_{13} \\ C_2 & w_{21} & w_{12} & w_{13} \end{matrix} \tag{2-10}$$

$w_{ij}$ is the weight comparison between the alternatives and criteria. $S_{weighted}$ is represented weighted super matrix. Every component is weighted with its corresponding Cluster Matrix weight. For equation 3, $S_{weighted}$ is expressed using evaluation matrix $U$ and evaluation matrix $W$ as following:

$$S_{weighted} = \begin{bmatrix} 0 & W \\ U & 0 \end{bmatrix} = \begin{matrix} & C_1 & C_2 & A_1 & A_2 & A_3 \\ C_1 & 0 & 0 & w_{11} & w_{12} & w_{13} \\ C_2 & 0 & 0 & w_{21} & w_{22} & w_{23} \\ A_1 & u_{11} & u_{12} & 0 & 0 & 0 \\ A_2 & u_{21} & u_{22} & 0 & 0 & 0 \\ A_3 & u_{31} & u_{32} & 0 & 0 & 0 \end{matrix} \tag{2-11}$$

Each matrix element of $S_{weighted}$, is not negative. And summation of each column should be "1" as follows,

$$\sum_{i=1}^{3} u_{ij} = 1, \quad \sum_{i=1}^{2} w_{ij} = 1 \tag{2-12}$$

Finally, multiplying $S_{\text{weighted}}$ in infinity times on theory produces converged value of $v_1$ to $v_5$ as final weight of each matrix element in $S_{\text{limited}}$ (limited super matrix) in Eq. (2-13) (Kone and Buke, 2007).

$$S_{\text{weighted}}^{\infty} = \begin{array}{c} \\ C_1 \\ C_2 \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & A_1 & A_2 & A_3 \end{array} \\ \begin{bmatrix} 0 & 0 & w_{11} & w_{12} & w_{13} \\ 0 & 0 & w_{21} & w_{22} & w_{23} \\ u_{11} & u_{12} & 0 & 0 & 0 \\ u_{21} & u_{22} & 0 & 0 & 0 \\ u_{31} & u_{32} & 0 & 0 & 0 \end{bmatrix}^{\infty} \end{array} \Rightarrow S_{\text{limited}} = \begin{array}{c} \\ C_1 \\ C_2 \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & A_1 & A_2 & A_3 \end{array} \\ \begin{bmatrix} 0 & 0 & v_1 & v_1 & v_1 \\ 0 & 0 & v_2 & v_2 & v_2 \\ v_3 & v_3 & 0 & 0 & 0 \\ v_4 & v_4 & 0 & 0 & 0 \\ v_5 & v_5 & 0 & 0 & 0 \end{bmatrix} \end{array} \quad (2\text{-}13)$$

When the numbers of matrix element in each row except for zero are closed to same value, super matrix $S$ has been reach at the final stage of calculation and the matrix multiplication process is halted. Then each value of $S_{\text{limited}}$ was considered as final weight of each element in the ANP model.

Table 2.1 The main different between energy and exergy (Dincer and Cengel, 2001)

| Energy | Exergy |
|---|---|
| - Dependent on the parameters of matter or energy flow only, and independent of the environment parameters. | - Dependent both on the parameters of matter or energy flow and on the environment parameters. |
| - Values different from zero (equal to $mc^2$ in accordance with Einstein's equation). | - Equal to zero (in a dead state by equilibrium with the environment). |
| - Guided by the first law of thermodynamics for all the processes. | - guided by the first law of thermodynamics for reversible processes only (in irreversible processes it is destroyed partly or completely). |
| - Limited by the second law of thermodynamics for all processes (include reversible ones). | - Not limited for reversible processes due to the second law of thermodynamics. |
| - Motion or ability to produce motion. | - Work or ability to produce work. |
| - Always conserved in a process, so can neither be destroyed nor produced. | - Always conserved in a reversible process, but is always consumed in an irreversible process. |
| - A measure of quantity. | - A measure of quantity and quality due to entropy |

Table 2.2 Fundamental scale for making judgments

| Intensity of importance on an absolute scale | Definition |
|---|---|
| 1 | Equal |
| 3 | Moderate |
| 5 | Strong |
| 7 | Very strong |
| 9 | Extreme |
| 2, 4, 6, 8, | Intermediate values to reflect comparison |
| | Decimal judgments, such as 3.5, are allowed for fine tuning, and judgments greater than 9 may be entered, though it is suggested that they be avoided. When a number greater than 9 is suggested by the inconsistency checking, this means that the elements that were grouped together are too disparate. |

Source: Super decision software tutorial, 2003

Table 2.3 Random index

| N | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R.I. | 0 | 0.58 | 0.90 | 0.12 | 1.25 | 1.32 | 1.41 | 1.45 | 1.49 | 1.54 | 1.48 | 1.56 | 1.57 | 1.59 |

(N= number of row or column of the matrix)

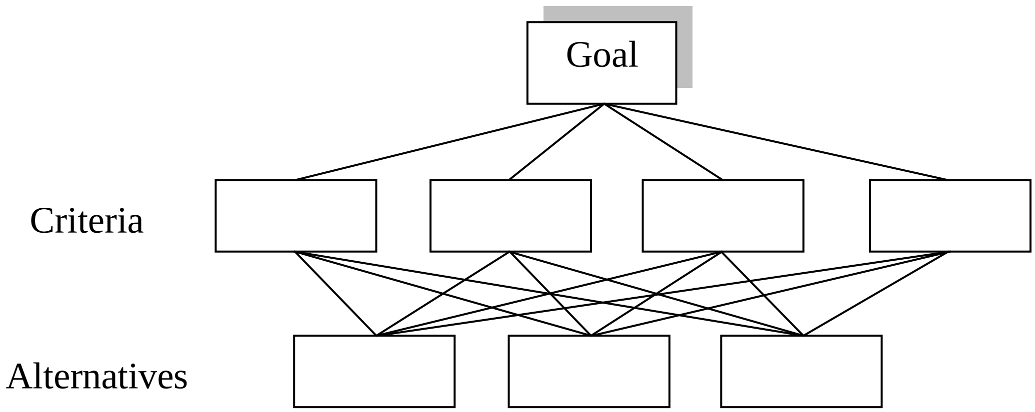



Fig. 2.1 Structure of AHP model

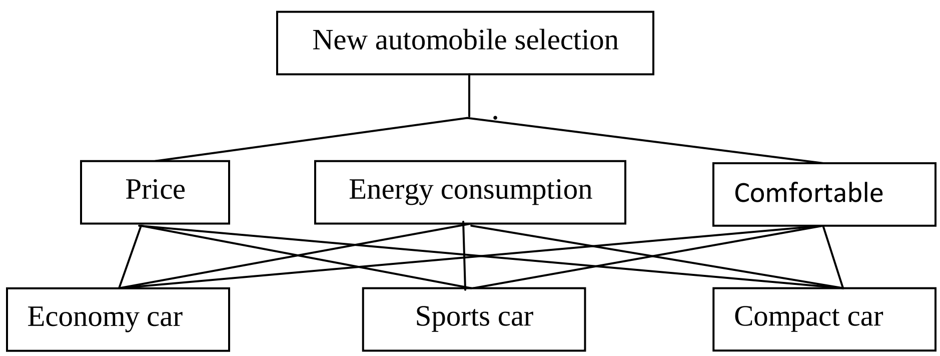



Fig. 2.2 Hierarchy model for automobile selection

# CHAPTER 3

# Bioenergy Resources in Rural Areas;

# Literature Review for Thailand and Japan

### *3.1 Overview of Energy Status*

#### World Energy Status

With the current situation of increasing energy demand, rising energy prices renewable energy sources have taken the spotlight. If the current trends continue, we may face an energy shortage in future. Fossil fuels continue to dominate as the main sources of energy produced and consumed worldwide. Oil and natural gas are the main fossil fuels and have remained so since the end of the Second World War (Goto *et al, 2010*). However, due to environmental concerns, coal power plants have to adhere to stricter environmental standards. Despite this ,the earth still has over 400 years of coal supplies compared to 60 years of oil thus of the fossil fuels, coal remains the cheapest to produce electricity from. Natural gas is currently in abundant supply which has led to a decline in gas prices which has helped boost electricity supply and lowered electricity tariffs.

According to the IEA World Energy Outlook (International Energy Agency, 2011), the world's primary energy supply has increased by 58% in 25 years, from about 7.2 billion TOE (Ton of Oil Equivalent). The OECD (Organization for Economic Cooperation and Development) countries used to be the center of energy demand. However, these OECD countries are lower than non-OECD countries in both of economic and population growth rates. Moreover, the increasing in demand stays low. In 2005 the non-OECD countries took the lead in demand, accounting for 51% of consumption in 2006. There is the expected that energy demand in the future will increase based on economic growing countries like China, India, and the Middle East. The estimated show that there is the possibility to increase by 48% over 25 years from about 11.43 billion TOE in 2005 to 17.0 billion TOE in 2030 (Fig. 3.1).

The world's energy demand in 2006 amounted to about 11,703 MTtoe (490 EJ) and was made up of about 81% fossil fuels (oil, natural gas and coal), about 10% renewable energy and waste, about 6% nuclear and about 2.2 are hydropower and 1% other energy such as geothermal, solar or wind respectively (Fig 3.2).

In addition, fossil fuel prices were increased year by year. The increasing prices involved by various factors (Breitenfellner *et al*, 2010):

- An increase in consumption in developing countries,
- Geopolitical risk and a decrease in stockpiles due to "resource nationalism" in supply countries,
- The influences of speculative investors, and
- Inflation and influences of dollar depreciation and quotation in dollars.

From the standpoint of attaining a stable energy supply and diversification supply sources, the importance of alternative fuels is expected to increase.

However, when we discuss on environmental problems in energy policy, particularly global warming concerns, have been given much attention now a days. Currently, the amount of fossil fuel origin carbon dioxide discharge has been increasing, with the corresponding increase in energy demand. Due to this increase, it has been strongly claimed that the greenhouse effect is the main cause. For biomass, $CO_2$ is absorbed during the growth process of the plants and then the same amount is ideally generated when the fuel is burned. This is considered carbon-neutral when we consider $CO_2$ exhaust emissions. Thus the importance of biomass and bio-fuels is evident because they not only increase diversification of energy supply sources but also aid in $CO_2$ reduction. The considering renewable energy forms like biomass, their introduction has been promoted as a core program towards a low carbon social structure. Therefore, Renewable energy has become more widespread. Also, biomass has been introduced and expanded (Goto *et al*, 2010 and Ladanai & Vinterbäck, 2009).

**Japan Energy Status**

Japan has relied on imported energy. Improvement of the self-sufficiency energy supply and diversification of the energy resources are significant issues in the energy security of Japan. The energy policy in Japan is to ensure stable energy supply, energy conservation and reduction of greenhouse gases (Yagi & Nakata, 2011 and Long *et al*, 2013).

Asia biomass energy cooperation promotion office reported that the government of Japan formulated an energy policy in 2003 from the viewpoint of long-term energy security and development, introduction and utilization of alternative energy. The consumption of fossil fuels induces the greenhouse gas emissions. The Japanese energy policy is provided in order to ensure stable energy supply, energy conservation and environmental problem. Trends of the primary energy supply in Japan are shown in Fig. 3.3.

The amount of primary energy supply is also increasing consequence with the energy consumption. The amounts of energy supply of coal and oil are almost constant. On the other hand, those of nuclear power and natural gas are increasing year by year. As a results, oil energy supply decreases from 77 to 49% between 1973 and 2001. Nuclear power significantly contributes to increase the Japanese self-sufficiency ratio up to 20%. Trends of the energy consumption in Japan are shown in Fig. 3.4 (The Institute of Energy Economics, 2006).

With the environmental problem concerned, especially greenhouse gas emission, an amount of $Co_2$ releasing from energy production increases by 10% in 2000 compared with 1990. Renewable energy such as solar and wind power are in the spotlight because they do not emit any environmental during power generation. However, these energies have disadvantages of high cost and instability. The cost of solar power generation is 2–3 times higher than that of other conventional power generation in Japan. Power output of the generator strongly depends on climate conditions. Therefore, the renewable energies account for only 1% of the primary energy supply in 2001 (Yagi, & Nakata, 2011 and Ogawa & Nishihara, 2004).

**Thailand Energy Status**

Thailand's demand for energy has increased over recent decades and tends to retain a similar pace continually. While energy demand in Thailand has been increased dramatically, supplies of energy sources in domestic are limited. Therefore, Thailand also relies on imports energy supplies. The most energy consumed sectors came from transportation, industrial and residential sectors. Form Fig. 3.5, it shows the energy situation in 2010 (DEDE, 2011). Thai’s primary energy consumption was 124,301 ktoe (1 ktoe equal $4.18 \times 10^{13}$ J) increased about 20% from year 2005. Commercial energy, which included crude oil, lignite, natural gas, condensate, hydro, geothermal, solar cell, and wind power, was the largest consumed energy of the total primary energy consumption. It increased from 2005 to 2010 with 18% or equal 101,733 ktoe. Crude oil was the highest consumption with 47,767 ktoe equal 46.95% of the total commercial energy consumption followed by natural gas consumption with 42,686 ktoe equal 41.96%. However, from a large amount of crude oil and natural gas consumption, Thailand imported crude oil for 85.28% from the total of crude oil consumption while Natural gas was imported for 26.61% from the total consumption.

As shown in Fig. 3.6, for the total of final energy consumption in 2010 was 70,247 ktoe. It increased 10% from 2005 and increased 4.77% from previous year. Commercial energy consumption was also shared 80.90% of the total final energy and the rest 19.1% was renewable energy that increased from 2005 for 23.97%.

The consumption of commercial energy was 57,749 ktoe and increased to 10.19% from 2005. Petroleum products are the highest consumption with 56.5% followed by electricity, coal and its products and natural gas with 22.4%, 14.5% and 6.6% respectively. All of commercial energy sources were increased from 2005 except coal and its products was decreased.

As the large amount of imported energy, total energy imported in 2010 was increased 11% from 2006. 99.9% of imported energy came from commercial energy and the rest of 0.1% was renewable energy. Imported commercial energy increased 11% from 2006 as well. Of this imported amount, crude oil was the highest imported quantity. In 2010, Thailand imported crude oil for 40,734 ktoe, increased 61% from 2000. However, coal was the second of imported quantity but its imported was the highest increased of commercial energy imported amount from 2000 with 304% (Fig. 3.7) (DEDE, 2011).

As mentioned before, Thailand heavily relies on imported energy supply. Thailand may face the risk of shortage supply. Therefore, Thai government promoted alternative energy to support the energy demand. One of the main objectives of Thai government is to motivate the utilization of renewable energy to be 20% of the consumption by 2022 (Sawangphol, 2011). This policy will help to reduce energy imports, encourage the utilize of domestic energy supply for sustainable economic growth and help to reduce the emission of green house gas as well.

### *3.2 Renewable Energy*

Renewable energy sources that can be replenished through natural energy flows include solar energy (heat and electricity), biomass, wind power, hydropower, and geothermal power, etc. There is also a strong commitment to financing sustainable development and renewable energy generation (Skambracks, 2007). Renewable energy sources are expected to play a key role in the future. The renewable energy production is also expected to grow quickly in order to increase its share of the global energy mix. Many countries adopted the policy to enhance the role of renewable sources in their energy supplies. For example, European Commission proposed a directive on the use of energy from renewable sources in January 2008 (Rosch & Skarka, 2008). In addition, there is a strong commitment of European to produce 20% of energy from renewable by 2020 (Marchal et al., 2009). The exploitation of renewable energy sources can help them to meet environmental and energy policy goals, including its obligation to reduce greenhouse gases under the Kyoto Protocol (EC, 2002a) and the aim of securing its energy supply (EC, 2002b; EC, 2005).

#### Biomass as a Renewable Energy Source

Since the beginning of civilization, biomass has been a major source of energy throughout the world. Biomass is the primary source of energy for nearly 50% of the world's population (Karekezi & Kithyoma, 2006). In the past decade, the number of countries exploiting biomass opportunities for the provision of energy has increased rapidly, and has helped make biomass an attractive and promising option in comparison to other renewable energy sources. The global use of biomass for energy increases continuously and has doubled in the last 40 years (Fig. 3.8). Concerns about sustainable energy supplies, commitments to the Kyoto Protocol have been major influences on the promotion of biomass energy policies (Hashiramoto, 2007, Sims, 2003). Renewability and versatility are among many other important advantages of biomass as an energy source. The biomass resources currently available come from a wide range of sources.

Contribution of biomass to the global energy demand of 470 EJ in 2007 is only 10%, mainly in the form of traditional non-commercial biomass (Fig. 3.9). Moreover, biomass can be used to produce different forms of energy, thus providing all the energy services required in a modern society. Furthermore, compared to other renewable resources, biomass is one of the most common and widespread resources in the world (WEC, 2004). Thus, biomass has the potential to be a source of renewable energy, both locally and in large parts of the world.

The future potential for the energy from biomass depends to a great extent on land availability. Currently, the amount of land devoted to growing biofuel is only 0.025 billion hectares or 0.19% of the world's total land area of 13.2 billion hectares and 0.5-1.7% of global agricultural land (Fig. 3.10).

**Biomass in Japan**

Biomass is getting popular and interest in Japan as an appropriate method to reduce global warming problem and to reach to the sustainable society. Furthermore, utilization of biomass could contribute to job creation in local community, enhancement of competitiveness in industries, and the activation of agriculture, forestry, and fishery in rural areas. In case of energy utilization, it could also contribute to the enhancement of energy security. The cabinet approved "Biomass Nippon Strategy" in December 2002 to promote the utilization of biomass in both energy and material uses (Kuzuhara, 2005). Japanese government approved Biomass Nippon Strategy in a Cabinet meeting in December 2002 in order to go forward utilization of biomass comprehensively and in a planned way. Furthermore, Biomass Nippon Strategy was revised in March 2006 from a viewpoint of "acceleration of biomass towns" and "promotion of utilization of biofuels". In Japan, annual biomass production is 322 million tons. Although recycling rate of biomass is 76%, the other 24% of biomass is not recycled. The amount of un-used biomass is 76.44 million tons a year; in particularly, the top un-used biomasses are sewage sludge, waste paper, food waste, non-edible agricultural product and forest residue. (Fig. 3.13, Table 3.1,)

Among un-used biomass, recycling rate of forest residue is only 1%. Forests cover about 70% of Japan's total area, and Japan is one of the largest forested countries in the world. However 80% of all woods have to be imported. Japanese forest industry and farming village can stimulate activity by reducing import of wood and using domestic wood. To achieve this, it is necessary that forest changes worn-out into valuable by reusing forest residue abandoned in the forest. It is strongly expected that forest residue is recycled even more.

Table 3.2 shows the energy potentials of various agricultural residues in Japan. The productivity figures covered the fiscal year 2000 and were obtained from the Monthly Report of Agricultural Production Statistics (Seisan and Geppo, 2002). Values for residual ratio, defined as the amount of residue production divided by agricultural production, moisture content, and ash content, were obtained from the book by Klass in 1998, The heating values of residues were assumed to be 18.6 MJ $kg^{-1}$ higher heating value on a moisture and ash free basis, regardless of the biomass species. The productivity of rice straw and rice husk far exceeds that of the other residues.

**Biomass in Thailand**

Thailand is an agricultural country which has high amount resources of renewable energy sources. The most of renewable energy sources come from agricultural residues. This energy derived from four main agricultural residues which are bagasse, rice husk, palm oil wastes, and wood residues. The agricultural residues can be used as a biomass for biomass energy plant (DEDE, 2009; Srisovanna, 2004) (Table 3.3). Potential of agricultural residue in 2004, almost 44 million tons out of 66 million ton of agriculture residues were unused and equivalent to 14,662 ktoe (Srisovanna, 2004).

Although, Fossil fuel is very importance because it can produces significant amounts of energy per unit weight, found in abundance, easy to transport, extract and process and cheaper; but there are some questions about the availability, the effects on environment and current rising of fossil fuel price in the world market or shortages of existing supplies. According to those problems, biomass is considered as sustainable source and environmental friendly. The substitution of fossil fuel by biomass is help to reduce environmental impacts and cost of imported fossil fuel such as coal, petroleum and natural gas (Shen, 2011; Sawangphol, 2011). Moreover, Biomass can bring rural area benefits such as new sources of income for farmers, more jobs, and economic development. Biomass also helps to achieve the increasing in demands for fuel and electricity in rural areas (Ravindranath, 2004).

The utilization of biomass for energy is applied for many technologies such as direct combustion, gasification, biochemical conversion, extraction, etc. Base on biomass utilization so far, direct combustion is the most applicable of heat and power generated technology (Suramaythangkoor, 2010).

### *3.3 Direct Combustion System vs. Gasification System*

The necessary factors that impact the decision for select the conversion processes are the type of the biomass, the available quantity of biomass, economic conditions; and project specific factors. The generation of electricity from biomass encompasses a wide range of different possible conversion processes (Fig. 3.11)

High heating values and Lower moisture contents of the biomass fuels are required for thermo chemical conversion processes. Direct combustion is the most common process to produce thermal energy. It is the most directly process for converting biomass to energy. It can be used as steam production for further steps. Direct combustion generates electricity by using steam turbines, steam engines or other energy converter (Basrz, 2008). However, it properties is complex process due to heat application process. This technology system is mature and commercially available worldwide and Thailand as well. Direct combustion system has higher operational reliability when compare with Gasification system (Quaak *et al*, 1999).

Gasification is a more than century old technology, which developed b during the Second World War. However, this technology disappeared after the Second World War because petroleum based fuel became more easily available than gasification technology. Recently, due to an increasing of fossil fuel prices and environmental concern, gasification technology has been interest and developed again as a high technology. Gasification process is to converts a solid fuel to a combustible gas by supply a restricted amount of oxygen. This contains many substances such as carbon monoxide, carbon dioxide, hydrogen, methane, trace amounts of higher hydrocarbons such as ethane and ethene, water, etc. and various contaminants such as small char particles, ash, tars and oils. The partial oxidation can be carried out using air, oxygen, steam or a mixture of these. (Barz, 2011; Bridgwater, 1999) (Fig. 3.12).

In Thailand, a large portion of the electricity production by biomass comes from Combustion system technology. Direct combustion has been the most important process in converting biomass to other useful form of energy (Srisovanna, 2004) but direct combustion technologies are available. However, many biomass energy plants, some of them are still running at low efficiency by using conventional burning to produce a stream for power generation. Therefore, thermo mechanical conversion process like gasification technology can help to solve the problems.

In spite of widely used of direct combustion system, recently, Ministry of Energy has fund to support for the construction of community biomass gasification system (Salam, 2008). Nevertheless, an increasing of gasification interesting is quite low. Biomass gasification processes are available under industrial, development at pilot scale and demonstration scales in Thailand. Several biomass gasification plants have been installed in Thailand during last 5 years. There are 25 of the plants which identified that 15 plants are in industrial or commercial applications and 10 are either government supported demonstration plants or research and development purposed plants by the universities. All the existing, identified electricity generation capacities are less than 400 kW except a plant with 1.5 MW capacities still under construction phase. Unfortunately, recently, there are only 5 plants in Thailand that continuously in operation. Commercial implementation has not yet been widely accepted. It caused the existing drawback such as the low of reliability for gasification technology (Salam, 2010; Barz, 2011).

Table 3.1 Annual biomass production and recycling rate
(Asia biomass energy cooperation promotion office, 2009)

| Biomass | | Annual Production (10,000 ton) | Recycling Rate (%) | Re-used Biomass (10,000 ton) | Un-used Biomass (10,000 ton) |
|---|---|---|---|---|---|
| Waste Biomass | Livestock wasre | 8,700 | 90 | 7,830 | 870 |
| | Sewage sludge | 7,900 | 75 | 5,925 | 1,975 |
| | Black liquor | 7,000 | 100 | 7,000 | - |
| | Waste paper | 3,600 | 60 | 2,160 | 1,440 |
| | Food waste | 1,900 | 25 | 475 | 1,425 |
| | Wood mill waste | 430 | 95 | 409 | 21 |
| | Wood construction waste | 470 | 70 | 329 | 141 |
| Non-used Biomass | Non-edible agricultural product | 1,400 | 30 | 420 | 980 |
| | Forest residue | 800 | 1 | 8 | 792 |
| Total | | 32,200 | 76 | 24,556 | 7,644 |

Table 3.2 Annual agricultural residue production in Japan

| | Production (t/year) | Residual ratio | Residue production (t/year) | Energy potential (PJ/year) |
|---|---|---|---|---|
| Rice | 9,472,000 | 1.43 | 13,544,960 | 157.2 |
| Wheat | 688,200 | 2.53 | 1,741,146 | 20.1 |
| Barley | 192,200 | 2.5 | 480,500 | 6.9 |
| Sweet potato | 1,008,000 | 1.14 | 1,149,120 | 2.1 |
| Potato | 2,844,000 | 1.14 | 3,242,160 | 6 |
| Soybean | 235,000 | 2.14 | 502,900 | 3.2 |
| Sugarcane | 1,395,000 | 0.52 | 725,400 | 2.3 |
| Corn | 5,287,000 | 1.1 | 5,815,700 | 51.6 |
| Sorghum | 1,625,000 | 1.57 | 2,551,250 | 15.9 |

Table 3.3 Main Thailand agricultural residues (2004)

(Unit: 1,000 t)

| Type | Production | Agricultural residues | CRR | Residues | Surplus availability factor | Available unused residue |
|---|---|---|---|---|---|---|
| Sugar cane | 70,101 | Bagasse | 0.291 | 20,399 | 0.207 | 4,223 |
| | | Trash | 0.302 | 21,171 | 0.986 | 20,874 |
| Rice | 26,841 | Rice husk | 0.230 | 6,173 | 0.493 | 3,044 |
| | | Rice straw | 0.447 | 11,998 | 0.684 | 8,207 |
| Oil palm | 4,903 | EFB | 0.250 | 1,226 | 0.584 | 716 |
| | | Fiber | 0.147 | 721 | 0.134 | 97 |
| | | Shells | 0.049 | 240 | 0.037 | 9 |
| | | Fronds | 2.604 | 12,767 | 1.000 | 12,767 |
| Total | | | | 74,695 | | 49,936 |

Remarks: CRR= Crop-to-Residue Ratios
EFB= Empty Fruit Bunches

Source: Papong *et al*, 2004

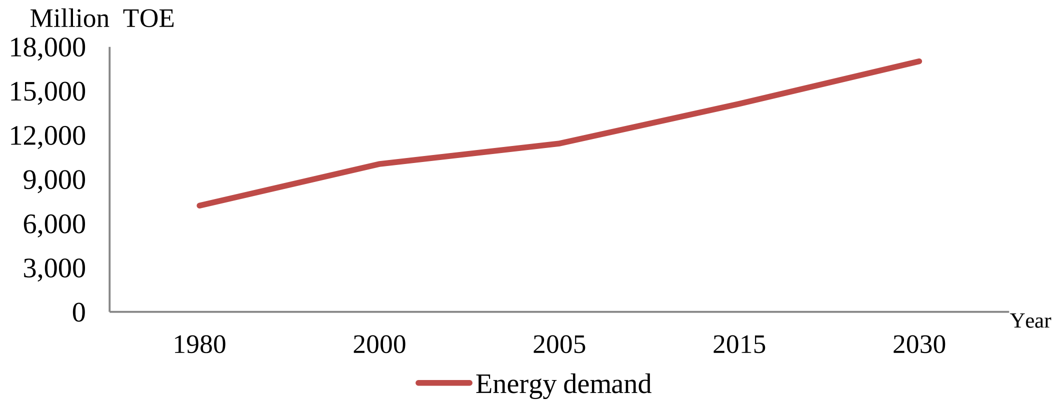
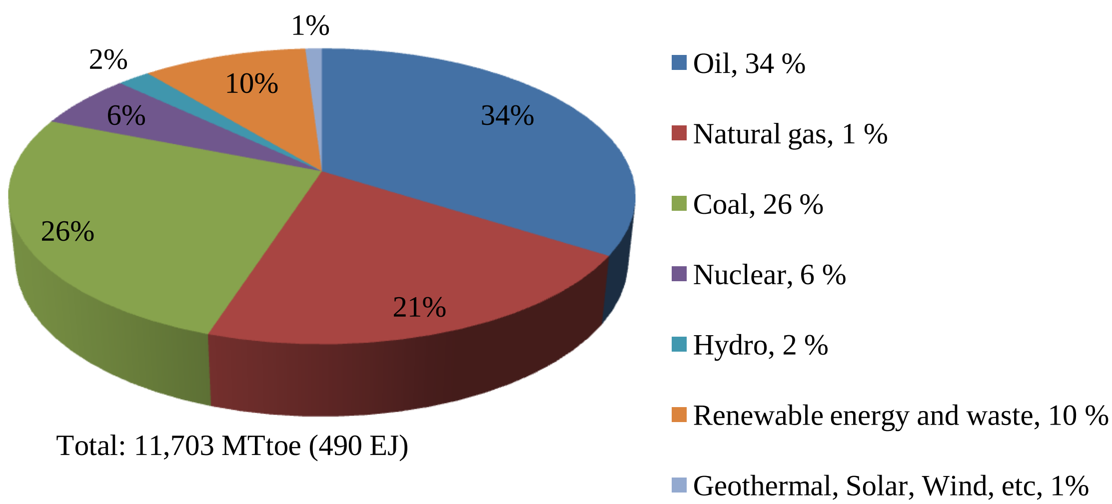



Fig. 3.1 Perspective of energy demand (Source: IEA World Energy Outlook 2007, 2008)




(MTtoe = Million tons of oil equivalent; 1 toe = 41.9 GJ)

Fig. 3.2 Constitutes of the global energy demand and share of the main categories in 2006 (Source: IEA, 2008)

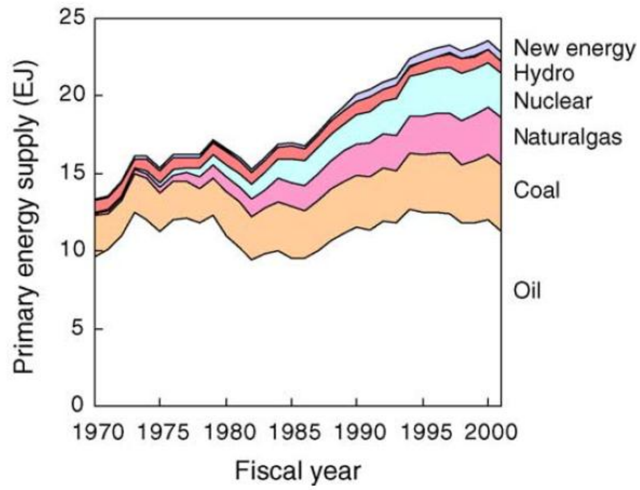
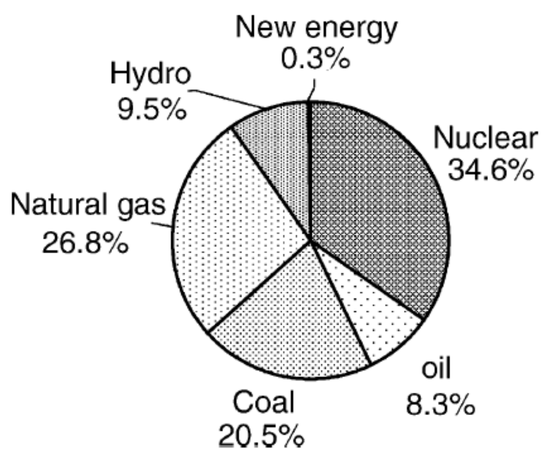
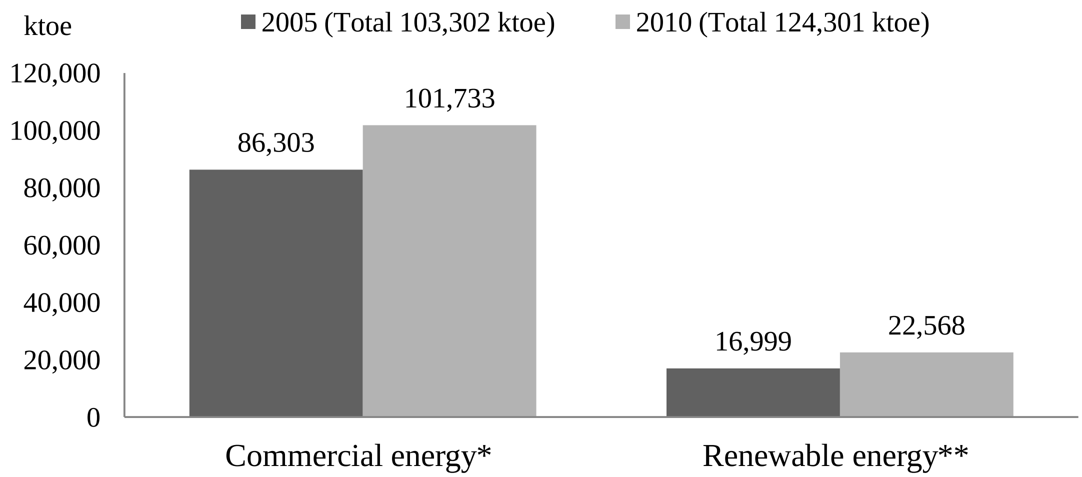



Fig. 3.3 Trends of the primary energy supply in Japan (Ogawa & Nishihara, 2004).




*(Total electricity generation is 924 billion kWh)

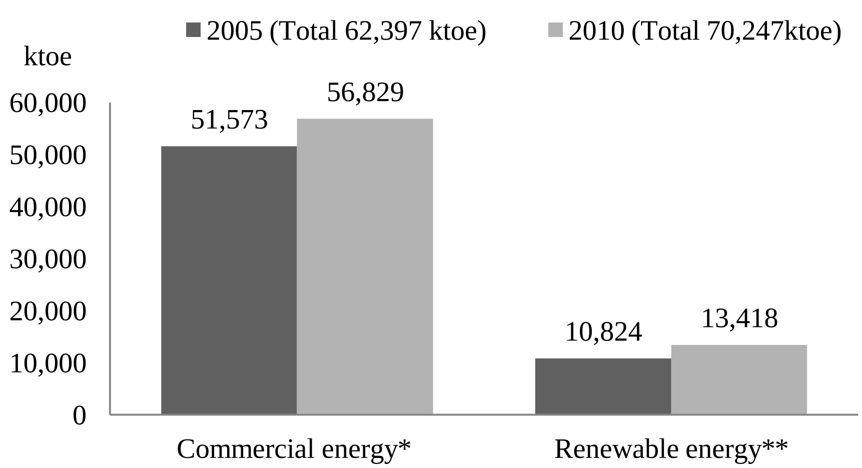
Fig. 3.4 Dependence of nuclear power in electricity generation in 2001
(The Institute of Energy Economics, 2006)




* Including crude oil, lignite, natural gas, condensate, hydro, geothermal, solar cell, and wind power
** Including wood, charcoal, rice husk, bagasse, agricultural waste, biogas, black liquor, biofuel, and residual gas from production processes

Fig. 3.5 Primary energy consumption in 2005 and 2010

(Department of Alternative Energy Development and Efficiency, 2005 and 2010)




* Including Petroleum Products, Electricity, Coal & its products, Natural gas
** including fuel wood, charcoal, paddy husk, bagasse, agricultural waste, garbage and biogas

Fig. 3.6 Final energy consumption in 2005 and 2010

(Department of Alternative Energy Development and Efficiency, 2005 and 2010)

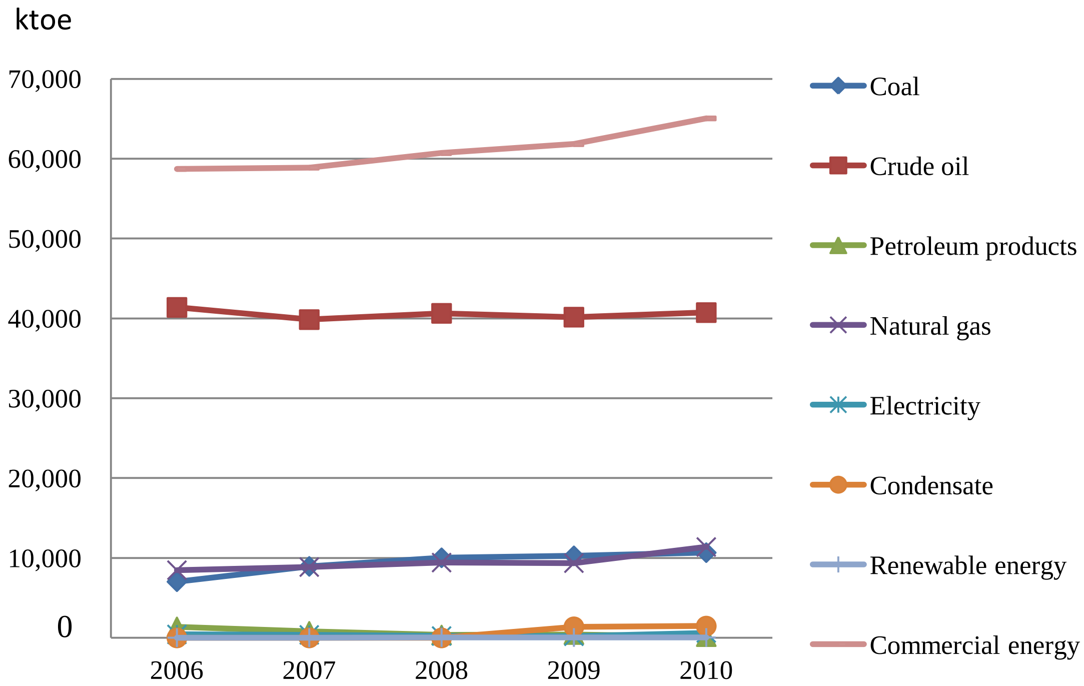



Fig. 3.7 Import of energy by fuel type, 2006 – 2010

(Department of Alternative Energy Development and Efficiency, 2011)

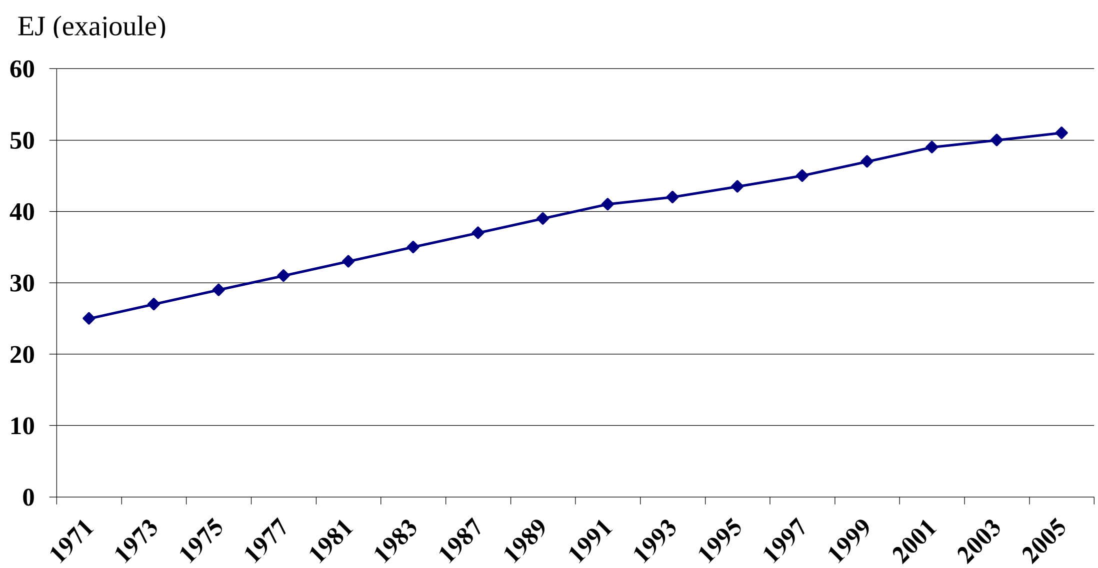



Fig. 3.8 World use of combustible renewable and waste 1971 – 2006 (World Bank, 2009)

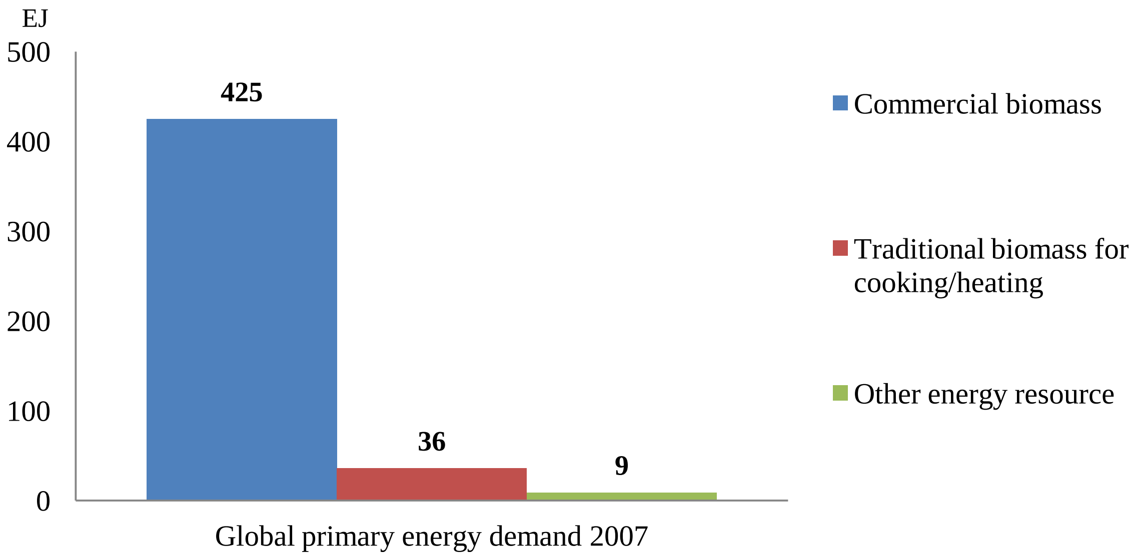



Fig. 3.9 Contribution of biomass to global primary energy demand of 470 EJ in 2007 (Faaij, 2008).

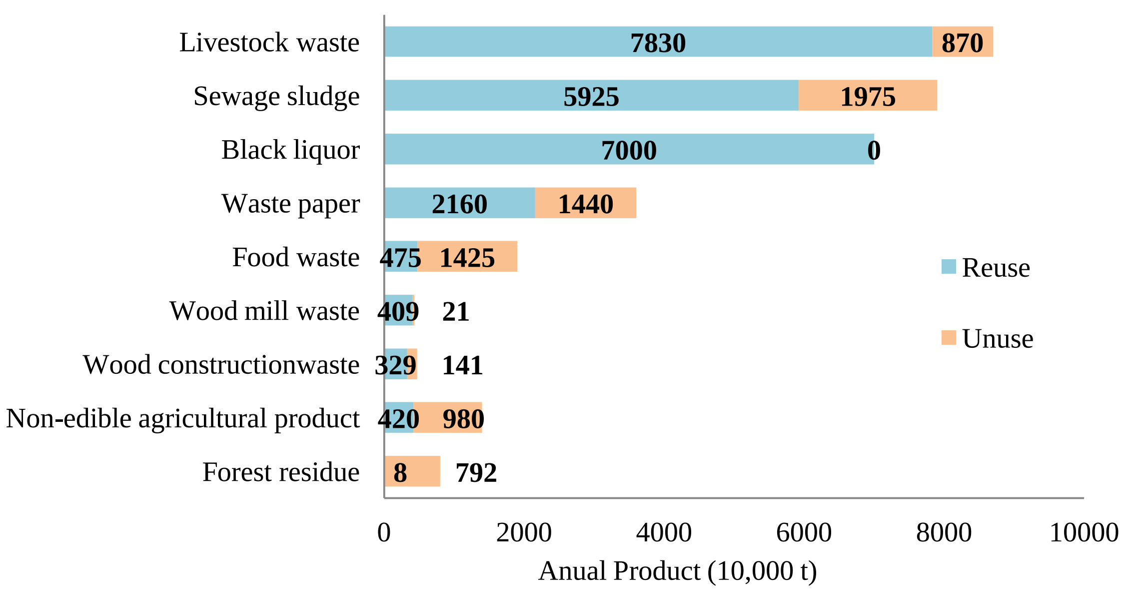
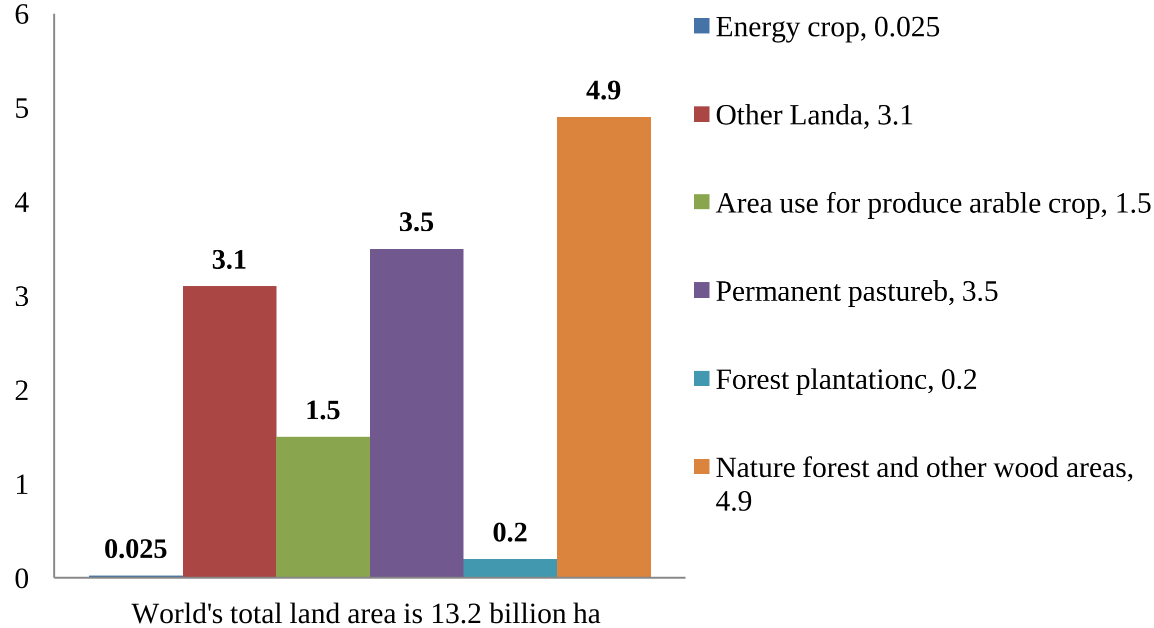



Fig. 3.10 Annual biomass production and recycling rate (Ministry of Agriculture, 2011)




Notes: [a]Other land: Land not included in the FAO land use categories
[b] Permanent pastures: Land used permanently for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land)
[c] ITTO, 2006ab
[d] Smeets et al., 2004

Fig. 3.11 Distribution of land use types in world's total land area (Faaij, 2008)

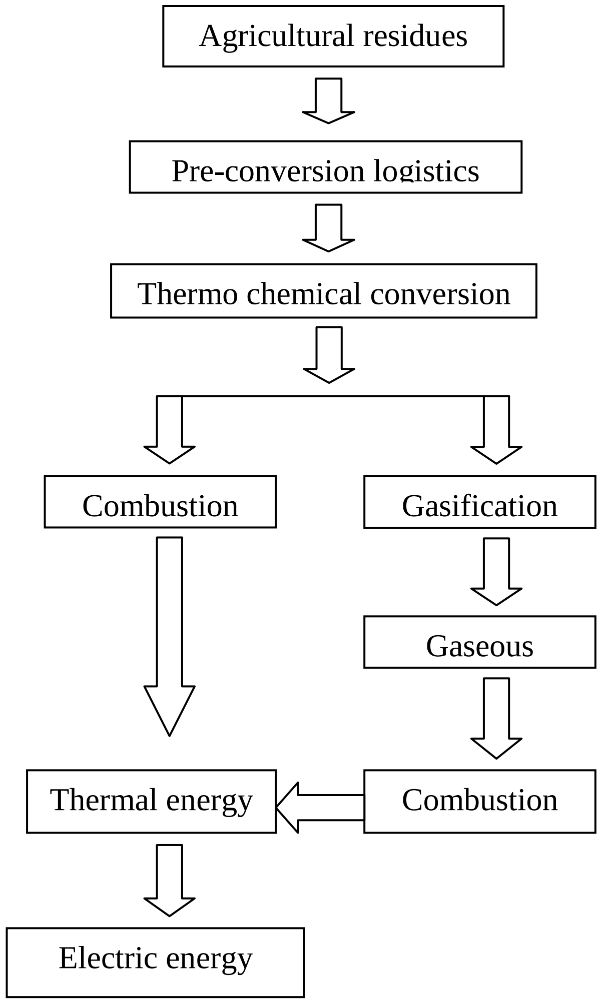



Fig. 3.10 Conversion routes for agricultural residues (Basrz, 2008)

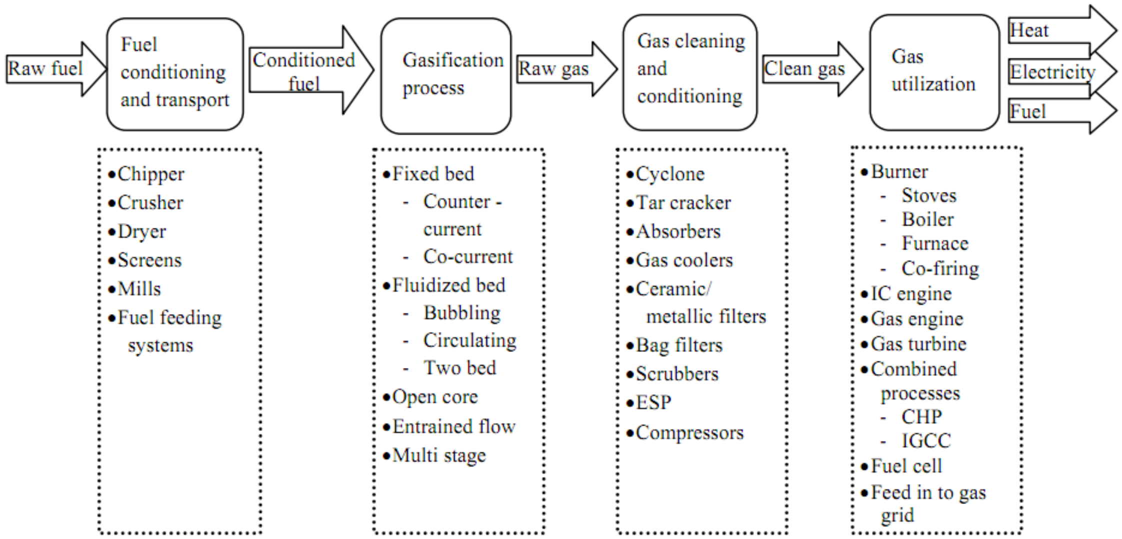



Fig. 3.11 Basic process steps of a biomass gasification plant (EEP, 2010)

# CHAPTER 4

## Part 1: Evaluation of Biofuel Production Using Energy and Exergy Analyses - Introduction of a System Design Concept for Achieving Final Benefits –

## A case study in Japan

### *4.1 Introduction*

Due to a significant increase in the cost of fossil fuels, biofuel has begun to gain acceptance as a viable resource of alternative energy. Fossil fuel is valuable because it can produce significant amounts of energy per unit weight, it is abundant, and it is easy to transport, extract and process as a liquid. However, some uncertainty exists regarding its availability, effect on the environment, cost in the world market and the shortage of existing supplies (United Nation, 2012). The substitution of fossil fuel with biofuel aims to reduce environmental impacts and the cost of imported fossil fuels, such as coal, petroleum and natural gas (Shen et al 2011; Sawangphol and Pharino, 2011). Biofuel is considered a feasible approach for reducing fossil fuel consumption and $CO_2$ emissions. Moreover, the promotion of biofuel can add high value to biomass.

There exists concern that the expansion of biofuel crop production will threaten food security around the world by affecting food supply and cost (International Union of Food Science and Technology (IUFoST, 2010). For example, bio-ethanol production in the USA requires vast amounts of edible maize (Farrell *et al*, 2006). Mitchell (2008) reported that more than 70% of increases in food costs were attributable to biofuel demand. According to Tollens (2009), the increasing cost of maize in the US from 2007-2008 was highly related to biofuel production. The impact on food security will depend upon the biofuel crop grown. Therefore, a new evaluation method is required to minimize the disparity between energy supply and energy demand and reduce field biomass production.

Field area of biomass production, variety of biomass and conversion efficiency of biofuel plants were used in the evaluation of total energy efficiency for biofuel production (Noguchi and Misumi, 2007). The evaluation method of total energy efficiency for biofuel production can be utilized in field production and lead to a more effective production of biofuel energy. Furthermore, the Energy Profit Ratio (EPR), which is a ratio of output energy to input energy in biofuel production, is a very popular and standard method of evaluation for decision making (Nomura Research Institute Ltd., 2007; Pimentel and Patzek, 2005; Silalertruksa and Gheewala, 2009). Energy consumers who are interested in biofuel production seek final benefits such as heating, lighting, and mileage (Hamamatsu, 2010; Central Research Institute of Electric Power Industry, 2011).

From the viewpoint of quality of life, environmental protection, and sustainable development, "backcasting" should be utilized to identify policies and programs that connect the future with the present for defining a desirable future (Oliver and Brooks, 2005). Forecasting is an estimation of future impact. To achieve established objectives, both should be followed by an explicit manifestation of future target goals and an evaluation of required policies. Backcasting involves setting policy goals and determining how those goals can be achieved. In addition, the measurement of precise physical quantities of energy for biofuel production is indispensable for determining the total amount of social benefit (Noguchi and Koyama, 2010).

Evaluation functions, which are based on energy benefits, were developed in this research to minimize the disparity between energy supply and demand and to reduce the field area of biomass production in biofuel production. An Exergy Profit Ratio (ExPR) which is extended EPR was also proposed to measure the quality and availability of energy. To validate the system design model, Utsunomiya City in the Tochigi Prefecture of Japan was selected as an example and studied to assess the credibility of the evaluation functions.

## *4.2 Methodology*

### System Design for Evaluation Functions

In a conventional system design for biofuel production, final benefit is considered after calculating field area, type of biomass, type of biofuel plant and type of biofuel, which are systematically based on single energy and single benefit (Fig. 4.1). In this research, the final benefit of specific area is considered at the beginning of system design for biofuel production via the backcasting method. Types of biofuel, type of biofuel plant, type of biomass and field area were systematically based on multiple types of energy. Subsequently, societal acceptance was also considered for introducing biofuel production, as shown in Fig. 4.1. If a shortage of energy results from achieving final benefits, biofuel production should be modified to increase the amount of energy. Conversely, if there is a surplus in field area during biomass production, surplus energy production should be reduced. Therefore, the purpose of proposing an evaluation function is to ensure adequate proportions of energy supply and demand with regards to the final benefit.

To obtain a greater evaluation when the difference between energy supply and demand is near zero, the evaluation function by energy $E_{system}$ [$J^2$], energy consumption $E_{cons}$ [J], and energy production $E_{pro}$ [J] were used in the evaluation function (Nakamizo 1988) as follows:

$$E_{system} = \left(E_{cons} - E_{pro}\right)^2 \qquad (4\text{-}1)$$

Additionally, there is extensive variation in final benefit and energy in biofuel production. $E_{system}$ can be expressed using a variety of energy $j$, energy consumption $E^j{}_{cons}$ [J], and energy production $E^j{}_{pro}$ [J] as follows:

$$E_{system} = \sum_j \left(E^j{}_{cons} - E^j{}_{pro}\right)^2 \qquad (4\text{-}2)$$

After defining field area of biomass production $S$ [ha], biomass yield per unit area $Y$ [t/ha], variety of energy $j$, energy conversion efficiency including biofuel plant $\eta^j$ [J/t], and $E^j{}_{pro}$, which is proportional to $S$, $E_{system}$ can be expressed as follows:

$$E_{system} = \sum_j \left(E^j{}_{cons} - SY\eta^j\right)^2 \qquad (4\text{-}3)$$

Generally, the field area of biomass production for converting biofuel is limited. Minimizing the field area of biomass production could satisfy the energy demand for final benefit. This objective function needs to incorporate the most appropriate strategies for reducing environmental impact and maintaining agricultural production.

Therefore, the most efficient system design of biofuel production can be achieved by minimizing field area, which can be obtained by differentiating Eq. (4-4) as follows:

$$\frac{dE_{system}(S)}{dS} = \frac{d\left\{\sum_{j}\left(E^{j}{}_{cons} - SY\eta^{j}\right)^{2}\right\}}{dS} = 0 \qquad (4\text{-}4)$$

**System Design Based on Final Benefit**

$E_{system}$ for biofuel production was examined using direct energy flow, which can be easily evaluated with clear numerical values. As illustrated by Fig. 4.2, a biofuel plant not only can produce biofuel but can also produce electricity. The final benefit could be achieved through mileage and heating. In this case, biofuel can be used for gasoline vehicles or direct combustion boilers. Electricity is used for electric vehicles or heat pumps. Biofuel & electricity are also used to satisfy the energy demand of biomass production in field and biofuel plants. Biofuel is used as an alternative to gasoline in automobiles. Because electricity and gasoline are primarily used for energy in the civilian sector, including households, the household is considered the smallest unit in this research.

A number of variables of biofuel production comprises the annual cycle of biomass production. The amount of final benefit was also based on one year. Annual mileage per household $M$ [km], annual heating per household $H$ [J], number of households with gasoline vehicles $n_{GV}$ [-], number of households with boilers (heating equipment by combustion) $n_{BL}$ [-], number of households with electric vehicles $n_{EV}$ [-] and number of households with heat pumps $n_{HP}$ [-] were used in the system design. In addition, mileage from gasoline vehicles using biofuel $\eta_{GV}$ [km/L], mileage from electric vehicles $\eta_{EV}$ [km/kWh], amount of heat energy produced by boilers using biofuel $\eta_{BL}$ [J/L], and amount of heat energy produced by heat pumps $\eta_{HP}$ [J/kWh] were also used in the system design.

In this case, total amount of mileage for final benefit in society $M_0$ [km] and total amount of heat $H_0$ [J] were expressed as follows:

$$M_0 = M(n_{GV} + n_{EV}) \quad (4\text{-}5)$$

$$H_0 = H(n_{BL} + n_{HP}) \quad (4\text{-}6)$$

The amount of biofuel expected from the final benefit $E_{BF}$ [L] and amount of electricity expected from the final benefit $E_{EL}$ [kWh] were expressed as follows:

$$E_{BF} = \frac{Mn_{GV}}{\eta_{GV}} + \frac{Hn_{BL}}{\eta_{BL}} \quad (4\text{-}7)$$

$$E_{EL} = \frac{Mn_{EV}}{\eta_{EV}} + \frac{Hn_{HP}}{\eta_{HP}} \quad (4\text{-}8)$$

Thus, conversion efficiency from biomass to biofuel in the plant $\eta_{\mathrm{BF}}$ [L/t], conversion efficiency from biomass to electricity $\eta_{\mathrm{EL}}$ [kWh/t], lower quantity of heat for biofuel $e_{BF}$ [J/L] and conversion efficiency from electricity to heat $e_{EL}$ [J/kWh] were used to calculate the evaluation function, which can be expressed as follows:

$$E_{system} = \left( \frac{Mn_{GV}}{\eta_{GV}} + \frac{Hn_{BL}}{\eta_{BL}} - SY\eta_{BF} \right)^2 e_{BF}{}^2 + \left( \frac{Mn_{EV}}{\eta_{EV}} + \frac{Hn_{HP}}{\eta_{HP}} - SY\eta_{EL} \right)^2 e_{EL}{}^2 \quad (4\text{-}9)$$

Moreover, liquid fossil fuels used for biomass production including transportation $E_{\mathrm{BBF}}$ [L], electricity used for biomass production including transportation $E_{\mathrm{BEL}}$ [kWh] and the proportional relationship between these two variables and the amount of biomass $\eta_{\mathrm{BBF}}$, $\eta_{\mathrm{BEL}}$ were used for $E_{\mathrm{system}}$ as follows:

$$E_{system} = \left\{ \frac{Mn_{GV}}{\eta_{GV}} + \frac{Hn_{BL}}{\eta_{BL}} + SY(\eta_{BBF} - \eta_{BF}) \right\}^2 e_{BF}{}^2 + \left\{ \frac{Mn_{EV}}{\eta_{EV}} + \frac{Hn_{HP}}{\eta_{HP}} + SY(\eta_{BEL} - \eta_{EL}) \right\}^2 e_{EL}{}^2 \quad (4\text{-}10)$$

Therefore, $E_{system}$ was expressed using a variety of energy conversion equipment $i$, number of $i$ $n_i$, efficiency of $i$ $\eta_i$, type of energy produced in the plant $k$, conversion factor of heat $e_k$ and amount of final benefit per unit for type of energy $j$ $F_j$ as follows:

$$E_{system} = \sum_{k} \left\{ \left( \sum_{i,j} \frac{F_j n_i}{\eta_i} \right) + SY\left(\eta_{Bk} - \eta_k\right) \right\}^2 e_k^{\,2} \qquad (4\text{-}11)$$

**Evaluation Function for Energy Conversion to Other Type of Energy**

If one type of energy is converted to other type of energy, as in excess and deficiency of biofuel energy or electricity, as shown in Eq. (10), $E_{\mathrm{system}}$ should be adjusted. If a shortage of electricity and surplus of biofuel occurs, $E_{system}$ can be minimized by producing electricity from biofuel using power generators. Then, $E_{\mathrm{system}}$ can be expressed using amount of electricity produced from biofuel $E_{BFtoE}$ [L] and efficiency of power generator $\eta_{GN}$ [kWh/L] as follows:

$$\begin{aligned} E_{system} &= \left\{ \frac{Mn_{GV}}{\eta_{GV}} + \frac{Hn_{BL}}{\eta_{BL}} + SY\left(\eta_{BBF} - \eta_{BF}\right) - E_{BFtoE} \right\}^2 e_{BF}^{\,2} \\ &+ \left\{ \frac{Mn_{EV}}{\eta_{EV}} + \frac{Hn_{HP}}{\eta_{HP}} + SY\left(\eta_{BEL} - \eta_{EL}\right) + E_{BFtoE}\eta_{GN} \right\}^2 e_{EL}^{\,2} \qquad (4\text{-}12) \end{aligned}$$

Therefore, based on energy conversion of all types of energy, $E_{system}$ can be expressed as follows:

$$E_{system} = \sum_{k} \left\{ \left( \sum_{i,j} \frac{B_j n_i}{\eta i} \right) + SY\left(\eta_{Bk} - \eta_k\right) - \sum_{l \neq k} E_{k\,to\,l} + \sum_{l \neq k} E_{l\,to\,k}\eta_k \right\}^2 e_k^{\,2} \qquad (4\text{-}13)$$

**Exergy Evaluation**

The conventional EPR is calculated using thermal unit [J] for energy production and energy consumption as follows:

$$\text{EPR} = \frac{\sum_j E^j{}_{pro}}{\sum_j E^j{}_{cons}} \tag{4-14}$$

The thermal unit [J] in EPR is not satisfied from an evaluation standpoint of available energy because its unit is not expressed for quality of available energy. Thus, $E_{system}^{EX,}$ which is $E_{\text{system}}$ based on exergy instead of energy, was proposed by considering exergy theory (Nobusawa 1980) (Oshida 1986) in the evaluation function $E_{system}$. Because electricity has 100% efficiency of exergy virtually 100% of electricity can be converted to energy for mechanical work. However, 15°C water in 15°C environmental temperature has 0% efficiency of exergy; thus, it is impossible to produce work energy from 15°C water because of the theory of the Carnot cycle. On the other hand, ExPR, which is expressed as a ratio of output exergy to input exergy, can be expressed by establishing the type of energy $j$, exergy consumption of $j$ $E_X{}^j{}_{cons}$ [J] and exergy production of $j$ $E_X{}^j{}_{pro}$ [J] as follows:

$$\text{ExPR} = \frac{\sum_j Ex^j{}_{pro}}{\sum_j Ex^j{}_{cons}} \tag{4-15}$$

**Simulation**

Mileage, heating, and lighting of all households in Utsunomiya City, as shown in Table 4.1, were used in the simulation. Mileage energy consumption was calculated using annual mileage of vehicles (Ministry of Land, Infrastructure, Transport and Tourism, 2008), fuel consumption of gasoline vehicles (Ministry of Land, Infrastructure, Transport and Tourism, 2005), and quantity of heat for gasoline.

The diffusion rate for heat pumps in households was 89% (Council on Competitiveness-Nippon (COCN) 2010; The Institute of Energy Economics, Japan 2008). Thus, vapor produced by biofuel plants not equipped with heat pump facilities can take advantage of the heat energy of households. A 100% diffusion rate of heat pumps in households was also considered in the simulation. The energy consumption of lighting was estimated for a household equipped with average lighting, such as fluorescent light, incandescent light and LED light (Environmental Pollution Control Center, Osaka Prefecture 2002). The energy flow of specialized bio-ethanol production and the bio-ethanol & electricity production (Saga et al, 2007) was utilized in the simulation. Energy consumption for biomass production was also included for the trial calculation in this simulation. Electricity, fuel (bio-ethanol, gasoline), vapor and heat were considered energy flows of biofuel production. 90% efficiency of exergy was used for fuel energy as estimated by Rant's approximation (Nobusawa, 1980). 41% efficiency of exergy was used for energy of vapor, which revealed a temperature of 500°C and a pressure of 1,960 kPa in the cogeneration of biofuel plants (The Institute of Applied Energy, 2002;Nobusawa, 1980). 10% efficiency of exergy was used for energy of heat, because 0.107 of the availability ratio for heat was observed for a waste heat temperature of 80°C and an environmental temperature of 10°C (Nobusawa, 1980).

## *4.3 Results and Discussion*

### Energy Profit Ratio and Exergy Profit Ratio

Direct energy for agricultural production, collection and transportation, biofuel plant, and final benefit was calculated in this research (Table 2). In agricultural production, collection and transportation, fuel and electricity were used. In biofuel plant, the bio-ethanol and electricity production doesn't use energy supply from outside, and produces not only bio-ethanol but also electricity, vapor, and heat. On the other hand, the specialized bio-ethanol production uses energy supply of electricity and vapor from outside. Accordingly, total amount of bio-ethanol is increased, but a vapor is not able to be utilized in outside of the biofuel plant. Because all vapor is used in the biofuel plant. Furthermore, total amount of heat also is also decreased.

Two types of biofuel production were evaluated from the standpoint of EPR and ExPR, as shown in Table 4.2. EPR and ExPR of bio-ethanol & electricity production were 10.4 and 7.14, respectively. The bio-ethanol and electricity production does not need the input energy, because of using rice straw and rice husk for energy supply to the biofuel plant. Thus, 10.4 of EPR and 7.14 of ExPR were very high compared with the normal value of EPR and ExPR for biofuel production. Because, input energy is very small, and all kinds of energy including bio-ethanol were used for calculation of EPR.

EPR and ExPR for the specialized bio-ethanol production were 1.31 and 1.86, respectively. The energy and exergy analysis revealed that the bio-ethanol & electricity production had a higher advantage than the specialized bio-ethanol production, if produced electricity could be used for final benefit, with the exception of mileage. Both values of EPR and ExPR of bio-ethanol & electricity production were higher than EPR and ExPR of the specialized bio-ethanol production because produced energy, except for bio-ethanol, was used for making bio-ethanol in the specialized bio-ethanol production. EPR was higher than ExPR in the bio-ethanol & electricity production. However, in contrast, ExPR was higher than EPR in the specialized bio-ethanol production. Because high-efficiency exergy, such as electricity, was used as input energy in the specialized bio-ethanol production, biofuel as a high-efficiency exergy was also produced. The method of converting low-efficiency exergy, such as vapor, from other type of energy to usable energy was crucial for improving EPR and ExPR in biofuel production. Evaluation by EPR and ExPR can be used to ascertain improvement points.

### Minimizing Field Area of Biomass Production Using the Evaluation Function

Minimum field area of biomass production based on societal demand was calculated by Eq. (4) in the case of introduction of the bio-ethanol and electricity production. Relationships between $E_{system}$ for energy and field area of biomass production is shown in Fig. 4.4. Relationships between $E_{system}^{EX}$ for exergy and field area of biomass production is depicted in Fig. 4.5. $E_{system}$ and $E_{system}^{EX}$ were calculated from 0 ha to 50,000 ha in 500 ha increments and based on several factors, such as mileage: 100 % biofuel; lighting: 100% electricity; and heating: 89% electricity and 11% of vapor. 5,851 ha of the current field area, 28,193 ha of the field area satisfied by biofuel demand, and 49,000 ha of the field area satisfied by the electricity demand are illustrated in Fig. 4.4 and 4.5.

When the field area of biomass production was 17,500 ha, the minimum value of $E_{system}$ was 1.857 $PJ^2$. The field area was 10,693 ha less compared with 28,193 ha that satisfied the biofuel demand, as shown in Fig. 4.4. The results indicate that the amount of energy for electricity, fuel, vapor, and heat increased according to field area of biomass production. However, the amount of energy for electricity did not satisfy the energy demand below 17,500 ha. Above 17,500 ha, the value of $E_{system}$ increased rapidly because vapor and heat were evaluated as waste energy, which did not contribute to use of the final benefit. When the field area of biomass production was 29,500 ha, the minimum value of $E_{system}^{EX}$ was 0.289 $PJ^2$. The field area was 1,307 ha greater compared with the 28,193 ha that satisfies the biofuel demand, as shown in Fig. 4.5. The total value of $E_{system}^{EX}$ was less than the total value of $E_{system}$ because the value of exergy was calculated by multiplying efficiency of exergy with energy.

As shown in Fig. 4.6 and Fig. 4.7, 100% heat demand was estimated to satisfy the heat pump in this simulation, based on factors such as mileage: 100 % biofuel; lighting: 100% electricity; and heating: 100% electricity. As a result, 28,193 ha were required to satisfy the biofuel demand, and 53,000 ha were required to satisfy the electricity demand. When the field area of biomass production was 17,000 ha, the minimum value of the evaluation function by energy $E_{system}$ was 2.172 $PJ^2$, as depicted in Fig. 4.6. The field area was 11,193 ha less compared with the 28,193 ha that satisfied the biofuel demand. When the field area of biomass production was 29,000 ha, as shown in Fig. 4.7, the minimum value of the evaluation function by energy $E_{system}^{EX}$ was 0.560 $PJ^2$. The field area was 807 ha greater compared with the 28,193 ha that satisfied the biofuel demand.

As in Table 4.4, when vapor produced in the plant was used effectively, a 0.315 $PJ^2$ (from 2.172 $PJ^2$ to 1.857 $PJ^2$) reduction in $E_{system}$ and a 0.271 $PJ^2$ (from 0.560 $PJ^2$ to 0.289 $PJ^2$) reduction in $E_{system}^{EX}$ were achieved in the case of total heat gained by the heat pump. Thus, using the waste energy of vapor in the bioenergy systems was effectively accepted by society. In particular, $E_{system}^{EX}$ was reduced to 48.6%. Therefore, an effective use of waste heat could contribute to a reduction in energy consumption from the viewpoint of exergy.

In the case of vapor use for heat, minimum values of $E_{system}$ and $E_{system}^{EX}$ were lower than the case of heating：electricity 100%. On the other hand, a minimum field area of 500 ha, which was higher than the field area for total heat gained through the heat pump, was obtained. The tendency for minimizing the value of field area and minimizing the values of $E_{system}$ and $E_{system}^{EX}$ differed when different types of energy and/or final benefit were demanded. In this case, selection based on similarity in energy demand for final benefit and energy demand for production, or based on minimization of field area is required. In addition, a difference of approximately 12,000 ha was observed between minimum field area in $E_{system}^{EX}$ by exergy and minimum field area in $E_{system}$ by energy. The minimum value of $E_{system}^{EX}$ is less than half the minimum value of $E_{system}$.

These results indicate that if EPR and $E_{system}$ of bio-ethanol & electricity production were underestimated for minimum field area, $E_{system}^{EX}$ can be used to maintain the result of introducing biofuel production to prevent a field area shortage for biofuel production because EPR and $E_{system}$ are categorized as quantity evaluations of energy, and ExPR and $E_{system}^{EX}$ are categorized as quality evaluations of energy. Thus, the values of ExPR and $E_{system}^{EX}$ should be examined when more than two types of energy must be considered in the design of biofuel production. The effect on system design of introducing a biofuel plant may have been completely different if the analysis method from the viewpoints of energy and exergy was used. The results of $E_{system}$ and $E_{system}^{EX}$ can highlight improvements in the system, and it is easy to work with different types of energy, as shown in Eqs. (12) and (13). Therefore, $E_{system}^{EX}$, which contain physical quantities of exergy and $E_{system}$, was suitable for the evaluation method using a system design approach.

In this simulation, 28,193 ha, which significantly exceeds 5,851 ha of the current field area of Utsunomiya City, was required to satisfy the biofuel demand of the final benefit. 53,000 ha, which exceeds 41,684 ha of Utsunomiya City, was required to satisfy the electricity demand. Therefore, there is significant variation between current field areas and future expected field areas. If the biofuel production field areas are unable to satisfy the energy demand, an energy shortage may occur. Agricultural extension for promoting the highest yield, and an energy import system from outside of Utsunomiya City should be considered. If fuel production areas were strongly promoted, they might cause a deficit of food in Utsunomiya City. The production of biomass energy crops for the purpose of fuel production may deplete land areas that are designated for agricultural production. Potential areas for biofuel production and food production should be evaluated to avoid a food shortage in Utsunomiya City. In this simulation, a reduction in final benefit is needed to introduce biofuel production in Utsunomiya City. A more stable and efficient system design of biofuel production can be achieved by employing the proposed evaluation function and conventional flow diagram of system design.

### *4.4 Conclusion*

1. The evaluation function by energy $E_{system}$ of the energy concept and $E_{system}^{EX}$ of the exergy concept were proposed for biofuel production to analyze the consistency between energy production and energy consumption, to achieve final benefits, and to

analyze available energy. The Exergy Profit Ratio (ExPR) was also proposed instead of the Energy Profit Ratio (EPR) from an exergy analysis standpoint.

2. If EPR and $E_{system}$ of bioethanol & electricity production were underestimated for a minimum field area, ExPR and $E_{system}^{EX}$ can be used to maintain the results of introducing biofuel production to prevent a field area shortage for biofuel production. EPR and $E_{system}$ are categorized as quantity evaluations of energy, and ExPR and $E_{system}^{EX}$ are categorized as quality evaluations of energy. Thus, the values of ExPR and $E_{system}^{EX}$ should be examined when more than two types of energy are considered in the design of biofuel production.

3. The results of $E_{system}$ and $E_{system}^{EX}$, in particular, can reveal improvements in the system. Therefore, $E_{system}^{EX}$, which contains physical quantities of exergy, and $E_{system}$ were suitable for the evaluation method using a system design approach.

4. An evaluation of two types of direct combustion and gasification systems by Energy Profit Ratio (EPR) and Exergy Profit Ratio (ExPR) can lead to demonstrate a more effective production of biomass energy. An Exergy Profit Ratio (ExPR) which is extended EPR was also proposed to measure the quality and availability of energy. The evaluation between two systems can help to choose the best system for introducing energy plants in rural areas.

Table 4.1 Final benefits and energy consumption in Utsunomiya City, Tochigi Prefecture, Japan

| Item | Value | Unit | Reference, Calculation basis |
|---|---|---|---|
| Area of city | 416.84 | $km^2$ | Utsunomiya City (2011) |
| Population | 510,898 | person | Utsunomiya City (2011) |
| Number of households | 212,430 | - | Utsunomiya City (2011) |
| Area of rice field | 5,851 | ha | Tochigi Prefecture (2010) |
| Area of rice field in unpractical use | 763 | ha | Tochigi Prefecture (2010) |
| Number of automobiles (passenger cars) | 101,981 | - | Utsunomiya City (2011) |
| Annual mileage of automobile per person | 4,989 | km | Ministry of Land, Infrastructure, Transport and Tourism (2008) |
| Fuel efficiency of gasoline vehicle | 10 | km/L | Ministry of Land, Infrastructure, Transport and Tourism (2005) |
| Quantity of heat: gasoline | 34.6 | MJ/L | Ministry of Economy, Trade and Industry Agency for Natural Resources and Energy (2007) |
| Quantity of heat: bio-ethanol | 23.9 | MJ/L | Ministry of Economy, Trade and Industry Agency for Natural Resources and Energy (2007) |
| COP (coefficient of performance): heat pump | 3 | - | The Energy Conservation Center, Japan (2004) |
| Diffusion rate of heat pump for household | 89 | % | Council on Competitiveness-Nippon (COCN) (2010) |
| Final benefit of one household for one year | | | |
| Mileage | 2,395 | Km | (Calculated) |
| Heating: Energy consumption | 10,420 | MJ | The Institute of Energy Economics, Japan (2008) |
| Lighting: Energy consumption | 573 | kWh | Environmental Pollution Control Center, Osaka Prefecture (2002) |

Table 4.2 Comparison of EPR and ExPR for two different types of biofuel production systems

| Reference data | | Bio-ethanol and electricity production [1)] | | Specialized bio-ethanol production[1)] | |
|---|---|---|---|---|---|
| Type of biomass | | Unmilled rice, Rice straw, Rice husk | | Unmilled rice, Rice straw, Rice husk | |
| | | Energy | Exergy | Energy | Exergy |
| Input (MJ/10a) | | | | | |
| Electricity | | 131 | 131 | 2869 | 2869 |
| Fuel | | 1672 | 1505 | 1672 | 1505 |
| Vapor | | 0 | 0 | 7890 | 4040 |
| Output (MJ/10a) | | | | | |
| Electricity | | 2367 | 2366 | 0 | 0 |
| Fuel | | 7916 | 7124 | 15625 | 14063 |
| Vapor | | 4303 | 2203 | 0 | 0 |
| Heat | | 4220 | 422 | 872 | 87 |
| Amount of produced bio-ethanol | | 358 L/10a | | 707 L/10a | |
| Amount of produced electricity | | 213 kWh/10a | | - | |
| EPR | ExPR | 10.4 | 7.14 | 1.31 | 1.86 |

1) Saga et al (2007)

2) Exergy efficiency：Electricity (100%), Fuel (90%), Vapor (41%), Heat (10%)：Nobusawa (1980),
The Institute of Applied Energy (2002), Oshida (1986)

3) EPR: Energy Profit Ratio, ExPR: Exergy Profit Ratio

4) The data regarding water is not included in this table because the type of energy is unclear.

Table 4.3 Evaluated values of different energy supplies for final benefits in the case of introduction of the bio-ethanol and electricity production

| Different energy supplies by final benefit | Minimum value of $E_{system}$ (Field area) | Minimum value of $E_{system}^{EX}$ (Field area) | Field area that satisfies biofuel demand | Field area that satisfies electricity demand |
|---|---|---|---|---|
| Mileage：biofuel 100%<br>Lighting：electricity 100%<br>Heating：electricity 89%, vapor 11% | 1.857 $PJ^2$<br>(17,500 ha) | 0.289 $PJ^2$<br>(29,500 ha) | 28,193 ha | 49,000 ha |
| Mileage：biofuel 100%<br>Lighting：electricity 100%<br>Heating：electricity 100% | 2.172 $PJ^2$<br>(17,000 ha) | 0.560 $PJ^2$<br>(29,000 ha) | 28,193 ha | 53,000 ha |

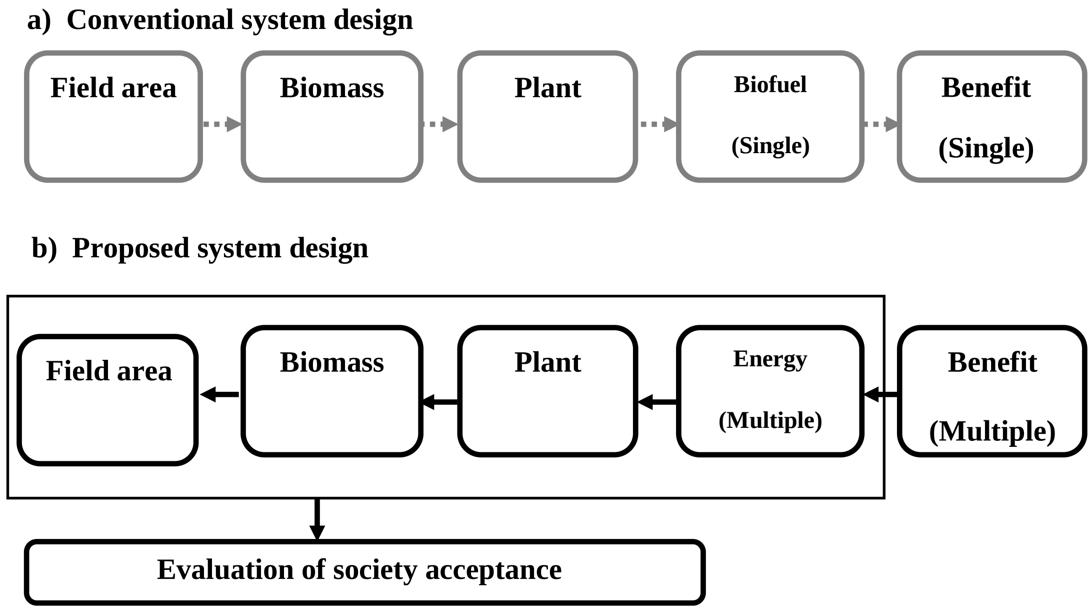



Fig.4.1 Concept diagram of system design for introduction of a biofuel plant

a) Conventional system design, b) Proposed system design

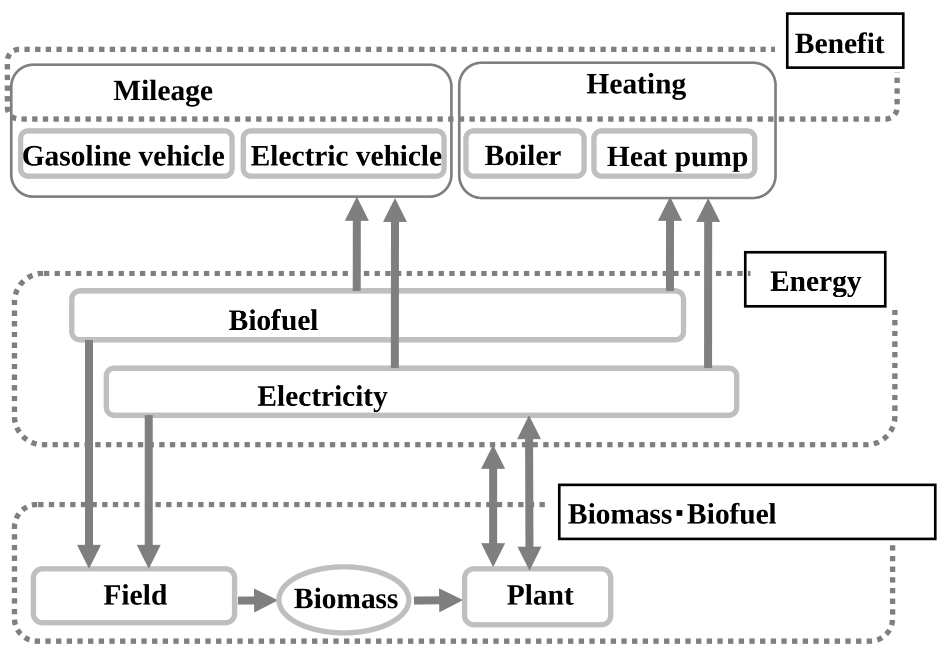



Fig. 4.2 Boundary and direct energy flows of system design for biofuel production

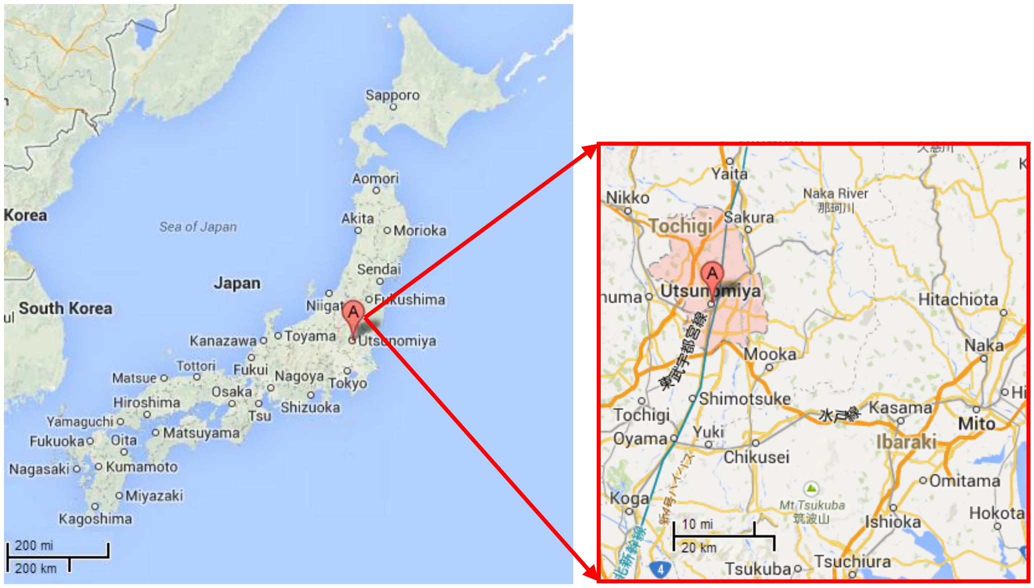



Fig.4.3 Utsunomiya City in the Tochigi Prefecture of Japan

(Google map of Japan, 2013)

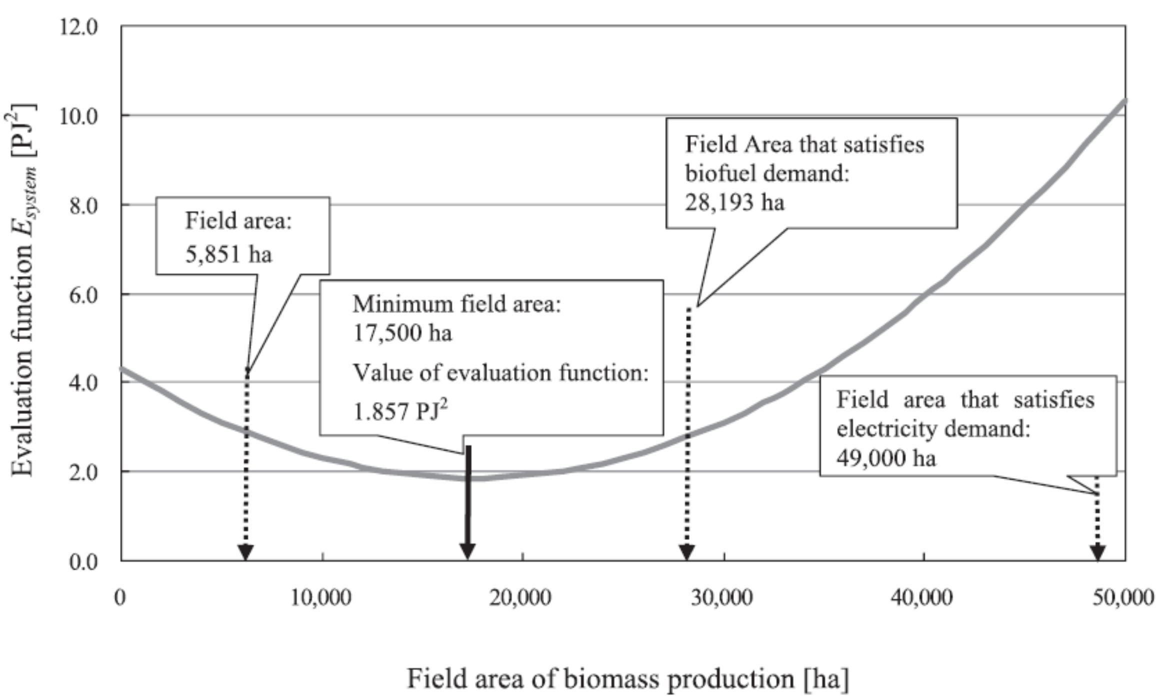



Fig.4.4 Evaluation by energy: $E_{system}$ and field area of biomass production (mileage: 100 % biofuel; lighting: 100% electricity; and heating: 89% electricity and 11% vapor) in the case of introduction of the bio-ethanol and electricity production

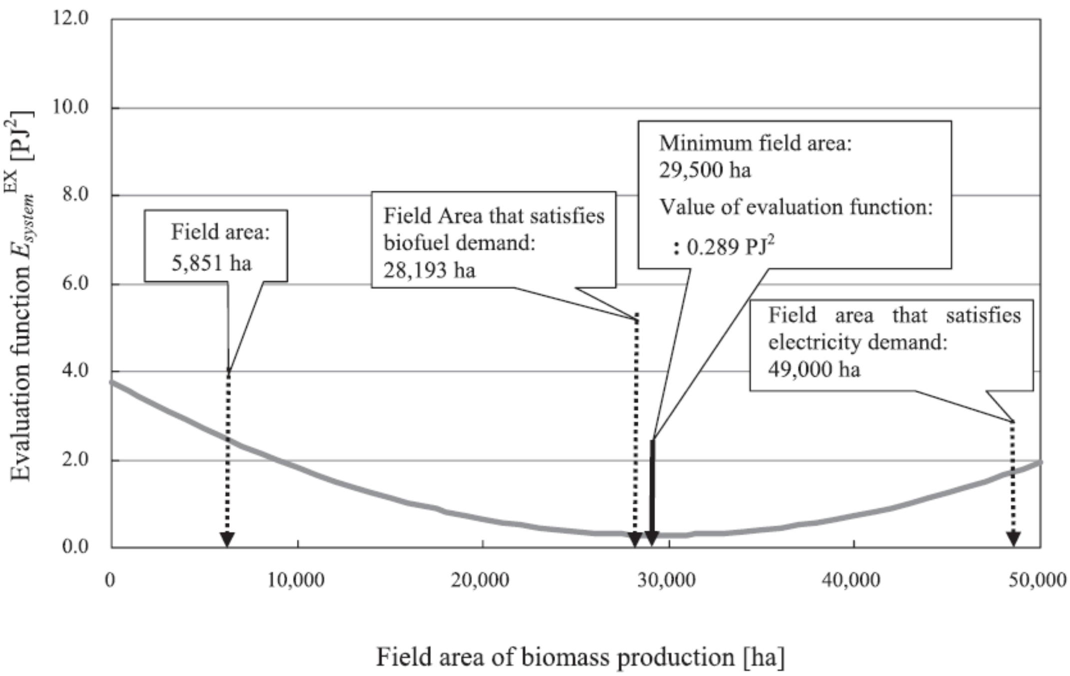



Fig.4.5 Evaluation by exergy: $E_{system}^{EX}$ and field area of biomass production (mileage: 100 % biofuel; lighting: 100% electricity; and heating: 89% electricity and 11% vapor) in the case of introduction of the bio-ethanol and electricity production

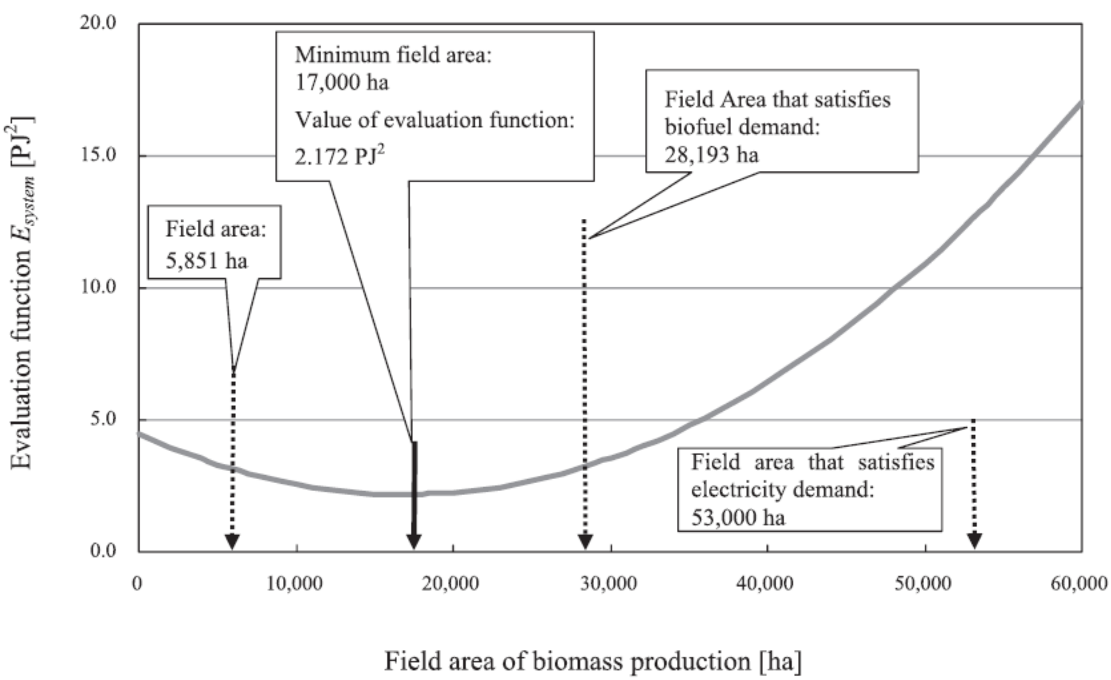



Fig.4.6 Evaluation by energy $E_{system}$ and field area of biomass production (mileage: 100 % biofuel; lighting: 100% electricity; and heating: 100% electricity) in the case of introduction of the bio-ethanol and electricity production

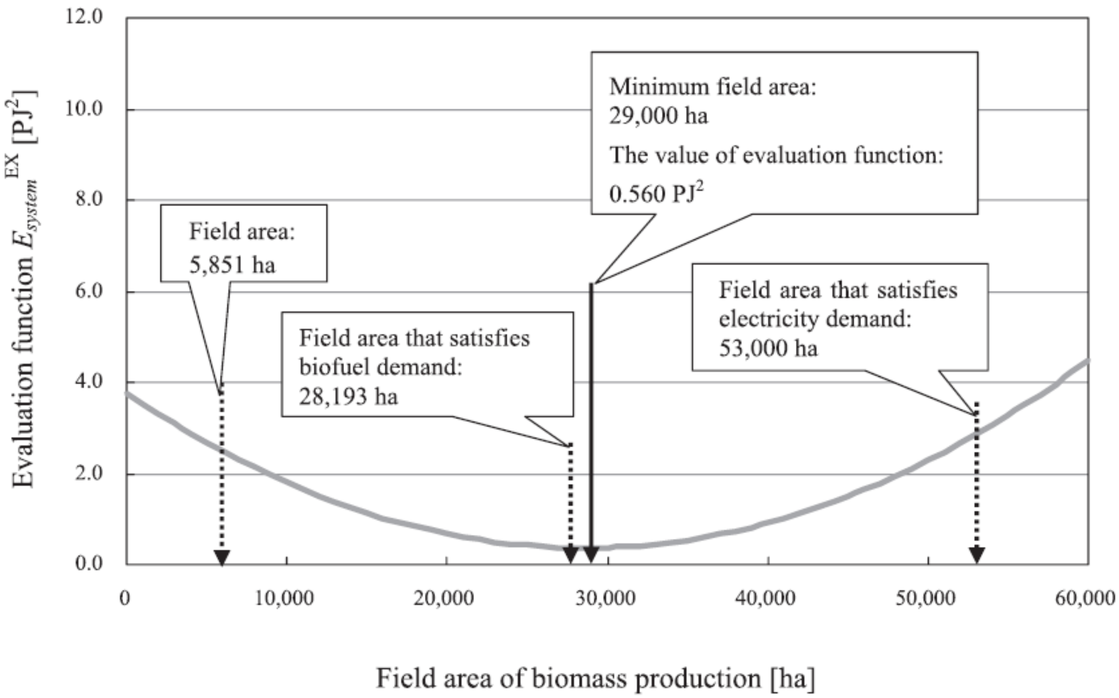



Fig.4.7 Evaluation by energy $E_{system}{}^{EX}$ and field area of biomass production (mileage: 100 % biofuel; lighting: 100% electricity; and heating: 100% electricity) in the case of introduction of the bio-ethanol and electricity production

## Part 2: Evaluation of Biofuel Production Using Energy and Exergy Analyses - Introduction of a System Design Concept for Achieving Final Benefits – A case study in Thailand

### *4.5 Introduction*

Biomass energy utilization in Thailand has gained an interest in recent years due the aim of the government of Thailand to reduce the imported of fossil fuels and greenhouse gas emissions. The government policies induce the utilization of renewable energy as biomass to the achievement of better environmental sustainability. Biomass will be used to meet a wide variety of energy needs, including generating electricity, providing process heat for industrial sector, homes and transportation fuel. The conversion of biomass into such useful forms of energy can be achieved using a number of different technologies that can be separated into two basic categories which are popular in Thailand. A process options classification based on the type of final energy products is presented in Table 4.4.

The direct combustion system converts biomass energy into heat or electricity. The conversion efficiencies range from 20% to 40%. It is the most directly process for converting biomass to energy. It can be used as steam for further production steps. Direct combustion generates electricity by using steam turbines, steam engines or other energy converter (Basrz, 2008). Direct combustion is the most common process to produce thermal energy. However, its properties are complex process due to heat application process. This technology system has matured and commercially available worldwide and Thailand as well. The direct combustion system has higher operational reliability when compare with the gasification system (Quaak, Knoef and Stassen, 1999). Gasification, which converts biomass into a combustible gas that can be burnt to produce heat and steam, or used in gas turbines cycles to obtain electricity. Recently, due to an increasing of fossil fuel prices and environmental concern, gasification technology has been interesting and developed again as a high technology. Although many biomass gasification processes have been developed commercially but the efficiency of gasification system is only 15-17%.

In Thailand, a large portion of the electricity production by biomass comes from direct combustion system technology. In spite of widely used of direct combustion system, recently, Ministry of Energy support for the construction of a community biomass gasification system (Salam, 2008). Nevertheless, an increasing of gasification interesting is quite low. Biomass gasification processes are available under industrial, development at pilot scale and demonstration scales in Thailand. Several biomass gasification plants have been installed in Thailand during last 5 years. There are 25 of the plants which identified that 15 plants are in industrial or commercial applications and 10 are either government supported demonstration plants or research and development purposed plants by the universities. Unfortunately, recently, there are only 5 plants in Thailand that continuously in operation. Commercial implementation has not yet been widely accepted. It caused the existing drawback such as the low of reliability for gasification technology. However, gasification system is being considered an adequate technology due to less operational cost and small scale production system. Nevertheless, in a small scale, the government initiation is not enough to encourage gasification system. Two types of biomass energy production were evaluated by Energy Profit Ratio (EPR) and Exergy Profit Ratio (ExPR). The evaluation method of total energy efficiency can lead to a more effective production of biomass energy. Energy Profit Ratio is a ratio of output energy to input energy in biofuel production. An Exergy Profit Ratio (ExPR) which is extended EPR was also proposed to measure the quality and availability of energy. From the viewpoint of "backcasting" should be utilized to define a desirable future (Oliver and Brooks 2005). Forecasting is an estimation of future impact. The measurement of precise physical quantities of energy for biomass production is indispensable for determining the total amount of final benefit (Noguchi and Koyama 2010). Energy consumers who are interested in biomass energy production seek final benefits such as heating or electricity (Hamamatsu 2010, Central Research Institute of Electric Power Industry 2011). Therefore, backcasting involves setting goals and determining how those goals can be achieved.

In Thailand, unutilized agricultural land has become available to increase rice yields. The area of unutilized agricultural land in 2010 was 7364.8 ha (Office of Agricultural Economics, 2011). However, when the unutilized agricultural land is left, it difficult to use the land as a productive rice field. Nevertheless, it is possible for maintenance unutilized areas to make the biomass energy such as rice products or uncrop agricultural products. The use of unutilized land becomes one choice from the viewpoint to increase the biomass energy supply. This research was conducted to analyze the EPR and ExPR of a rice husk energy production system. Minimum field area for rice production for energy was examined in order to minimize the disparity between energy supply and demand. Two energy conversion systems of rice produce husk are also considered. The evaluation between two systems which are direct combustion and gasification systems can be helpful to choose the best system for introducing energy plants in rural areas. In order to validate the system, Suphanburi province, Thailand was selected as an example and investigated in this studied.

### *4.6 Methodology*

#### Biomass Conversion Systems

Fig.4.8 shows the process flow of rice husk energy production system. The system is divided into two processes: agricultural and conversion. Two systems are considered in the conversion process of rice husk. Rice husk was used for biomass conversion and surplus energy is exported. One system is direct combustion and another one is gasification system.

#### Conversion Process

Table 4.5 shows the input and output energy of rice husk energy production from both two systems. The data which use for calculated EPR and ExPR were derived from the biomass plant interview in Suphanburi and Lopburi provinces, Thailand. Electricity was used to produce energy in both two systems. Direct combustion has higher electricity input because of its energy production capacity.

#### Rice Husk

Rice husk is one of the major agricultural residues produces in Thailand, where about 21–26 million tons of rice is annually produced (OAE 2003). Rice husk is produced from paddy milling that constitutes about 23% by weight, based on milling statistics (Witichakorn 2004). Rice husk is also used as a fuel since it is of low cost, low moisture content, small size and small environmental impact. However, about a half is currently consumed, mainly as fuel in rice mills for drying, milling and parboiling paddy rice (Kapur et al. 1998). Unutilized of rice husk is fermented and causes methane which emitted contributing to the global warming problem (Chunsangunsit, 2004). Half of it is lost to rot or is burned in open air unless utilized otherwise, as burning husks in open air produces smoke. It is also reported that airborne husks coming from open piles from gusty winds, have caused skin irritations for local residents (Ueda 2007). The availability of this resource was estimated at 3 million tons per year. Based on a heating value of 14,700 kJ/kg (Srisovanna 2004, Utistham 2007, Witichakorn 2004, Ueda 2007) and the preceded assumptions, aggregate power generation potential from rice husk in Thailand about 375 MW (Utistham 2007) (Table 4.6).

**System Design for Evaluation Functions**

In this studied of final benefit of Suphanburi province, Thailand is considered at system design for rice husk energy production by the backcasting concept. If a shortage of energy results from achieving final benefits, rice husk energy production should be modified to increase the amount of energy. Conversely, if there is a surplus in the field area during rice production, surplus energy production should be reduced. Therefore, the purpose of proposing an evaluation function is to ensure adequate proportions of energy supply and demand with regards to the desired final benefit. In order to evaluate for the difference between energy supply and demand, the evaluation function by energy $E_{system}$ [$J^2$] as equation (1)

However, field area of rice production for converting to energy is limited. The evaluation to consider for minimum required field area of rice husk production could help to satisfy the energy demand for final benefit in specific areas. This objective function was needed to incorporate the most appropriate decision for reducing environmental problems and maintaining agricultural productions.

Therefore, the most efficient system design of biofuel production can be achieved by minimizing field area, which can be obtained by differentiating Eq. (4).

The conventional EPR and ExPR were calculated using thermal unit [J] for energy production and energy consumption as in equation (14) and (15).

### Investigated Areas

The investigated rural area of Thailand was considered from the past statistics of rice husk as a biomass fuel. Each criterion was used to evaluate for small energy plant (Witichakorn, 2004). To identify the location, this research was focused on the amount of rice husk available supply and together with appropriate areas. For the investigated area, this research was conducted in *Suphanburi* province (Fig. 4.9).

Electricity demands of all households in Suphanburi, as shown in Table 4.7, were used in the simulation. However, vapor and heat produced by rice husk energy plants not equipped with any facilities for households unlike other countries such as Japan. A 100% diffusion rate of heat pumps in households was also considered as in chapter 4. Energy consumption for biomass production was also included for the calculation.

## *4.7 Results and Discussion*

### Energy Profit Ratio and Exergy Profit Ratio

Two systems of rice husk energy production were evaluated from the standpoint of EPR and ExPR, as shown in Table 5. EPR and ExPR of direct combustion system were 56.29 and 32.36, respectively. EPR and ExPR for the gasification system were 29.84 and 28.93, respectively. The energy and exergy analysis demonstrated that the direct combustion system had a higher advantage than the gasification system. Both values of EPR and ExPR of direct combustion system were higher than EPR and ExPR of the gasification system because of the higher capacity and efficiency to produce electricity. EPR was higher than ExPR in both of Direct combustion system and gasification system because an energy input in both systems were producing high-efficiency exergy products as electricity and also low low-efficiency exergy product as heat and vapor. The method of converting low-efficiency exergy, such as vapor and heat to usable energy are also crucial for improving EPR and ExPR in rice husk energy production and also the other energy type of biomass. Evaluation by EPR and ExPR can be used to as certain improvement points which are not clearly identified through only a conventional evaluation of EPR. Moreover, in Thailand, the energy output product will be loosed by waste or used by small amount within biomass plant. There is the possibility to utilize vapor and heat to reduce the energy consumption in their areas.

From the higher value of EPR and ExPR of direct combustion, direct combustion system is suitable for private company investment because direct combustion is well-developed and commercially available technology. Moreover beyond the higher energy efficiency, direct combustion is the most cost effective use of biomass for power generation. Due to direct combustion system is well developed, these systems are reliable system for investor.

However, this system requires large scale of investments. The direct combustion plant also has higher transportation cost due to collection and transportation of rice husk from adjacent rural areas. In addition, direct combustion system also requires the construction of vast amount of electrical transmission infrastructure to the users. There are reported that in some areas also were characterized by fluctuating voltage and shortage of supply. The problems of loss on transmission are occurred as the in accessibility of households electric. In order to generate energy more sustainably, energy system in which small scale of energy conversion units, located close to energy consumers and short transmission may be the alternative choices. Gasification system has been considered to be an alternative choice for rural areas in Thailand due to those problems. The advantage of gasification system is source of energy that is immediately accessible within small areas. Moreover, this system is considered as a source to increase the rural development. Gasification plant has the scope to generate income and employment, and utilize agricultural residue within communities (Ravindranath, 2004). Ministry of Energy has fund to support for community biomass gasification system because of an adequate technology of gasification plant for rural areas. Therefore, the government of Thailand policy that being consider that the gasification plant is an adequate technology due to less operational cost and small scale production system.

## Minimizing field area of biomass production using the evaluation function

Minimum field area of rice production based on energy demand was calculated by Eq. (4-3) in the case of introduction of the biomass power plant to rural areas in Thailand. The $E_{system}$ and minimum field area of direct combustion system for energy and field area of biomass production is shown in Fig. 4.10, 4.11 and 4.12. In Fig. 4.10, it shows the evaluation of 100% energy demand by rice husk energy. Fig. 4.11 shows the evaluation of

25% energy demand by rice husk energy and Fig. 4.12 shows the evaluation of 8% energy demand by rice husk energy. The results of the calculation of 8% and 25% energy demand because the current situation and target of government policy. The energy demand by 8% from biomass energy is the current situation now (Mahakhant, 2013). Moreover, the government of Thailand has plan for the increasing of renewable energy resources utilization to 25% utilization. The government of Thailand plan to increase the utilization to from the total energy consumption within year 2021 (Ministry of energy, 2012). Therefore, 100%, 25% and 8% of energy demand is derived from total energy consumption in Suphanburi by year.

$E_{system}$ of direct combustion and gasification were calculated from 0.1 ha increments. 190,472 ha are the current rice field areas (Statistical Forecasting Bureau, 2011) and 7364.8 ha are the unpractical use areas.

From Fig. 4.10, when the field area of biomass production was 82,766.7 ha, the minimum value of $E_{system}$ was 0.48 $GJ^2$. The results indicate that the amount of energy for electricity satisfy the energy demand with 82,766.7 ha. In addition, the amount of energy for electricity can be also increased according to field area of biomass production. For Fig. 4.11, when the minimum field area was 20,691.8 ha, the minimum value of $E_{system}$ was 0.50 $GJ^2$. This minimum field area can satisfy for the electricity demand in Suphanburi province while energy demand from biomass was 25% from the total energy demand. Finally, Fig.4.12 shows that the minimum field area was 6,621.2 ha which below the current field areas, the minimum value of $E_{system}$ was 0.62 $GJ^2$. It also can provide enough energy demand to contribute electricity to Suphanburi province. The total value of $E_{system}$ of direct combustion 25% and 8% was less than the total value of $E_{system}$ of direct combustion (100%) because the value of energy was calculated by 25% of total energy demand in Suphanburi province.

As shown in Fig. 4.13, Fig. 4.14 and Fig. 4.15 the results shows that the minimum area field requirement was 6,327,946.9 ha for the gasification system with 100% demand of energy and 158,219.1 ha were required to satisfy the 25% of electricity demand. While the minimum field area for 8% of energy demand was

When the field area of biomass production was 6,327,946.9 ha, the minimum value of the evaluation function by energy $E_{system}$ of gasification (100%) was 0.48 $GJ^2$, as shown in Fig. 4.13. While the field area of biomass production was 158,219.1 ha as shown in Fig.

4.14, the minimum value of the evaluation function by energy $E_{system}$ of gasification (25%) was 0.15 $GJ^2$. Lastly in Fig. 4.15, minimum field area was 50,628.4 ha which below the current field areas, the minimum value of $E_{system}$ was 0.01 $GJ^2$

From the results, in case of the selection based on similarity in energy demand for final benefit and energy demand for production, or based on minimization of field area are required to improve the sustainability and rural area development. These results indicate that minimum field area of energy demand for 100%, 25% and 8% of direct combustion system were below the current rice field area in Suphanburi province. However, the results of minimum field area of energy demand for 100%, 25% and 8% of gasification system were different. The minimum field area of energy demand for 100% was significantly exceeded the current rice field area. Although in case of unpractical use area was include to provide more energy resource, but the minimum area is not enough to satisfy the minimum area for energy demand. However, while the energy demands for 8% and 25% of gasification system were calculated. It shows that the minimum field area was below the current rice field area in Suphanburi. Therefore, if the energy demand for 8% and 25% were propose to measurement, both direct combustion system and gasification system can satisfy the energy demand. While only direct combustion system can provide enough energy demand for 100% energy demand. Nevertheless, energy demand in the rural area by the different energy resources should be concerned to provide the satisfy energy supply and demand (Table 4.9).

In the study, there is significant variation between current field areas and future expected field areas. If the biofuel production field areas are unable to satisfy the energy demand, an energy shortage may occur. Suitable management for promoting the highest yield production in similar cultivation areas, and the introduction of an energy import system from outside of Suphanburi province should be also considered.

In addition, the consideration of the other biomass resources to provide for energy demand in these areas is also necessary. More than two types of energy resources may be the alternative choice to design for the biomass energy production. However, there are some conflicts that if the energy resources were food crop, they might cause a deficit of food in Suphanburi province. Furthermore, the production of biomass energy crops for the purpose of fuel production is strongly promoted which it may reduce land areas that were designated for agricultural production. Potential areas for biofuel production and food production should be evaluated to avoid a food shortage. In this evaluation, a reduction in

final benefit is also needed to introduce rice husk energy production in Suphanburi province as this study calculate for 100%, 25% and 8% of total energy demand in Suphanburi. For the unpractical use areas, there is the opportunity to increase energy resources.

By the small scale gasification system, the minimum requirement for field area can be decreased by the more introducing of gasification plant in the areas. However, gasification is preferred by the small scale in order to provide energy to small areas such as by the communities, villages, or sub-districts, etc. Therefore, if the evaluation is calculated by the small amount of areas that required little amount energy, gasification will be provided enough amount of energy to this area.

The result of direct combustion system can provide enough energy demand for the province. However, rice husk resource has been utilized for many purposes such as fertilizer. Soil will be improved its nutrition by application of rice-husk, preserved a moisture content and prevent weed growth. Rice husk is also utilized as fuel and raw material for industrial sector such as cement, tyre, medicine, etc. (Ngaemngam, 2006). About a half is currently consumed and another half was left (Kapur et al. 1998). Therefore, there are some problems that some large scale of rice husk energy as direct combustion plants are facing the problem of supply shortage. There are many rice husk energy plant in the same areas causes the competition of supply providing. This causes the significantly increase of rice husk price. Now a day, rice husk price is high depended on the location. Prices are between 900 Baht/ton up to 1,600 Baht/ton in some regions (Sarasuk, 2011). According to this problem, gasification plant is the choice to solve the problem of energy and resource supply because lower raw material requirement. A more stable and efficient system design of rice husk energy production can be achieved by employing the proposed evaluation function and conventional flow diagram of system design. The results of system design to introducing a biomass energy plant may have been completely different if the analysis method from the concept or viewpoints of energy and exergy was used.

### *4.8 Conclusion*

1. An evaluation of two types of direct combustion and gasification systems by Energy Profit Ratio (EPR) and Exergy Profit Ratio (ExPR) can lead to demonstrate a more effective production of biomass energy. The evaluation between two systems can help to choose the best system for introducing energy plants in rural areas in Thailand.

2. EPR and ExPR of direct combustion system were 56.29 and 32.36, respectively. EPR and ExPR for the gasification system were 29.84 and 28.93, respectively. The result of energy and exergy analysis demonstrated that the direct combustion system had a higher advantage than the gasification system. EPR was higher than ExPR in both of Direct combustion system and gasification system because an energy input as electricity in both systems were producing high-efficiency exergy products as electricity and also low low-efficiency exergy product as heat and vapor.

3. Minimum field area of rice production based on energy demand in the case of introduction of the biomass power plant to rural areas in Thailand. Minimum field area of biomass production by direct combustion system was 82,767 ha in case of 100% energy demand. While the minimum field area was 20,692 ha incase of 25% energy demand. While the minimum area field requirement was 6,327,945 ha for the gasification system with 100% demand of energy and 158,220 ha as for 25% of energy demand.

4. From the results, in case of the selection based on similarity in energy demand for final benefit and energy demand for production. The minimum field area of energy demand for 100% and 25% of direct combustion system were below the current rice field area in Suphanburi province. However, the results of minimum field area of energy demand for 100% significantly exceed the current rice field area in case of gasification system. Although unpractical use area was included to provide more energy resource. While the 25% of energy demand in case of gasification system was proposed can satisfy the energy demand in areas.

5. In addition, the consideration of the other biomass resources to provide for energy demand in these areas is also necessary. More than two types of energy resources may be the alternative choice to design for the biomass energy production. However, the potential areas for biofuel production and food production should be evaluated to avoid a food shortage.

Table 4.4 Classification of conversion system

| **Conversion systems** | **Final products** |
|---|---|
| Direct combustion | - Steam<br>- Process heat<br>- Electric energy |
| Gasification | - Steam<br>- Process heat<br>- Electric energy<br>- Fuel gas |

Table 4.5 Input and output energy of rice husk energy production

| **Direct combustion** | Unit: MJ/10a |
|---|---|
| Input: Electricity | 80 |
| Output: Electricity | 1934.65 |
| Output: Vapor | 1281.17 |
| Output: Heat | 1287.32 |

| **Gasification** | Unit: MJ/10a |
|---|---|
| Input: Electricity | 0.88 |
| Output: Electricity | 25.14 |
| Output: Vapor | 0.43 |
| Output: Heat | 0.60 |

Table 4.6 Estimate of the power generation from rice husk

| Item | Value |
|---|---|
| Available rice husk as a resource for power generation | $\leq 3.05 \times 10^6$ t |
| Potential power generation | 2,500 GWh/year |
| Potential power capacity | 375 MW |

(Source: Srisovanna, 2004; Ueda *et al*., 2007; Utistham *et al*. 2007)

Table 4.7 Final benefits and energy consumption in Suphanburi province, Thailand

| Item | Value | Unit | Reference, Calculation basis |
|---|---|---|---|
| Area of city | 535,800 | ha | Office of Agricultural Economics, 2011 |
| Population | 847,308 | Person | Statistical Forecasting Bureau, 2011 |
| Number of households | 263,100 | | Statistical Forecasting Bureau, 2011 |
| Area of rice field | 190,472 | ha | Office of Agricultural Economics, 2011 |
| Area of unpractical use | 7365 | ha | Office of Agricultural Economics, 2011 |
| Final benefit of one household for one year | | | |
| Lighting: Energy consumption | 1,620.67 | kWh | (Calculated) |

Table 4. 8 Comparison of EPR and ExPR for two different types of biofuel production systems

| Reference data | | Direct combustion | | Gasification | |
|---|---|---|---|---|---|
| Capacity | | 96,400 kW | | 430 kW | |
| | | Energy | Exergy[1)] | Energy | Exergy[1)] |
| Input (MJ/10a) | | | | | |
| Electricity | | 80 | 80 | 0.88 | 0.88 |
| Output (MJ/10a) | | | | | |
| Electricity | | 1934.65 | 1934.65 | 25.14 | 25.14 |
| Vapor | | 1281.17 | 525.28 | 0.43 | 0.18 |
| Heat | | 1287.32 | 128.73 | 0.60 | 0.06 |
| EPR [2)] | ExPR[2)] | 56.29 | 32.36 | 29.84 | 28.93 |

1) Exergy efficiency：Electricity (100％), Fuel (90％), Vapor (41％), Heat (10％)：Nobusawa (1980), The Institute of Applied Energy (2002), Oshida (1986)
2) EPR: Energy Profit Ratio, ExPR: Exergy Profit Ratio

Table 4.9 Evaluated values of different energy system for final benefits

| Different energy supplies by final benefit | Minimum value of $E_{system}$ (100%) (Field area) | Minimum value of $E_{system}$ (25%) (Field area) | Minimum value of $E_{system}$ (8%) (Field area) |
|---|---|---|---|
| Direct combustion | 0.48 $GJ^2$ ( 82,766.7 ha) | 0.50 $GJ^2$ (20,691.8 ha) | 0.62 $GJ^2$ ( 6,621.27 ha) |
| Gasification | 0.48 $GJ^2$ ( 6,327,946.9 ha) | 0.15 $GJ^2$ (158,219.1 ha) | 0.01 $GJ^2$ ( 50,628.4 ha) |

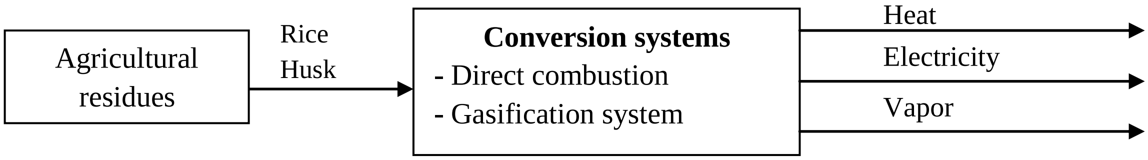



Fig.4.8 Process flow of rice husk energy production systems


Fig.4.9 Map of Suphanburi province, Thailand
(Thai mapping, Geospatial Information Center, 2010)

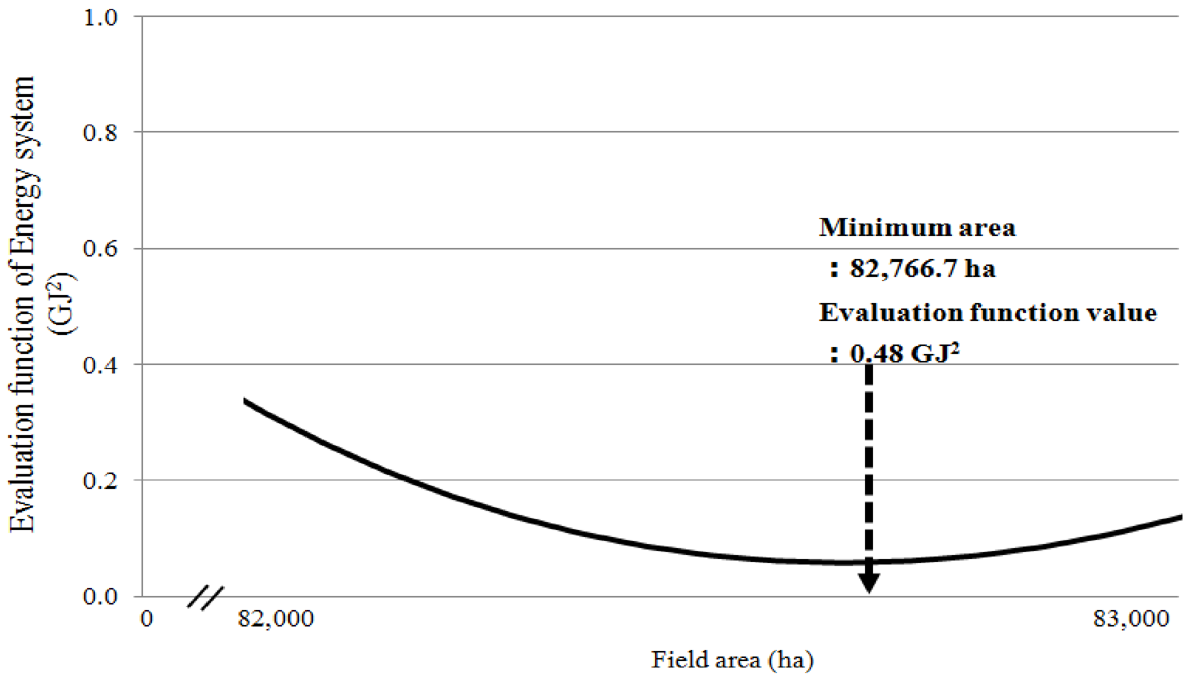



Fig.4.10 Evaluation by energy: Esystem and field area demand (electricity demand: 100%) in case of direct combustion system

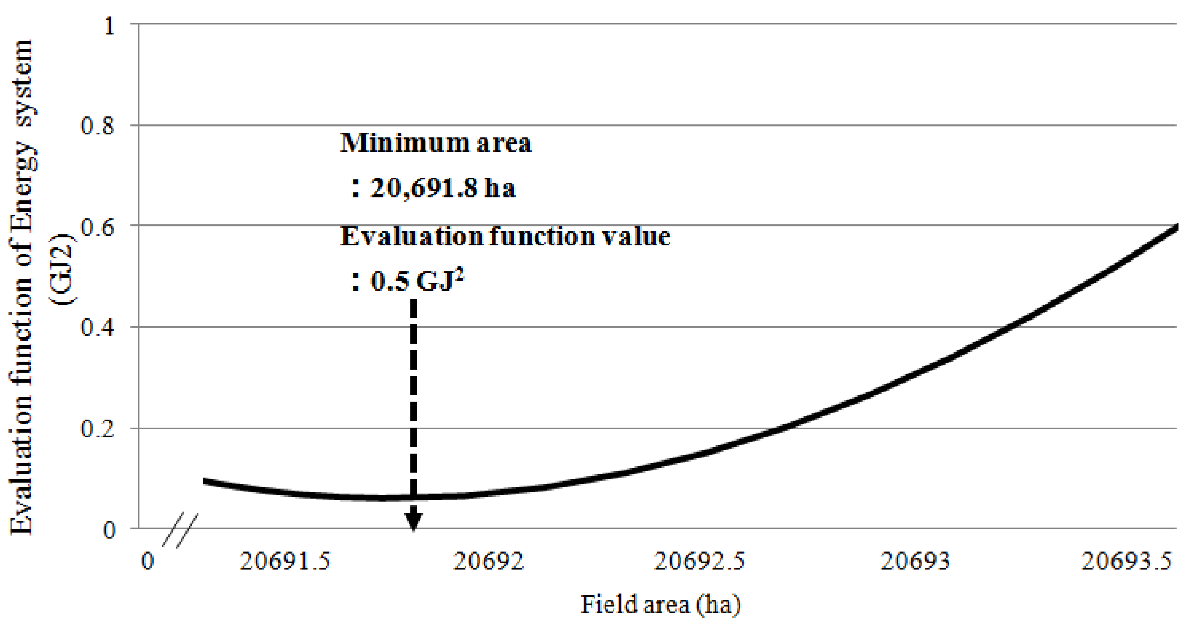



Fig.4.11 Evaluation by energy: Esystem and field area demand (electricity demand: 25%) in case of direct combustion system

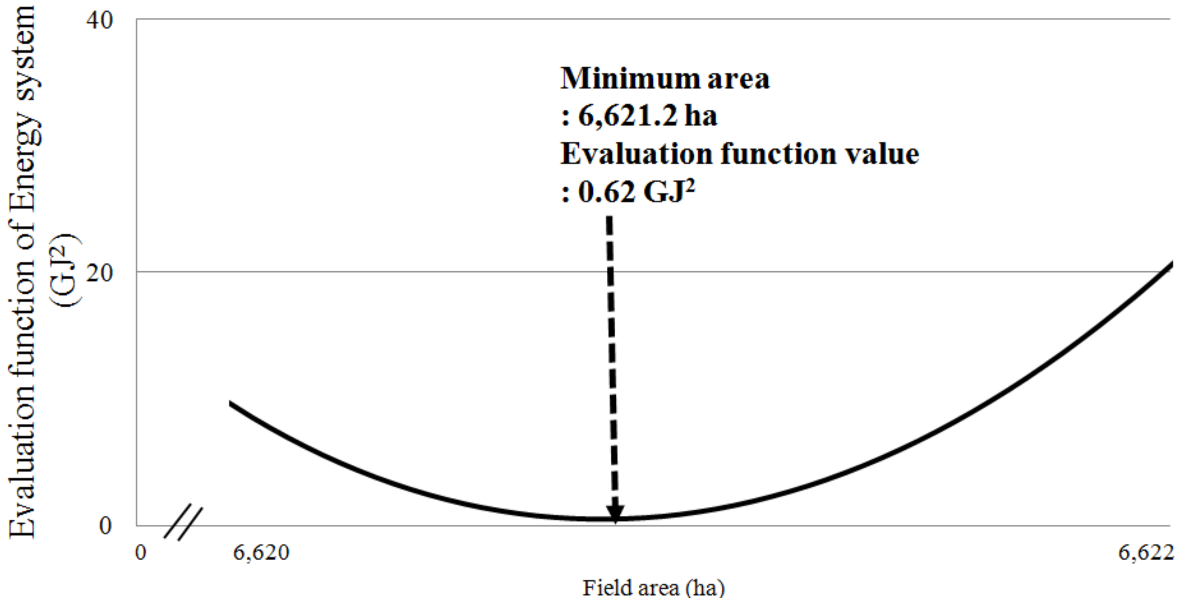



Fig.4. 12 Evaluation by energy: Esystem and field area demand (electricity demand: 8%) in case of direct combustion system

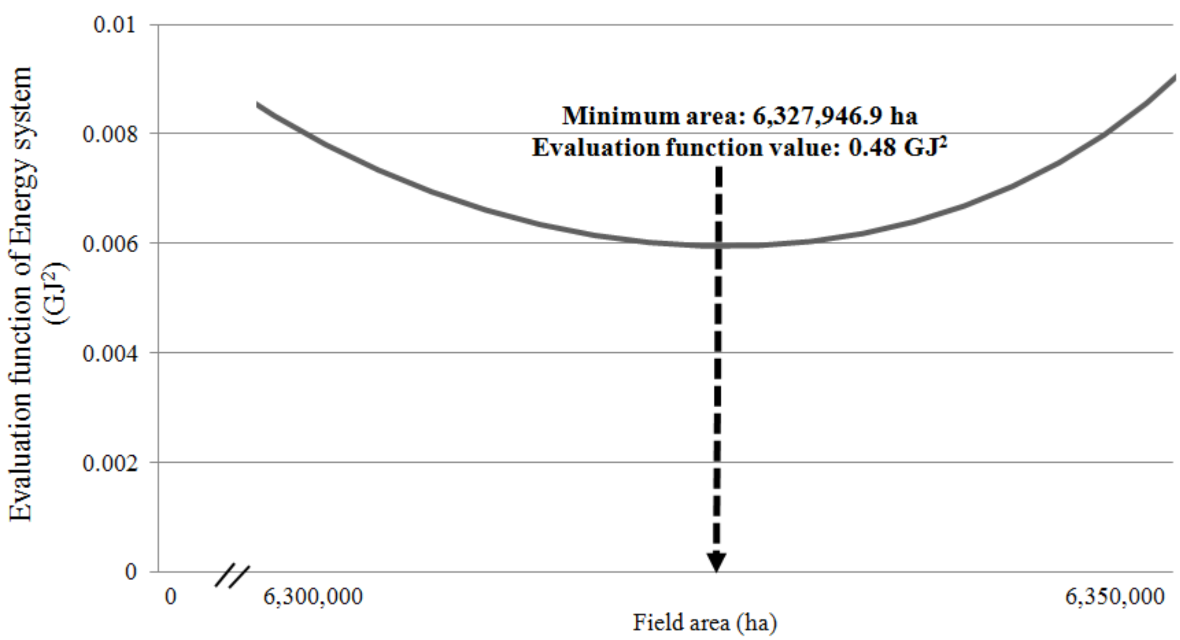



Fig.4.13 Evaluation by energy: Esystem and field area demand (electricity demand: 100%) in case of gasification system

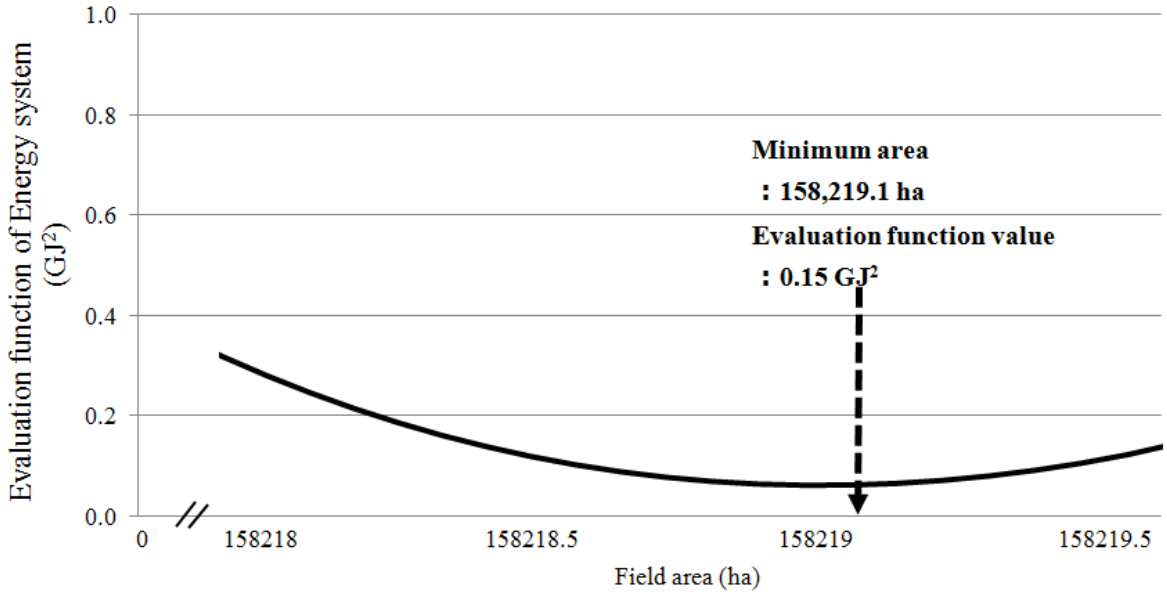



Fig.4.14 Evaluation by energy: Esystem and field area demand (electricity demand: 25%) in case of gasification system

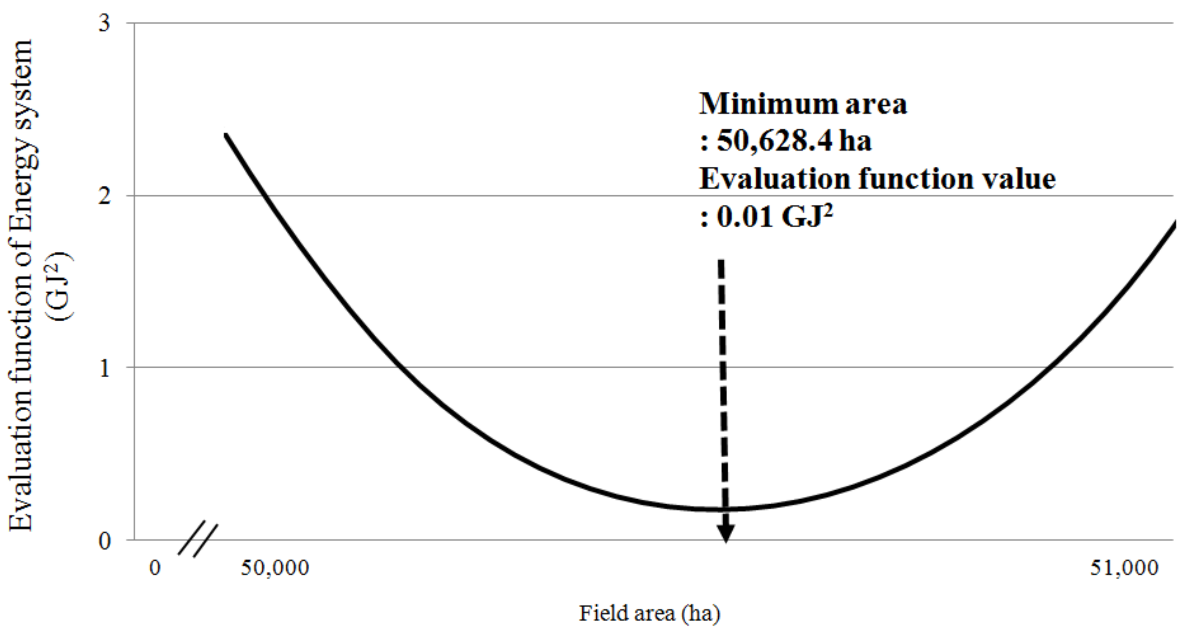



Fig.4. 15 Evaluation by energy: Esystem and field area demand (electricity demand: 8%) in case of gasification system

# CHAPTER 5

# ANP Modeling to Select Biomass Energy Plant in Rural Areas of Thailand

## *5.1 Introduction*

### Overview of Energy Status in Thailand

The total electricity consumption in Thailand was increased 10.4% from 2009 to 2010. At the year 2010, the total electricity consumption became 149,320 GWh (Electricity Generating Authority of Thailand (EGAT), 2011). From the annual report of Ministry of Energy, Thailand's demand for energy has increased over recent decades and tends to retain a similar pace continually while supplies of energy sources in domestic are limited. Therefore, Thailand relies on imports energy supplies. The total energy imported in 2010 was increased to 11% from 2006. Almost all of imported energy came from crude oil and coal. Fossil fuel prices have increased significantly (Shafiee and Topal, 2010). That means the high imported energy consumption causes the country a huge amount of foreign currency exchange and financial crisis (Coffey et al, 2009; Shafiee and Topal, 2010).

Therefore, government has been promoted alternative energy to support the energy demand. One of the main objectives of government is to motivate the utilization of renewable energy to be 20% of the consumption by 2022 (Sawangphol and Pharino, 2011). This policy will help to reduce energy imports, encourage the utilization of domestic energy supply for sustainable economic growth and help to reduce the emission of green house gas.

Nevertheless, as EGAT was established since 1969 and the increasing of energy demand year by year however, 15.3% of total households in rural area of Thailand were not electrified till now (Ministry of Energy, Thailand, 2009). Inaccessibility of electricity has been reducing the quality of life and increasing the gap of living condition between rural and urban areas. In this context, utilization of renewable energy resources for electricity generation in those rural areas has got importance to address the unavailability of electricity. The potentials of renewable energy in rural areas have been studied and biomass is a potential source of renewable energy. The conversion of biomass has to be taken care for utilization and electricity generation.

**Decentralized Electricity Generation**

Ninety one percent of electricity generated in Thailand is mainly by centralized electrification (EGAT, 2009). The centralized system requires long transmission lines to the users and stable structure to carryout source to user. In some areas, transmission losses are occurred frequently. In order to generate energy more efficiently and sustainably, the potential of decentralized electrification has been introduced recently. Decentralized electrification is the generation of electricity within local communities and integrated with the distribution systems including SPP (Small Power Producer) with capability of producing electricity of 10-90 MW and *VSPP* (very small power producer*)* with capability of less than 10 MW.

In order to support decentralized electrification, biomass energy plant have a great potential. More recently, Ministry of Energy has funded to support community-based biomass gasification system (Salam et al, 2010) to promote decentralized electrification system throughout rural areas considering renewable energy. To promote the renewable energy production, Government established policy to encourage private sectors to generated power in 1992. There are the Energy Conservation (ENCON) Program of Renewable energy funding (Prasertsan and Sajjakulnukit, 2006) regulations for the purchase of electricity from SPP and *VSPP* (Srisovanna 2004). These regulations motivate the private sector to introduce energy plant from renewable energy sources. Over 700 more SPP and VSPP licenses were approved, with a combined potential of over 10,000 MW of green energy (Department of Alternative Energy Development and Efficiency (DEDE)**, 2010)**. The government established Power Development Plan (PDP) of 2010-2030 (PDP-2010) to ensure the reliability of energy supplies, reduce imported energy, and increase fuel diversification. PDP-2010 purposes to increase the use of renewable energy to be 19% and reduce consumption of coal to only 6.4% (Sawangphol, 2011) (Fig. 5.1)

In addition, National Energy Committee (NEC) also approved the tariff adders to encourage the renewable energy investment by adding tariff and special purchasing rate higher than power generated from mainstream fuel purchasing (Sawangphol and Pharino, 2011)(Ministry of Energy, Thailand, 2009) (Table 5.1). The Government also devised incentive measures in order to encourage the utilization of renewable energy such as tax credit, privilege or subsidies. Thai government also support research and development on renewable energy and encourage the participations and partnerships of the local communities in renewable energy plants.

Thai government wants to solve the difficulty of introducing renewale energy, and uses many attractives method to promote renewable energy investment. To popularize the decentralized electrification system, using agricultural residues is considered as one of the most valuable resource.

### Biomass Energy Potential and Conversion

The most of renewable energy sources come from agricultural residues. This energy derived from four main agricultural residues which are bagasse, rice husk, palm oil wastes, and wood residues. The agricultural residues can be used as a biomass for biomass energy plant (DEDE, 2010; Srisovanna, 2004). Potential of agricultural residue in 2004, almost 44 million tons out of 66 million ton of agriculture residues were unused and equivalent to 14,662 ktoe (Srisovanna, 2004). From the mainly agricultural residues, especially, rice husk is one of the major agricultural residues, because $6.17\times10^6$ t/year of rice husk is produced as a by-product in processing the rice at rice mills across the country. Biomass energy plant for generation using agricultural residue are considered as an integrated community development to solve the shortage of electricity and management of remaining rice husk. About a half amount of rice husk is currently consumed for producing heat, electricity, soil conditioner and so on (Kapur et al., 1998). Unutilized rice husk is lost due to rot or burn in open air. And these managements cause environmental pollution and skin irritations for local residents (Ueda et al., 2007). Producing of 2,500 GWh/year generation is estimated using $3.05\times10^6$ t/year of available rice husk based on a heating value of 14.7 MJ/kg and standard efficiency for electricity generation (Srisovanna, 2004;Witichakorn and Bundhit, 2004;Ueda et al, 2007;Utistham et al., 2007). There are two main methods have been practices for biomass conversion in rural areas: direct combustion and gasification systems

### Biomass Energy Plant

#### *Direct Combustion System*

Direct combustion plant is the most common plant to produce thermal energy, and generates electricity by using steam turbines, steam engines or other energy converter (Barz and Delivand, 2011). The direct combustion system of biomass energy plant produces a large portion of the electricity using biomass (Salam et al, 2010). This combustion system burns the biomass to generate hot flue gas, which is either used directly to provide heat or fed into a boiler to generate steam (Peterson and Haase, 2009). This system could be suitable for large scale of energy plant having efficiency of 20-30 % approximately.

***Gasification System***

Gasification plant converts solid fuel to a combustible gas by supply a restricted amount of oxygen. The combustible gas is used for the gas engine to generate electricity (Quaak at el, 1999). This gasification system has been considered as one of the decentralized electrification system from biomass supported by Ministry of Energy in Thailand (Samudrala, 2010; Salam et al., 2010). Over the years, the biomass gasification plant received adequate technology for rural areas in order to distribute electricity through transmission grid. The efficiency of gasification system is 15-17%. A gasification system required approximately 4 people in one plant which is lower number of employees than direct combustion system. Also, local people can participate with plant working such as co-operation of agriculture. Many private company develop and introduce the gasification system, however, the gasification technology is still not established as systematic utilization.

The gasification plant is being considered an adequate technology due to less operational cost and small scale production system. On the other hand, the direct combustion requires large scale investments. In addition, the direct combustion plant has higher transportation cost due to collection and transportation of rice husk from adjacent rural areas. However, in a small scale, the government initiation is not enough to encourage gasification system. The policy planer has no clear guideline for the small scale farmers and other risk assessment parameters including environment and GHG emission. Therefore, policy maker needs to decide the best choice either directs or gasification systems based on cost, opportunity, risk and benefit.

The evaluation between direct combustion and gasification systems can be helpful to choose best system for introducing energy plants in rural areas. Then systematic approach is required to develop the evaluation method. Because when introducing biomass energy plant to rural area, we have to consider many things from social background to technology.

**Objectives**

The evaluation to choose the best biomass conversion system focuses on benefit and opportunities. On the other hand, the risk assessment is also major concern considering environment and GHG. Therefore, a decision support system with analytic hierarchy would help to decide the best biomass conversion methods from different alternatives. In the analytic hierarchy, the Analytic Network Process (ANP) theory has scope to include different criteria, sub-criteria, and alternatives to judge the best conversion method from rice husk in rural areas. This research aimed to propose a decision support system for introducing the most suitable rice husk energy plants in rural areas of Thailand, using ANP theory considering environmental and social problems in the rural areas.

## *5.2 Methodology*

**Establishment of model in ANP**

ANP model considering criteria and sub-criteria and alternatives for environmental and social issues had been proposed (Fig. 5.2). There were four main criteria that include Benefits, Opportunities, Costs and Risks (BOCR). These are further divided to sub-criteria level. The definition of each criteria and sub-criteria are;

**Criteria:**

- **Benefits (*B*)**: This criteria is the related to the favorable situation, advantage, positive expectation and future benefits. Benefits criteria is used to compare the most advantage systems to the rural areas of Thailand.
- **Opportunities (*O*)**: Opportunities is the good chances of the introducing of biomass energy plant to rural areas of Thailand such as the more jobs, more income, etc.
- **Risk (*R*)**: This criteria is the unfavorable condition or negative aspects from the introducing of biomass energy plant in rural areas.
- **Costs (*C*)**: The financial involve from before the introducing until the processing of energy generation.

**Sub-criteria:**

- **Capacity of energy production ($B_c$)**: The ratio of the actual output of a power plant over a period of time. This sub-criteria was used to compare the average capacity of energy production between two systems.

- **Employment ($B_e$)**: this sub-criteria was used to compare between two systems for the chances to getting job of the local residents
- **GHG reduction ($B_g$)**: this sub-criteria compare between direct two systems on the opportunity to reduce environmental problem especially GHG.
- **Participant of farmer ($O_f$)**: this sub-criteria is the chance of local residents to involve, manage, taking part or sharing the decision, and participate as the owner of biomass energy plant.
- **Participant of entrepreneur ($O_e$)**: this sub-criteria is the chance of group of the companies, organizations, financial institutions or local administrations are participating and join the network.
- **Reliability of technology ($R_r$)**: the comparison between two systems about the satisfactorily perform and its function under given circumstances such as environmental conditions, limitations as to operating time, and frequency and thoroughness of maintenance for a specified period of time.
- **Environmental risk ($R_e$)**: This sub-criteria refer to the potential of the systems that may cause the environmental problems or negative effects to the residents during the processes.
- **Available of material ($R_a$)**: This sub-criteria means the availability of the rice husk resources. In some areas of Thailand, the rice husk shortage are occurs because rice husk is used in many industries. Therefore, the available of material was involved in the model analysis.
- **Initial cost ($C_i$)**: An investment required for the introducing of biomass energy plant. This sub-criteria was related to the decision for the introducing of biomass energy plant base on profit.
- **Running cost ($C_r$)**: This sub-criteria related to the amount of money that spent to the operation of plant or to the operation of component, maintenance, salary and wage, raw material, tax, etc.

**Establishment of scenarios in ANP**

In the ANP modeling, the two scenarios were identified in this study: industrial and cooperative scenarios. Direct combustion system is considered closely to the industrial scenario because direct combustion is well-developed and commercially available technology. For industrial applications, direct combustion in large-scale plants is the most cost effective use of biomass for power generation. Due to direct combustion system is well developed, these systems are reliable system for investor. However, direct combustion system requires the construction of vast amount of electrical transmission infrastructure to the users. Nevertheless, direct combustion plants in some areas also were characterized by fluctuating voltage and shortage of supply. In some areas of Thailand, the problems of loss on transmission are occurred as the in accessibility of households electric. In order to generate energy more sustainably, the cooperative scenario was designed. Cooperative scenario refers to an energy system in which small scale of energy conversion units, located close to energy consumers and short transmission. Gasification system has been considered closely to the cooperative scenario. The advantage of gasification system is source of energy that is immediately accessible within small areas. Moreover, this system is considered as a source to increase the rural development. Gasification plant has the scope to generate income and employment, and utilize agricultural residue within communities (Ravindranath, 2004). Ministry of Energy has fund to support for community biomass gasification system because of an adequate technology of gasification plant for rural areas. However, in spite of the governmental support for gasification technology, but the gasification system still has been progressed at low rates due to lack of knowledge and technical support. Therefore, Industrial and cooperative scenarios were designed for providing the directions in policy level to develop the strategic approach on sustainable energy development. The strategic approach can help to identify and discuss the problems of the sustainable development of the biomass energy plants.

**Development of ANP model**

A decision support system for introducing renewable energy should have opportunities in wide range considering as environmental and social problems. Renewable energy technology development is occurred in community and requests an agreement of residents (Ladpala et al. 2006). In this research, Analytic Network Process (ANP) (Saaty, 1999, 2002), which is the extended theory of Analytic Hierarchy Processes (AHP), was used to construct the ANP model to introduce biomass energy plant in rural areas of Thailand. Because criteria, alternative, and scenario that is outside viewpoint of a decision system of AHP model using criteria and alternatives should be considered to compromise many opinion and decision in rural area. In the ANP model, scenario affects criteria and sub-criteria. On the other hand, criteria and sub-criteria affects to alternative, and alternative affects to scenario.

To understand the affects between the above decisions parameters, the pairwise comparison is conventionally used. Fundamental scale for pairwise comparison matrix is given (Saaty 1999) by taking into account the 1–9, Saaty scale for determining the weight of each matrix element for super matrix. Evaluation matrix U, which shows Criteria ($C_1$, $C_2$) evaluates alternative ($A_1$, $A_2$, $A_3$), and can be expressed as:

$$U = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{matrix} C_1 & C_2 \end{matrix} \\ \begin{bmatrix} u_{11} & u_{12} \\ u_{21} & u_{22} \\ u_{31} & u_{32} \end{bmatrix} \end{array} \qquad (5\text{-}1)$$

$u_{ij}$ is the weight comparison between the criteria and alternatives. i is the row and j is the column. Evaluation matrix $W$ which shows criteria ($A_1$, $A_2$, $A_3$) evaluates alternatives ($C_1$, $C_2$) can be expressed as:

$$W = \begin{array}{c} \\ C_1 \\ C_2 \end{array} \begin{array}{c} \begin{matrix} A_1 & A_2 & A_2 \end{matrix} \\ \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{12} & w_{13} \end{bmatrix} \end{array} \qquad (5\text{-}2)$$

$w_{ij}$ is the weight comparison between the alternatives and criteria. $S_{weighted}$ is represented weighted super matrix. Every component is weighted with its corresponding Cluster Matrix weight. For equation 3, $S_{weighted}$ is expressed using evaluation matrix $U$ and evaluation matrix $W$ as following:

$$S_{weighted} = \begin{bmatrix} 0 & W \\ U & 0 \end{bmatrix} = \begin{array}{c} \\ C_1 \\ C_2 \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & A_1 & A_2 & A_3 \end{array} \\ \begin{bmatrix} 0 & 0 & w_{11} & w_{12} & w_{13} \\ 0 & 0 & w_{21} & w_{22} & w_{23} \\ u_{11} & u_{12} & 0 & 0 & 0 \\ u_{21} & u_{22} & 0 & 0 & 0 \\ u_{31} & u_{32} & 0 & 0 & 0 \end{bmatrix} \end{array} \qquad (5\text{-}3)$$

Each matrix element of $S_{\text{weighted}}$, is not negative. And summation of each column should be "1" as follows,

$$\sum_{i=1}^{3} u_{ij} = 1, \quad \sum_{i=1}^{2} w_{ij} = 1 \qquad (5\text{-}4)$$

Finally, multiplying $S_{\text{weighted}}$ in infinity times on theory produces converged value of $v_1$ to $v_5$ as final weight of each matrix element in $S_{\text{limited}}$ (limited super matrix) in Eq. (5-5) (Kone and Buke, 2007).

$$S_{\text{weighted}}{}^{\infty} = \begin{array}{c} \\ C_1 \\ C_2 \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & A_1 & A_2 & A_3 \end{array} \\ \begin{bmatrix} 0 & 0 & w_{11} & w_{12} & w_{13} \\ 0 & 0 & w_{21} & w_{22} & w_{23} \\ u_{11} & u_{12} & 0 & 0 & 0 \\ u_{21} & u_{22} & 0 & 0 & 0 \\ u_{31} & u_{32} & 0 & 0 & 0 \end{bmatrix}^{\infty} \end{array} \Rightarrow S_{\text{limited}} = \begin{array}{c} \\ C_1 \\ C_2 \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & A_1 & A_2 & A_3 \end{array} \\ \begin{bmatrix} 0 & 0 & v_1 & v_1 & v_1 \\ 0 & 0 & v_2 & v_2 & v_2 \\ v_3 & v_3 & 0 & 0 & 0 \\ v_4 & v_4 & 0 & 0 & 0 \\ v_5 & v_5 & 0 & 0 & 0 \end{bmatrix} \end{array} \qquad (5\text{-}5)$$

When the numbers of matrix element in each row except for zero are closed to same value, super matrix $S$ has been reach at the final stage of calculation and the matrix multiplication process is halted. Then each value of $S_{\text{limited}}$ was considered as final weight of each element in the ANP model.

### ANP model analysis and sensitivity analysis

Super Decisions software® (Saaty, 2002) was used for calculation of pairwise comparison and super matrix. All weights calculated by pairwise comparison which was given by respondents through questionnaire. The responded values were averaged under supposing one of the energy plant systems for decision support to introduce biomass plant in rural area in Thailand. Percentage of respondent number for each pairwise comparison in the questionnaire was used to the weight of each element in eq. (5-6) as $S_{weighted}$.

$$
S_{weighted} = \begin{array}{c|cccccccccccccccccc|}
 & DS & GS & S_{in} & S_{co} & B & O & R & C & B_c & B_e & B_g & O_f & O_e & R_a & R_e & R_r & C_i & C_r \\
\hline
DC & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{19} & w_{1A} & w_{1B} & w_{1C} & w_{1D} & w_{1E} & w_{1F} & w_{1G} & w_{1H} & w_{1I} \\
GS & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{29} & w_{2A} & w_{2B} & w_{2C} & w_{2D} & w_{2E} & w_{2F} & w_{2G} & w_{2H} & w_{2I} \\
S_{in} & u_{31} & u_{32} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
S_{co} & u_{41} & u_{42} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
B & 0 & 0 & u_{53} & u_{54} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
O & 0 & 0 & u_{63} & u_{64} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R & 0 & 0 & u_{73} & u_{74} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
C & 0 & 0 & u_{83} & u_{84} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
B_c & 0 & 0 & 0 & 0 & u_{95} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
B_e & 0 & 0 & 0 & 0 & u_{A5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
B_g & 0 & 0 & 0 & 0 & u_{B5} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
O_f & 0 & 0 & 0 & 0 & 0 & u_{C6} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
O_e & 0 & 0 & 0 & 0 & 0 & u_{D6} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R_a & 0 & 0 & 0 & 0 & 0 & 0 & u_{E7} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R_e & 0 & 0 & 0 & 0 & 0 & 0 & u_{F7} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R_r & 0 & 0 & 0 & 0 & 0 & 0 & u_{G7} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
C_i & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{H8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
C_r & 0 & 0 & 0 & 0 & 0 & 0 & 0 & u_{I8} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array} \quad (5\text{-}6)
$$

$S_{\text{weighted}}$ is expressed as follows based on categorizing of "Alternatives", "Scenarios", and "Criteria"with $W_A$, $W_S$, and $W_C$.

$$
S_{\text{weighted}} = \begin{array}{c} \\ A \\ S \\ C \end{array} \begin{array}{c} \begin{array}{ccc} A & S & C \end{array} \\ \begin{bmatrix} 0 & 0 & W_A \\ W_S & 0 & 0 \\ 0 & W_C & 0 \end{bmatrix} \end{array} \quad (5\text{-}7)
$$

Then, $S_{\text{weighted}}^{3n+1}$ is calculated as follows (Saaty 1980; Kaku et al. 2009).

$$S_{\text{weighted}}^{3n+1} = \begin{bmatrix} \mathbf{0} & \mathbf{0} & (W_A W_C W_S)^n W_A \\ (W_S W_A W_C)^n W_S & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & (W_C W_S W_A)^n W_C & \mathbf{0} \end{bmatrix} \quad (5\text{-}8)$$

$S_{\text{limited}}$ was calculated by following equation.

$$S_{\text{limited}} \cong \lim_{n \to \infty} S_{\text{weighted}}^{3n+1} \quad (5\text{-}9)$$

Finally, weight of each element of the ANP model is shown in Eq. (5-10).

$$S_{\text{limited}} = \begin{matrix} \\ DC \\ GS \\ S_{in} \\ S_{co} \\ B \\ O \\ R \\ \mathrm{C} \\ B_c \\ B_e \\ B_g \\ O_f \\ O_e \\ R_a \\ R_{\mathrm{e}} \\ R_r \\ C_i \\ C_r \end{matrix} \begin{matrix} \text{Weight} \\ \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \\ v_7 \\ v_8 \\ v_9 \\ v_{10} \\ v_{11} \\ v_{12} \\ v_{13} \\ v_{14} \\ v_{15} \\ v_{16} \\ v_{17} \\ v_{18} \end{bmatrix} \end{matrix} \quad (5\text{-}10)$$

**Focus Group Discussion**

At the beginning of field survey, a focus group discussion was conducted with plant managers and experts. The focus group discussion was summarized based in criteria, sub-criteria and alternatives in order to make an alternative establishment for considering present practices. The alternative assessment is necessary to compare between two systems.

Suphanburi and Nakhonsawan provinces of Thailand (Fig. 5.2) were found to be suitable areas for analyzing the potential for introducing a rice husk energy plant. Both provinces have the advantages of rice husk availability, a cultivated cycle (2–3 times/year) and favorable geographic conditions. At the beginning of the field survey, a focus group discussion was conducted with plant managers and experts. The focus group discussion was summarized based on criteria, sub-criteria and alternatives to establish the consideration of alternatives to present practices. The alternative assessment was necessary to compare the two systems (Table 5.3).

The direct combustion plant requires employees about 25 people and investment cost of 20 million US dollar On the other hand, the gasification plant requires 4 - 5 employees and investment cost was 0.65 million US dollars (Table 5.3). A gasification plant requires less supply of rice husk than direct combustion system. Direct combustion plant consumes 168 t/d of rice husk while gasification plant consumes 0.75 t/d (Table 5.3). Gasification system receives more governmental support, but difficult to get loan from bank due to low operational reliability. For the raw material, rice husk can be found inside village so there is no transportation cost. However, gasification plant is rarely use in Thailand.

For the investigated areas, Suphanburi and Nakhonsawan provinces (Fig. 5.3) are suitable areas to analyze the potential of introducing rice husk energy plant. Both of the provinces have the advantage of the availability of rice husk, cultivated cycle (2-3 times/year) and the geographic conditions are favorable (Table 3).

For the biomass energy plant estimation, a potential number was calculated from the rice husk availability supply in Suphanburi and Nakhonsawan provinces (Table 5.2). Rice husk residue in Suphanburi was 74,599 t (Office of Agricultural Economics, 2009) could be produced energy of 66 GWh (Table 5.2). Total of available energy of rice husk was calculated for the capacity of supply. For the availability of direct combustion system, the capacity was 7,488 kW and gasification system was 22,481 kW. In Nakhonsawan, the availability of rice husk for power generation was 119,003 t (Office of Agricultural Economics, 2009) (Table 5.2). Hence, energy potential from rice husk could be achieved approximately 105 GWh. The available capacity for direct combustion plant in Nakhonsawan was 11,946 kW and gasification plant was 35,864 kW based on their efficiency (Table 5.2).

For the capacity of two systems, the capacity of direct combustion system was design at the 8,000 kW due to the maximum of the capacity potential from rice husk availability in two provinces. However, the gasification system is still being a test plant or demonstration in Thailand. The capacities of those plants are between 10 – 450 kW. Therefore, in this research was designed as the highest capacity of gasification capacity of energy production in Thailand. Finally, the potential supply for rice husk energy plants were calculated, Suphanburi and Nakornsawan have a potential of 1 direct combustion plant in each province. For gasification system, Suphanburi has the potential at 50 gasification plants and in Nakhonsawan has the potential at 80 plants (Table 5.2).

**Field Survey**

The investigated rural areas were considered as potential region of producing of rice husk. Therefore, this research was conducted in Suphanburi and Nakhonsawan. The questionnaire for the ANP model was conducted during November 2011. The survey was focused on the comparisons between each criteria and sub-criteria in order to make the alternatives assessment. The questionnaire was used to analyze the perception of Thai people for the renewable energy especially biomass energy plant introducing. The main purpose of this survey was to investigate the overall people who may affected by the introducing of biomass energy plant attitude. The interview was based on the structured questionnaire performed among the 35 respondents from Suphanburi and Nakhonsawan provinces included 3 energy experts. There are 18 female and 17 male from different occupations selected from villagers who may be affected by certain problems after a plant is introduced. The respondents were not only farmers but also held other occupations in the areas. Moreover, the 3 energy experts who understood the circumstances for biomass power plants in Thailand were investigated.

There were 18 questions in the survey. The questions asked respondents for their information; 1: Sex, 2: Occupation, 3: Living place, 4: Attitude for introducing a biomass energy plant, 5: Attitude for the awareness of renewable energy, 6: Awareness of biomass, 7: Awareness of renewable energy, 8: Awareness of global warming issues, 9: Awareness of disease in daily life, 10: Awareness of biomass energy plants, 11: Acceptance of biomass energy plants in their areas, 12: Reasons of accepted and not accepted, 13: Opinions for the advantage and disadvantage for introducing a biomass energy plant, and 14: Important issues of a biomass energy plant such as economic growth, environmental benefit, employment increase, risk from a biomass energy plant, opportunity, development of rural areas, and the preferable size of a biomass energy plant. Moreover, their preference for 2 types of biomass energy plants was asked in 15–18 questions. 15: The preference comparison of high capacity and low capacity of energy production, 16: The preference comparison of old technology and new technology, 17: The preference comparison of high investment support from the government or low investment support, and 18: Do they agree that a biomass energy plant can help to increase jobs or not?

For criteria in selecting items, the results of questionnaire were separated to two types of answers. The first type is the comparison type. Their answers were shown in Yes/No questions. And the second type is the explanation such as respondent's answers and opinions. Fig. 3 shows results of Yes/No questions from the respondents.

**Sensitivity analysis**

The ANP model shows the order of alternatives with weight after pairwise comparison and supermatrix calculation. The order of alternatives is very important to judge which a biomass energy plant is preferred. However, the purpose of the ANP model was not only selecting the best alternative, but also clarifying the detail for the order of alternatives by using total weight for every alternative. So, sensitivity analysis was executed in this research for the result of the ANP model by changing the weight of evaluation items to check the robustness of the result for the best alternative.

### *5.3 Results and Discussion*

**Characteristics of respondents**

The selected results of the questionnaire are shown in Fig. 5.4. There are two types of answers. The first type is the comparison type. Their answers are shown in Yes/No questions (Fig. 5.4). However, all of the results were used in pairwise comparison.

At the beginning of questionnaire, 34 of the respondent (97.1%) were aware of the renewable energy as well as the global warming issue. But only 16 of the respondent (45.7%) were aware of the biomass energy plant. Especially, local people as like worker, farmer, and trader did not know the biomass energy plant, and they never heard about the biomass from agricultural residue came from rural areas. This result indicated the understanding about the biomass energy plant is not reaching much people in rural areas.
For the awareness of biomass energy plant, 48.6 % have been ever heard about it, while 51.4 % never heard (Fig. 5.4). This indicated the understanding about the biomass energy plant is not reaching much people in rural areas. Although, in some areas have biomass energy plant already but people did not know or hear about it. 88.6 % of respondents accepted the introducing of biomass energy plants in their provinces from the survey. The reasons were biomass energy plants could be an alternative method to reduce global warming, clean and alternative energy source, increase employment for local communities, etc. Moreover, certain respondents thought that biomass energy plant could aid in decreasing agricultural residues. Despite the large percentage of acceptance, four from five farmers do not agree for biomass energy plant introducing. Their reasons are biomass energy plant may cause the impacts to rural areas such as causing environment problems such as producing environmental problems. The respondents were concerned about environmental problems, especially pollution. Given the problems with certain energy plants in rural areas in Thailand, environmental concerns have reached critical levels with hazardous substances at greater than acceptable standards in certain areas, as shown in the pollution control (Gilbertson 2009, Nantiya 2009).

For the comparison between capacities of biomass energy plant, it was not necessary to introduce high capacity of biomass plant. They preferred medium to small capacity biomass power that could serve enough demand for rural areas (68.6 %) and the 31.4 % preferred high capacity biomass energy plants due to the reasonable cost of high capacity system. Almost of them agree with the increasing of employment in rural areas area as well. The reason is if their areas have enough available jobs for local people is the best way to solve the problem of migration.

The comparison between low investment cost technology with low support from the government and high investment cost technology with high support from the government, group preferred high investment cost technology rather than low investment cost technology due to the support from the government. High support can reflect the reliable of technology as well even though it is a new technology in Thailand. For the technology of biomass energy plant, group was concerned about the reliability of the old technology more than new technology. However, People who select the new technology vision for the development technology in Thailand. The initial cost of a direct combustion system (*DC*) is higher than the initial cost of a gasification system (*GS*). However, the technology of the direct combustion system (*DC*) is reliable technology. So the private company can manage the direct combustion system (*DC*), and make profits independently. The technology of the gasification system (*GS*) is still developing technology. Then the private company hesitates to introduce it according to its economy. The gasification system (*GS*) should be supported by the government for initial and running cost of it. Thus respondents were interested in the reliability of the old technology as like a direct combustion system (*DC*) more than the new technology as like a gasification system (*GS*). On the other hand, the respondents preferred high investment support from the government in a comparison between high investment support and low investment support from the government. Because the respondents thought that high investment support could reflect the future reliability of the technology even though it is a new technology in Thailand.

Then, the result of questionnaire about the comparison between two systems of energy plants was used to calculate for the pairwise comparison of the ANP model.

**Analysis results**

The super-matrix in eq. (11) presents the results of $S_{weighted}$ which shows the relative importance measures for each element which imported from the pairwise comparison. The entries of the weighted super matrix itself give the direct influence of any one factor on any other factor. The weighted super matrix has some zeros indicating no interaction.

$$
S_{weighted} = \begin{array}{c|cccccccccccccccccc}
 & DC & GS & S_{in} & S_{co} & B & O & R & C & B_c & B_e & B_g & O_f & O_e & R_a & R_e & R_r & C_i & C_r \\
\hline
DC & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.75 & 0.17 & 0.33 & 0.17 & 0.75 & 0.75 & 0.67 & 0.17 & 0.33 & 0.50 \\
GS & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.25 & 0.83 & 0.67 & 0.83 & 0.25 & 0.25 & 0.33 & 0.83 & 0.67 & 0.50 \\
S_{in} & 0.75 & 0.25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
S_{co} & 0.25 & 0.75 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
B & 0 & 0 & 0.30 & 0.30 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
O & 0 & 0 & 0.10 & 0.30 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R & 0 & 0 & 0.30 & 0.30 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mathrm{C} & 0 & 0 & 0.30 & 0.10 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
B_c & 0 & 0 & 0 & 0 & 0.12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
B_e & 0 & 0 & 0 & 0 & 0.32 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
B_g & 0 & 0 & 0 & 0 & 0.56 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
O_f & 0 & 0 & 0 & 0 & 0 & 0.75 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
O_e & 0 & 0 & 0 & 0 & 0 & 0.25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R_a & 0 & 0 & 0 & 0 & 0 & 0 & 0.16 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R_e & 0 & 0 & 0 & 0 & 0 & 0 & 0.54 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
R_r & 0 & 0 & 0 & 0 & 0 & 0 & 0.30 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
C_i & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.50 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
C_r & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.50 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}
\qquad (5\text{-}11)
$$

The questionnaire results, energy expert suggestion and alternative assessment were modified to the 1-9 Saaty scale. Then the pairwise comparison of each element was calculated. For the weight of super matrix, the weight comparison of alternatives to scenarios and scenarios to criteria were derived from the discussion with energy experts. The weight comparison of criteria to sub-criteria was determined from the questionnaire results and the discussion with the energy experts. Finally, weights of sub-criteria to alternative were derived from questionnaire results, energy expert discussion and alternative assessment (Table 2).

The weight comparison of alternatives to scenarios shows that direct combustion system (*DC*) had higher weight in the Industrial scenario ($S_{in}$) than gasification system (*GS*) with 0.75 priority weighted while gasification system (*GS*) match for cooperative scenario ($S_{co}$) (0.75). Direct combustion system (DC) could provide the large energy supply, low investment and more technology reliable while gasification system support for the rural areas development such as increasing job and income and lower environmental effect. The characteristics of two scenarios were determined for the weight comparison of scenarios to criteria. In addition, weight comparison of scenarios to criteria show that the important criteria for industrial scenario ($S_{in}$) are benefits (*B*), risks (*R*) and costs (*C*) while the opportunities ($O$ ) was not emphasize. On the other hand, the most important criteria for cooperative scenario ($S_{co}$) were benefits ($B$), opportunities ($O$) and risks ($R$). Costs criteria had not much influence for cooperative scenario view point.

For the weight comparison of benefits sub-criteria to alternatives, gasification ($GS$) got the highest weight of employment ($B_e$) and GHG reduction ($B_g$) with 0.83 and 0.67 priority weights respectively. However, the capacity of energy production ($B_c$) shows that direct combustion ($DC$) more suitable than gasification system ($GS$) due to the efficiency of direct combustion plant in alternative assessment with 0.75 priority weight. For the opportunities sub-criteria, gasification system ($GS$) had the highest weight of participant of farmer ($O_f$) (0.83) with the lowest of participation of entrepreneur ($O_e$) sub-criteria (0.25). In case of risk sub-criteria, the results show the worst alternative as the highest weight. Equation (11) including result of weight comparison shows gasification was also gain the highest preferable alternative while determined with environmental risk ($R_e$) and available of material sub-criteria ($R_a$) with priority weight of 0.33 and 0.25 respectively. The lower values indicate the better alternative for risk sub-criteria and cost sub-criteria. However, direct combustion ($DC$) has the highest preference of unreliable of technology ($R_r$) due to the reliable of direct combustion technology in Thailand with 0.17 priority weight. Although gasification system ($GC$) got more weight in the most sub-criteria but direct combustion system ($DC$) was preferred for initial cost sub-criteria ($C_i$) (0.33) due to the lower priority of investment cost. In spite of the lower initial cost, direct combustion system had higher of storage and transportation cost while gasification system was not stable in Thailand. Therefore, the running cost which means the operational and maintenance cost was equal to gasification system.

***Analysis by Criteria***

The final step is the calculation of the limiting priorities of the weighted super matrix. According the limiting super matrix is given in Table 5.4, Cooperative scenario with 0.137 score was favorable scenario compared with Industrial scenario. Cooperative scenario was considered as an idea to support for sustainable development, clean energy, and strong local communities. Highest priorities of criteria were benefits and risks with 0.075 same score respectively compared with opportunities with 0.052 score, and costs with 0.048 score. From ANP model analysis, the gasification system was preferable with 0.149 score compared with direct combustion system with 0.101 (Table 5.4). The ANP model ensured that the gasification plant had more advantage compared with direct combustion system. The result of sub-criteria for benefit shows that highest priorities of sub-criteria was GHG reduction under benefit criteria with 0.042 score compared with employment with 0.024 score, and capacity of energy production with 0.009 score. So, respondents are more concern about reducing of fossil fuel, GHG gas, global warming and climate. Most of respondents also focused on GHG reduction more than other two sub-criteria under benefit criteria. Due to the purpose to increase more job and income, employment sub-criteria is the second rank important under benefit criteria. Most of respondents think that they prefer optimum capacity more than large capacity energy plant, because of the result of score for capacity of energy production.

The result of sub-criteria for opportunity shows that participant of farmer with 0.040 score is preferable compared with participant of entrepreneur with 0.013 score (Table 5.4). Participant of entrepreneur is a way that investor or financial institution accompany with. But this tendency in sub-criteria of opportunity criteria is affected by the strong relationship of participant of farmer and cooperative scenario in order to increase of local community development.

The result of sub-criteria for risk shows that environmental risk is the most important with 0.040 scores compared with reliability of technology and available of material (Table 5.4). Reliability of technology sub-criteria is the second rank of important with 0.022 score, and followed by available of material with 0.012 score. So, the respondents concerned about the environmental problem, especially pollution. According to the problem of some energy plants in rural area in Thailand, it has reached critical levels with hazardous substances more than the acceptable standard in some areas as shown in the Pollution Control Department report (Gilbertson, 2009; Sirikun, 2010).

There are some issues in Thailand report about some energy plant cause the air pollution to villages and cause health problem to villagers. Therefore this weight was concerned for the environmental pollution and villager health must be safe first. For the technology, it is the second rank of importance. If energy plant uses reliable technology, it may be ensured that it will cause fewer problems to itself or communities. The availability of material is also important because some areas face the shortage of material due to rice husk consumption of large energy plant.

The result of sub-criteria for cost shows that initial cost and running cost were equal score with 0.024 (Table 5.4). The initial cost and running cost are important for introducing energy plant. The initial cost can be reduced by the support from the government, international fund and loan from financial institution. There were many factors to consider for the running cost. Not only the technology that can be reliable but also maintenance, transportation of raw material and storage must be low cost. These results can be used to aid and suggest to the policy maker or local administration in decision making regarding energy plants in rural areas.

A sensitivity analysis had been made to ensure the stability of the outcome of the ANP model. The sensitivity analysis for most cases demonstrated that the alternatives were not changed based on sensitivity to criteria and sub-criteria primarily, because the gasification system had high advantage to contribute the benefit for rural areas and reduce environmental pollution compared with the direct combustion system. In other instances, the sensitivity analysis had no influence on the rating. As shown in Fig. 5.5, the outcome from this analysis was very robust, even though the weight of participation of farmers as sub-criteria increased, the result had no effect. But, the preferred order of alternatives was changed based on the sensitivity analysis for only "capacity of energy production" as sub-criterion (Fig. 5.6). When the weight of "capacity of energy production" increased, priority for the gasification system decreased. If the weight of "capacity of energy production" was over the value of 0.78, the direct combustion system (*DC*) was considered more preferable than the gasification system (*GS*). However, the weight of "capacity of energy production" as sub-criterion was very small at 0.009 in the ANP model. Then, fluctuation for the weight of "capacity of energy production" in the weighting stage of the ANP model was practically not able to affect the preferred order of alternatives.

Therefore, the gasification system was expected to be higher priority alternative as a biomass energy plant using rice husk based on this calculation in the research herein. And, the direct combustion plant was a suitable plant for large scale of energy production by its high efficiency for its economy. The direct combustion plant had high reliability of its technology (Table 5.3), therefore it is mainly used in Thailand to generate electricity using rice husk. Industrial scenario drives centralization of power plants using large initial cost for construction. As a result, direct combustion system was more suitable energy plant from the benefit and economy in an industrial scenario. The ANP modeling proposed herein provided important information for policy management for introducing not only choice between alternatives but also the new alternatives according to mixed rate between two different types of energy plants in rural areas of Thailand.

### *5.4 Conclusions*

1. The ANP model was proposed as a tool of decision support system for introducing biomass power plant using rice husk based on four criteria: benefits, opportunities, risks, and costs with ten sub-criteria: capacity of energy production, employment, GHG reduction, participant of farmer, participant of entrepreneur, unreliable of technology, environmental risk, available of material, initial cost and running cost.

2. Scenario is outside viewpoint of decision systems of normal AHP model using criteria and alternatives was used as the feedback systems to compromise many opinion and decision in rural area for introducing biomass energy plant.

3. Specific data of alternatives for a direct combustion system and a gasification system was calculated and determined using preparatory survey data in Suphanburi and Nakhonsawan provinces in Thailand to evaluate the ANP model objectively. The most important criteria were benefits and risks compared with opportunities and costs. It can be concluded that for the cooperative scenario, benefits and risks are the most necessary criteria for the introducing of energy plant system in rural areas.

4. The most important sub-criteria were related to the concern of environmental and social problems. GHG reduction, participant of farmer and environmental risk got the highest priorities weighting. This result shows that people are more concern about the environment and reduction problems such as the increasing of fossil fuel, GHG gas, global warming and climate change. Some report shows some energy plant in Thailand because the pollution and health problems to the residents that motivates the awareness of residents for the introducing of energy plant. Moreover, the participant of farmer was considered as source to increase of local community development.

5. The ANP model accompanied with sensitivity analysis provided important information for introducing gasification system in the rural areas of Thailand. It should be taken into account of benefits and threat points in order to support the utilization and development of gasification technology.

Table 5.1 Adder to the normal tariff for increase incentive for renewable energy in Thailand

| Fuel type | Adder (US cent/kWh) |
|---|---|
| | |
| < 1 MW | 1.43 |
| > 1 MW | 0.86 |
| Biogas | |
| < 1 MW | 1.43 |
| > 1 MW | 0.86 |
| Waste | |
| Fertilization / Landfill | 7.14 |
| Thermal process | 10 |
| Wind | |
| < 50 MW | 12.86 |
| > 50 MW | 10 |
| Hydropower | |
| 50 kW ~ +200 kW | 2.29 |
| < 50 kW | 4.29 |
| Solar | 22.86 |
| Total capacity | |

Source: Ministry of Energy, 2009

Table 5.2 Potential provinces for biomass energy plant introducing

| Potential provinces | Rice husk (t) | Availability of rice husk*(t) | Energy potential (GWh) | Potential for energy production DC ** (kW) | GS** (kW) | Potential plant (plant) DC (8000 kW) | GS (450 kW) |
|---|---|---|---|---|---|---|---|
| Saraburi | 41,294 | 20,358 | 18 | 2,043.70 | 6,135.29 | - | 13 |
| Nakhonsaan | 241,385 | 119,003 | 105 | 11,946.46 | 35,863.92 | 1 | 80 |
| Lopburi | 94,980 | 46,825 | 41 | 4,700.67 | 14,111.67 | - | 31 |
| Singburi | 53,702 | 26,475 | 23 | 2,657.78 | 7,978.80 | - | 17 |
| Chainart | 121,958 | 60,125 | 53 | 6,035.86 | 18,119.98 | - | 40 |
| Suphanburi | 151,317 | 74,599 | 6 | 7,488.86 | 22,481.97 | 1 | 50 |
| Ang-th0ng | 47,789 | 23,560 | 21 | 2,365.14 | 7,100.27 | - | 15 |
| Ayutthaya | 107,311 | 52,904 | 47 | 5,310.93 | 15,943.70 | - | 35 |
| Nonthaburi | 15,791 | 7,785 | 7 | 781.54 | 2,346.22 | - | 5 |
| Pathumthani | 46,329 | 22,840 | 20 | 2,292.88 | 6,883.35 | - | 15 |
| Nakhonnayok | 43,615 | 21,502 | 19 | 2,158.58 | 6,480.18 | - | 14 |
| Prachinburi | 61,134 | 30,139 | 27 | 3,025.59 | 9,082.99 | - | 20 |

*Calculate by Rice husk amount × Surplus availability factor (0.493) (Srisovanna, 2004)
**Calculated by Availabilityof rice husk×actual heating value (0.88 kWh/kg) divided by operation hour. Direct combustion operation hour is 8,766 hour (24 × 365) and Gasification is 2,920 hour ( 8 × 365).
Source: Office of Agricultural Economics, 2010

Table 5.3 Alternative establishment for ANP modeling using criteria and sub-criteria based on Benefit, Opportunity, Risk, and Cost at criteria

| Criteria | Sub-criteria / Alternatives | *DC* (8,000 kW × 1 plant in both provinces) | *GS* (450 kW × 50 plants for Suphanburi) (450 kW × 80 plants for Nakhonsawan) |
|---|---|---|---|
| *B* | $B_c$ (Efficiency) | Suitable for large scale<br>Efficiency : 20 - 30 %[1)] | Suitable for small scale<br>Efficiency : 13 ~ 24 %[4)] |
| | $B_e$ | 25 × 1 = 25 people[2)] | 4 ×minimum 50 plants = 200 people[3)]<br>4 × maximum 143 plants = 492 people[3)] |
| | $B_g$ | Reduction using agricultural residue<br>$CO_2$ emission of biomass transportation | Reduction using agricultural residue |
| *O* | $O_f$ | Participant as worker | Participant as worker or shared owner<br>Co-operation of agriculture |
| | $O_e$ | No support from government | Support from government |
| | $R_r$ | Mainly use in Thailand (many plants)<br>High reliability for operation<br>Real capacity: 5,500 kW[2)] in 6,000 kW | Rarely use in Thailand<br>Few number of expert<br>Low reliability for operation<br>Real capacity: 250 kW[2)] in 450 kW |
| *R* | $R_e$ | Value is below standard[2)]<br>$NO_X$, CO, $SO_2$<br>Particular matter (dust and ash)<br>Water pollution<br>$CO_2$ emission of biomass transportation | Value is below standard[3)]<br>$NO_X$, CO, $SO_2$<br>Particular matter (dust and ash)<br>Water pollution<br>Tar can be eliminated by technology |
| | $R_a$ | Rice husk: 168 t/day/plant (24 h)[2)]<br>Risk of shortage of rice husk | Rice husk: 0.75 t/day/plant<br>Operation: 8 h/day[3)] |
| *C* | $C_i$ | 6,000 kW = 20 Million US dollars[2)]<br>Easily to loan from bank<br>High cost of complex equipment<br>High investment for storage | 32.5 to 92.95 Million US dollars<br>(450 kW = 0.65 Million US dollars [3)] )<br>Difficult to get loan from bank<br>Low reliability for investment loan |
| | $C_r$ | High maintenance cost<br>(97,000 to 130,000 US dollars/year [2)] )<br>High transportation cost<br>High storage cost and personal cost | No transportation cost<br>High maintenance cost |

Rate: 31 Thai baht = 1 US dollars

Source:

1) Quaak et al. 1999

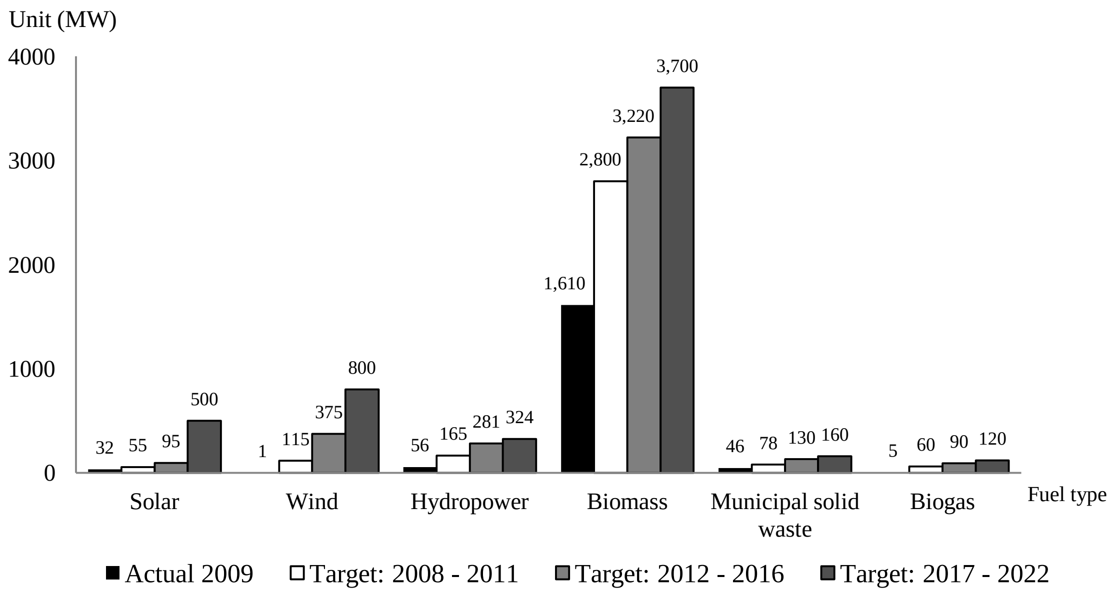
2) Permchart, personal interview, 8–9 March 2011

3) Phanpradit, personal interview, 8–9 March 2011

4) Fichtner Consulting Engineers Ltd 2004

Table 5.4 limited matrix of ANP synthesis model

| | Weight |
|---|---|
| Direct Combustion *(DC)* | 0.101 |
| Gasification *(GS)* | 0.149 |
| Industrial scenario $(S_{in})$ | 0.113 |
| Cooperative scenario $(S_{co})$ | 0.137 |
| Benefits *(B)* | 0.075 |
| Opportunities *(O)* | 0.052 |
| Risks *(R)* | 0.075 |
| Cost *(C)* | 0.048 |
| Capacity of energy production $(B_c)$ | 0.009 |
| Employment $(B_e)$ | 0.024 |
| GHG reduction $(B_g)$ | 0.042 |
| Participant of farmer $(O_f)$ | 0.040 |
| Participant of entrepreneur $(O_e)$ | 0.013 |
| Reliability of technology $(R_r)$ | 0.012 |
| Environmental risk $(R_e)$ | 0.040 |
| Available of material $(R_a)$ | 0.022 |
| Initial cost $(C_i)$ | 0.024 |
| Running cost $(C_r)$ | 0.024 |




Source: Ministry of Energy, 2009

Fig. 5.1 Target for electricity generation from renewable energy during 2008-2022

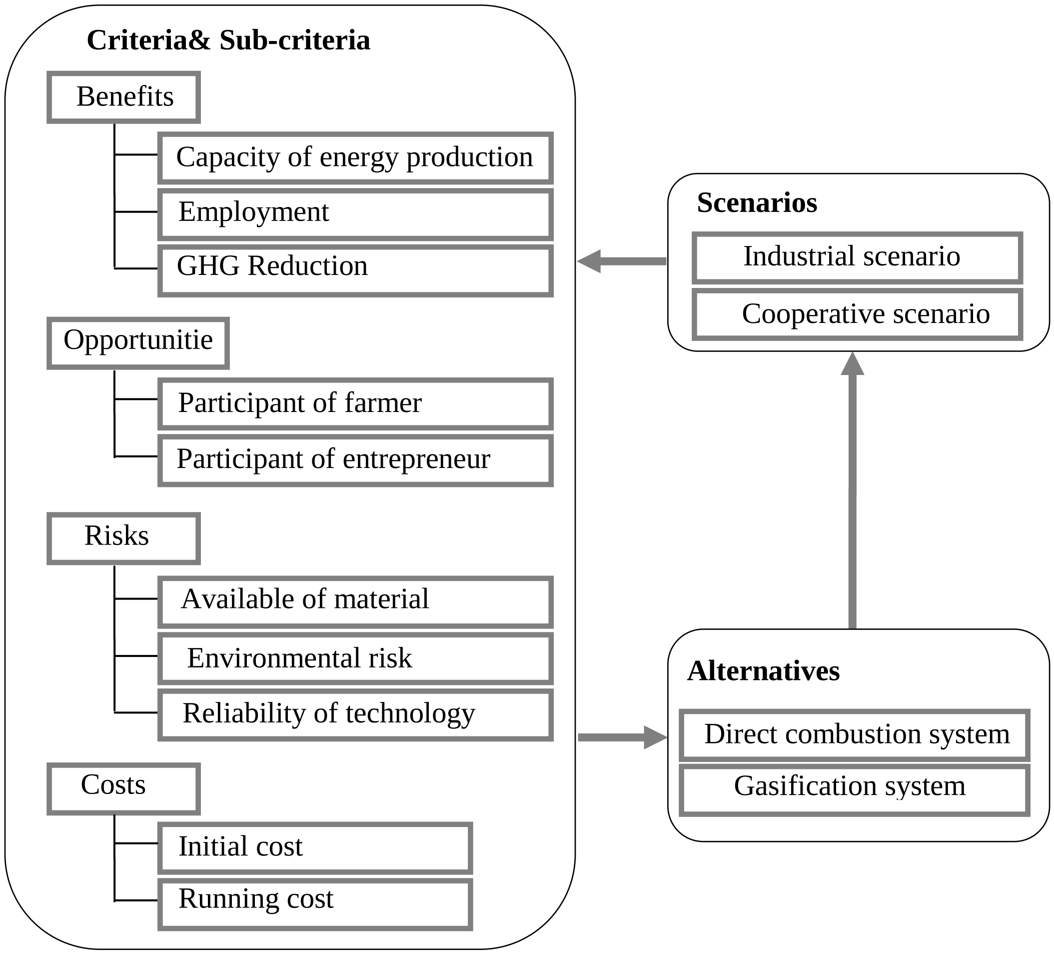



Fig. 5. 2 The ANP model composed of three clusters as criteria & sub-criteria, alternative, and scenarios to introduce biomass energy plant in Thai rural areas

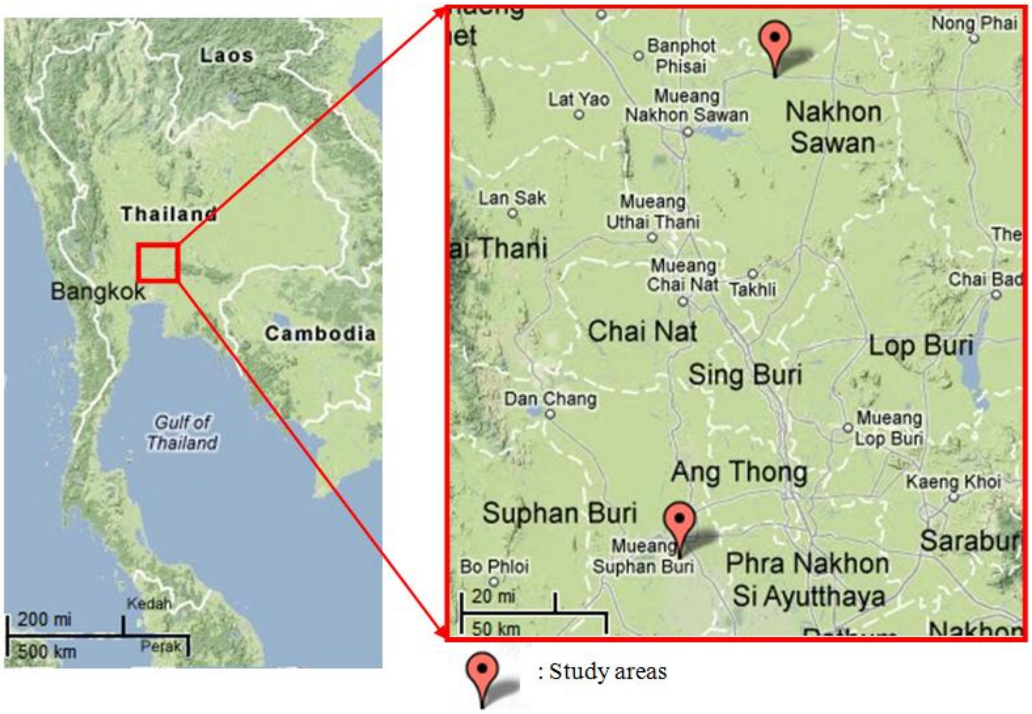



Fig. 5.3 Map of Suphanburi and Nakhonsawan provinces, Thailand
(Thai mapping, Geospatial Information Center, 2010)

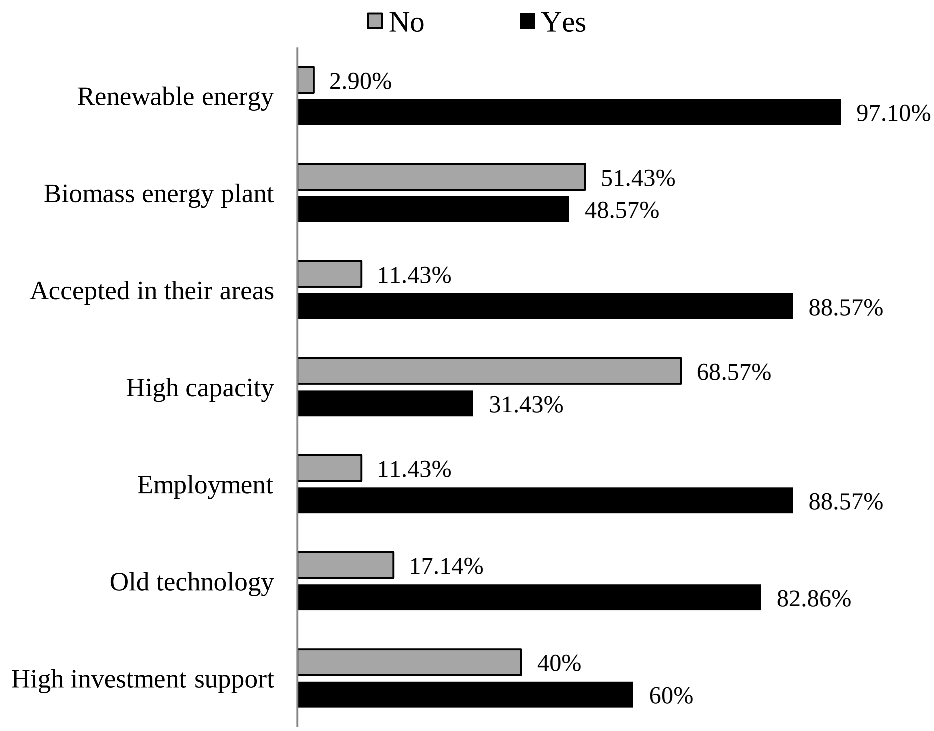



Fig. 5.4 Awareness and preferences of participants

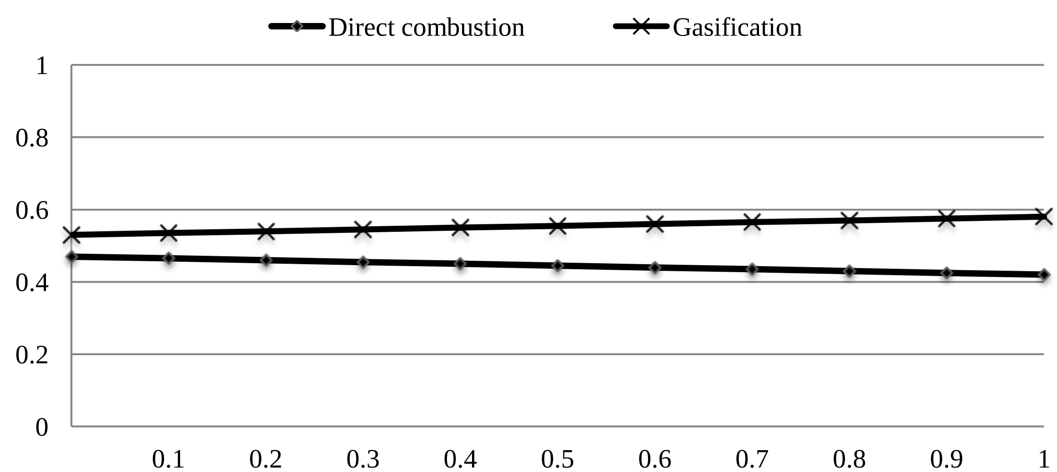



Fig. 5.5 Sensitivity analysis for "participant of farmer" as sub-criteria with no changed preferable order of alternatives

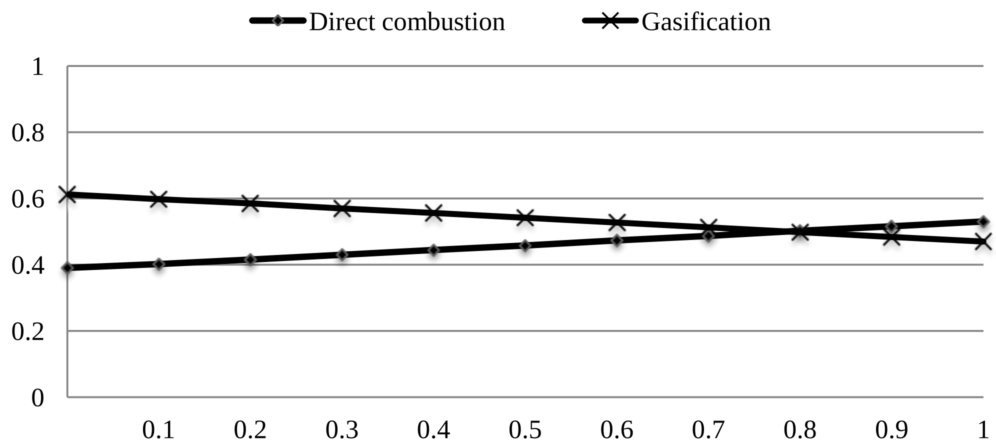



Fig. 5.6 Sensitivity analysis for "Capacity of energy production" as sub-criteria to change the preferable order of alternatives

# Chapter 6

# Systems Integration and Conclusions

### *6.1 Merits of System Informatics and System Dynamics in this research*

The substitution of fossil fuel with biomass aims to reduce environmental impacts and the cost of imported fossil fuels, such as coal, petroleum and natural gas. Biomass is considered a feasible approach for reducing fossil fuel consumption and $CO_2$ emissions. However, biomass resource, field area of biomass production, variety of biomass, conversion efficiency of biomass plants and suitable conversion system should be evaluate for the more effective production of biomass energy and rural areas development. The objective of this study was to evaluate the conversion technology by using energy and exergy analysis, and decision support system to aid in the decision to introduce a biomass power plant using rice husk for rural areas in Thailand. Therefore, the research herein was aimed at proposing a decision support system by using ANP theory and system design by evaluate the energy and exergy for biomass energy resources utilization. These proposes aim to introduce the most suitable rice husk energy plant in rural areas of Thailand. This research was expected that the result would be useful for energy policy planner of Thailand, local administration in rural area, private Entrepreneur and local cooperative, farmer and local people in rural areas, etc.

### *6.2 Conclusion*

According to the results of the two research studies, in case of the selection based on the evaluation to select the most suitable energy generated system, the decision was decided base on two aspects. Firstly, the evaluation function by energy $E_{system}$ of the energy concept and $E_{system}^{EX}$ of the exergy concept were proposed for biomass production to analyze the consistency between energy production and energy consumption, to achieve final benefits, and to analyze available energy. The Exergy Profit Ratio (ExPR) was also proposed instead of the Energy Profit Ratio (EPR) from an exergy analysis standpoint. In case study in Japan shows that, if EPR and $E_{system}$ of bioethanol & electricity production were underestimated for a minimum field area, ExPR and $E_{system}^{EX}$ can be used to maintain the results of introducing biofuel production to prevent a field area shortage for biofuel production. EPR and $E_{system}$ are categorized as quantity evaluations of energy, and ExPR and $E_{system}^{EX}$ are categorized as quality evaluations of energy. Thus, the values of ExPR and $E_{system}^{EX}$ should be examined when more than two types of energy are considered in the design of biofuel production. The results of $E_{system}$ and $E_{system}^{EX}$, in particular, can reveal improvements in the system. Therefore, $E_{system}^{EX}$, which contains physical quantities of exergy, and $E_{system}$ were suitable for the evaluation method using a system design approach. By the case study in Thailand shows that the evaluation between two types of direct combustion and gasification systems by Energy Profit Ratio (EPR) and Exergy Profit Ratio (ExPR) can lead to demonstrate a more effective production of biomass energy as well. An evaluation between direct combustion and gasification systems by Energy Profit Ratio (EPR) and Exergy Profit Ratio (ExPR) can lead more effective production of biomass energy planning. The evaluation between two systems can help to choose the best system for introducing energy plants in rural areas in Thailand. The results can be concluded that the direct combustion system had a higher advantage than the gasification system. EPR was higher than ExPR in both of Direct combustion system and gasification system because an energy input as electricity in both systems were producing high-efficiency exergy products as electricity and also low low-efficiency exergy product as heat and vapor. Furthermore, the minimum field area of rice production based on energy demand in the case of introduction of the biomass power plant to rural areas in Thailand. Minimum field area of biomass production based on similarity in energy demand for final benefit and energy demand for production energy demand shows the result by the following. For the 100% , 25% and 8% of energy demand in case of energy produced by direct combustion system, the minimum field areas to produce enough energy demand were below the current rice field area in Suphanburi province. However, the results of minimum field area of energy demand for 100% significantly exceed the current rice field area in case of gasification system. Although unpractical use area was included to provide more energy resource but it can not satisfy for energy demand. While the 25% and 8% of energy demand in case of gasification system can satisfy the energy demand in areas.

For second analysis result, the evaluation base on rural area benefits was studied. A decision support system with an ANP results provided the suggestion and guideline to the government of Thailand to select the most appropriate system with the environmental and social problems consideration. The ANP model was proposed as a tool of decision support system for introducing biomass power plant using rice husk based on four criteria: benefits, opportunities, risks, and costs with ten sub-criteria. Scenario is outside viewpoint of decision systems of normal AHP model using criteria and alternatives was used as the feedback systems to compromise many opinion and decision in rural area for introducing biomass energy plant. The result shows the most important criteria were benefits and risks compared with opportunities and costs. It can be concluded that for the cooperative scenario, benefits and risks are the most necessary criteria for the introducing of energy plant system in rural areas. The most important sub-criteria results illustrated that the concern of environmental and social problems are the most important. This result shows that people are more concern about the environment and reduction problems such as the increasing of fossil fuel, GHG gas, global warming and climate change. Some report shows some energy plant in Thailand because the pollution and health problems to the residents that motivates the awareness of residents for the introducing of energy plant. Moreover, the participant of farmer was considered as source to increase of local community development.

For the final conclusion, the result shows that direct combustion system was a suitable plant for large scale of energy production by its high efficiency for its economy. The direct combustion plant had high reliability of its technology, more energy efficiency as EPR and ExPR and smaller field areas which were required to produce biomass. The direct combustion system was more suitable energy plant from the benefit and economy advantage to introduce in the rural areas of Thailand. However, the advantage of a gasification system is the energy source which has small-scale energy conversion units located near energy consumers with a short transmission. Moreover, this system is considered as an energy source that will increase rural development. A gasification plant can generate income and employment as well as use of agricultural residues within communities. Therefore, Gasification plant may use as an additional support energy plant fluctuated voltage areas or established the transmission grid areas in order to support the power for direct combustion plant. At the conclusion, direct combustion plant had an advantage compared with the gasification system by the benefit and economic concerned. The both two evaluation results herein provided important information for policy management for introducing not only choice between alternatives but also the new alternatives according to mixed rate between two different types of energy plants in rural areas of Thailand.

The both two evaluation results herein provided important information for policy management for introducing not only choice between alternatives but also the new alternatives according to mixed rate between two different types of energy plants in rural areas of Thailand.

### *6.3 Further study*

For the further study, Decision support system for exploiting local renewable energy sources. Renewable energy demand and its estimation of the available resources are necessary to evolve better management for providing and ensuring the energy resources. The Geographical information system (GIS) will help to integrate and match suitable rural renewable energy supplies with the demand. GIS is the technology for analyze and manage spatial data. GIS and AHP can be applied and joint together in order to determine the capacity and find the best area with the best receptive capacity to introduce biomass energy plant in rural area. The future study will attempt to establish a decision support system to evaluate the renewable potential for exploiting much renewable energy. GIS analyze the investigated potential site by screen the possible areas to locate the renewable energy source. Selection of the most suitable and optimal technical, social and environmental impact are studied by using surveys and focus group discussions with the local people. The objectives of the future study are to;

- 1. To access the availability and potential of renewable energy resources in Thai rural areas,
- 2. To establish a decision support system with aid of a geographical information system (GIS) to facilitate evaluations for exploiting local renewable energy sources,
- 3. To analyze the resources and demand for implementing location – specific renewable energy technologies

This research will provide the offer of appropriated renewable energy technology for the area which has low capacity to access the electricity. The evaluating of the potential technology and energy sources will be matched to reach the local energy demand (Fig. 6.1). Expected Outcome is to provide the offer of appropriated renewable energy technology for the area which has low capacity to access the electricity. The evaluating of the potential technology and energy sources will be matched to reach the local energy demand.

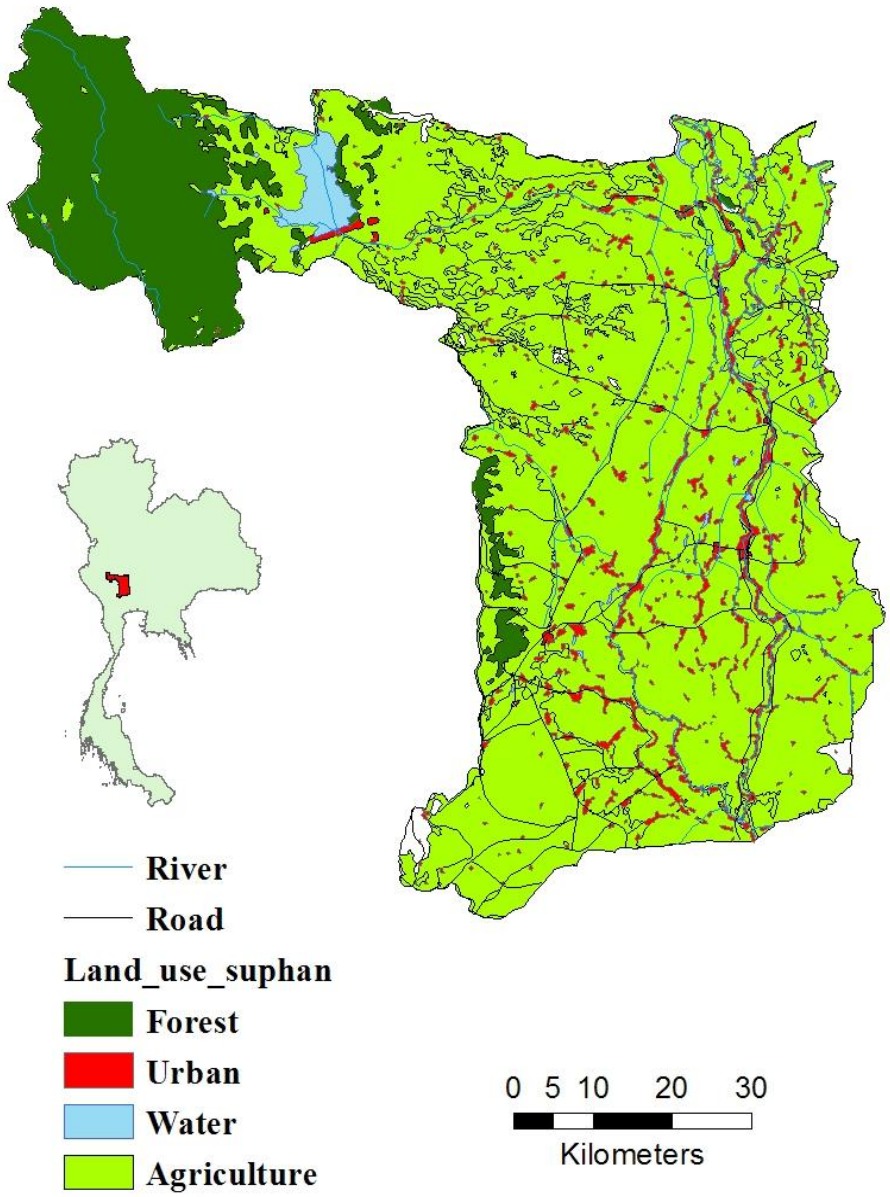



Fig. 6. 1 Spatial map with land use of Suphanburi

# Acknowledgement

First of all, the author would like to express my respectful gratitude to Prof. Dr. Zhang Zhenya, her academic advisor, for the kindness of helping and support throughout over two years of her doctoral study. Sincere thanks are extended to. Prof. Dr. Kitamura Yutaka and Assoc. Prof. Dr. Yingnan Yang for their invaluable comment and suggestion while reviewing this thesis.

The author wishes to express her sincere appreciation to Assoc. Prof. Dr. Ryozo Noguchi, for his interest, direction, encouragement and many helpful suggestions in this research. He did not give her only an academic guidance, but also always let author learn to improve her intellectual, vision or even her personality.

The author would like to express profound thanksgiving to Prof. Dr. Tomohiro Takigawa for his supportive and giving her an opportunity to study at the University of Tsukuba. His substantial advises and keen thoughts enable her to improve herself and inspire many ideas that are very helpful for this study. Cordial appreciation should also be expressed to Assoc. Prof. Dr. Tofael Ahamed and Asst. Prof. Dr. Takuma Genkawa for thier kind assistance of English checking, research suggestion and daily life concerned.

The author is indebted to her academic advisor in Thailand, Asst. Prof. Dr. Kriengkri Kaewtrakulpong, for giving an opportunity to study in Japan and his continual encouragement while studying here. My appreciation is extended to all of her laboratory members for their helping from first day until now.

With all humbleness and sincerity, I hereby express my thanks to the Japanese Government for providing financial support throughout my graduate study that made this doctoral study program possible.

All beneficence of this thesis is dedicated to my beloved family, and everyone at home especially her grandmother and mother for their love, perceiving the importance of education and moral support both the time author was with them and the time she was away. And you, the author also wishes to express her appreciation to Mr. Juthithep Vongphet, who the author knows how invaluable his support was.

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