Research Article

Energy, Economic and Environmental (3E) Analysis for Sustainable Development: A Case Study of a 9.9 MW Biomass Power Plant in Thailand

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Abstract
In Thailand, the use of biomass for electricity generation has been implemented with incineration technology for many years. However, recent reports indicate that electricity demand is still high and biomass power plant is one of the key factors for electricity management. The major purpose of this research paper is to analyze the energy, economic and environmental features of biomass power plant for the national sustainable development strategy. An existing 9.9 MW biomass power plant located in Suphanburi is selected as the case study to assess thermal combustion for electricity generation. The in-house operations of biomass-based power plant and the process flow of energy in terms of electricity generation using agricultural wastes and forestry residues are provided. Different expenses like capital cost, processing cost, and transportation cost and the major revenue from the sale of electricity are taken into consideration. Five environmental factors (air, sound, water, ash, and transportation) of biomass power plant for sustainability are investigated. Findings from this research project indicate that incineration is a suitable technology for biomass-based electricity generation with considerable profit for all stakeholders.

Keywords: Biomass, Energy, Economy, Environment, Incineration, Sustainability

1 Introduction

Electricity is one of the major concerns for social and economic development worldwide. As the global population increases dramatically, the demand of electricity continues to grow for many decades [1]. Besides electricity from the main grid, biomass is one of the most popular sources of renewable energy in building small local power plants in Thailand due to large amounts of biomass feedstock from agricultural wastes and forestry residues [2]. Consequently, increasing electricity supply with biomass-based

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power plant could be a proper alternative for Thailand's energy problem solving [3].

In Thailand, biomass-based power plant has been practiced and generated electricity since 1980. The number of new biomass power plants is expected to increase to support the growth of economy and community [4]. A study reveals that biomass feedstock can generate 30% of electricity demand in ASEAN countries. It has been predicted that Thailand consumes nearly the estimated supply of biomass feedstock of approximately 60 million tons per year [4]. Therefore, it is very important to have a better understanding on how much biomass feedstock is available and how to utilize it effectively in order to manage biomass power plant business for sustainability [1]–[4].

2 Research Framework and Methodology

2.1 *Overview of the case study*

This research project focuses on the assessment of energy, economic and environmental (3E) factors [5], [6] including the adaptable and creative model of business risk management [7] for the sustainable development of biomass power plant business model in Thailand. This case study is conducted with a biomass-based power plant located in Suphanburi, central region of Thailand (Figure 1). This biomass power plant has been found in 2013 and operated in 2015. The plant operation is analyzed from the point of view of using incineration technology to generate electricity and transmit it to the grid. The entire process of biomass feedstock preparation before boiler combustion process for a steam turbine and a generator as well as the environmental protection system is evaluated and presented in this paper.

More specifically, this biomass incineration power plant is under power purchase agreement (PPA) with Provincial Electricity Authority (PEA) of Thailand for electricity generation and sale of 9.9 MW. The Thailand's Ministry of Energy reports the total generation of electricity in Suphanburi in 2018 is 451.6347 MW. The sources of renewable energy for electricity generation in Suphanburi are solar (225.3527 MW – 49.90%), biomass (215.0613 MW – 47.62%) and other renewables (11.216 MW – 2.48%) [8].

The framework and methodological process applied in this research project is presented in Figure 2.

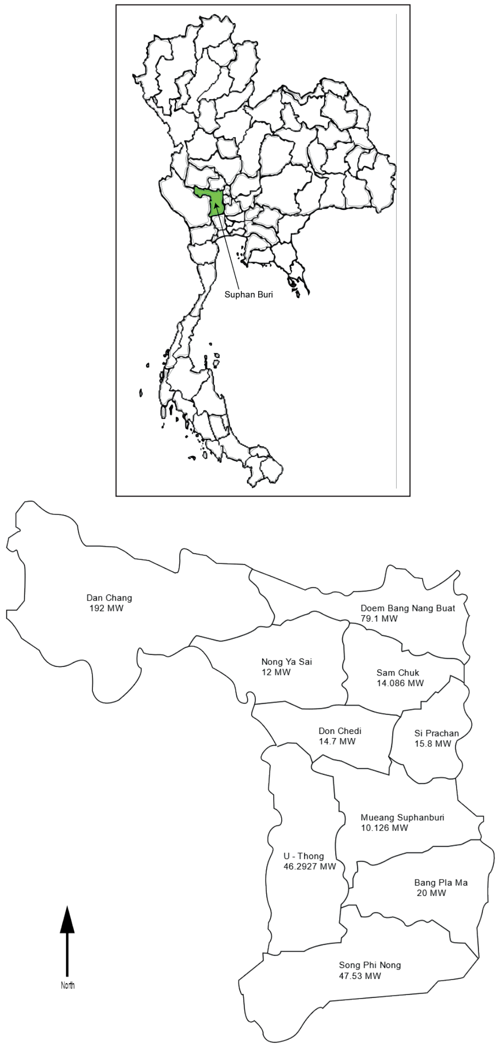

Figure 1: Highlighted is the area of a biomass power plant case study in Suphanburi, within the map of Thailand (Top: a map of Thailand) (Bottom: the area of study in Suphanburi where the plant is located).

Findings from the assessment of 3E (Energy, Economy and Environment) of biomass power plant can result in having a better understanding of its business sustainability and development in Thailand.

Figure 3 illustrates a concept of biomass-based power plant general operations. In fact, the process of electricity generation in biomass power plant begins at farmland and forestry where raw materials are produced until transmitting electricity as the final product of the plant to the grid distributed to customers.

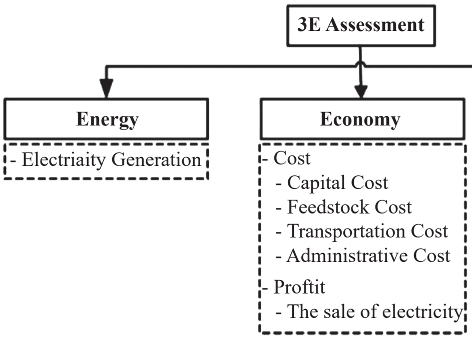

Figure 2: 3E assessment framework for the biomass power plant case study.

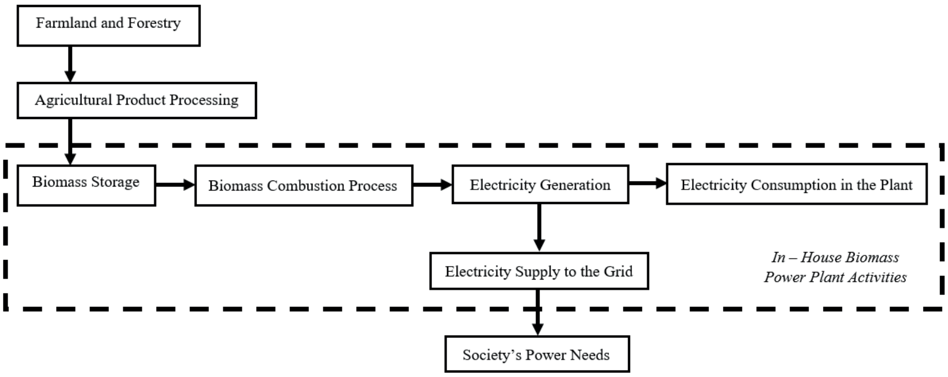

Figure 3: A general concept of biomass-based power plant operations.

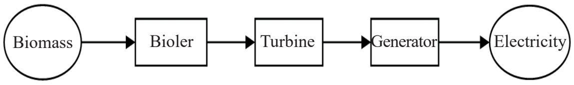

Figure 4: A fundamental biomass incineration process for electricity generation.

2.2 *Methodology for the energy analysis*

Over 90% of biomass power plant in Thailand is incinerated and equipped with power generation facilities. Biomass incineration process is the primary approach of biomass treatment technology that converts biomass to electricity as shown in Figure 4. Incineration is a thermal treatment that involves the combustion of waste materials as an input and the generation of electricity as an output. Biomass incineration converts organic waste materials into hot gas, heat, and ash forms. The ash from biomass combustion is the inorganic and incombustible part of biomass feedstock. The content of ash after complete combustion depends upon the mineral fraction of the original biomass. A study has reported that ash is found less than 2% in wood and up to 30–40% in rice husks and milfoil [9]. However, in this study it has been found that the average of ash from the biomass combustion is approximately 20% or 48 tons per day.

In fact, the organic waste materials include agricultural wastes and forestry residues. They are used as raw biomass as the input and electricity as the end product transmitted to the electrical grid for society's power need. In the hierarchy of raw biomass, the prioritized the input for the most favorable biomass feedstock in combustion process for electricity generation is presented in Figure 4.

2.3 *Methodology for economic analysis*

The economical approach applied in this research is based upon the revenue of the project made by a Feed-in Tariff (FiT) energy payment system. It is a national

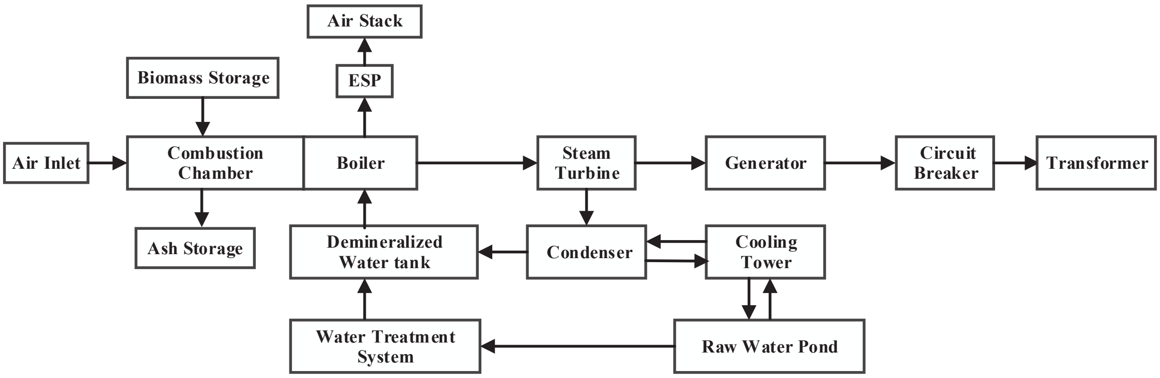

Figure 5: The electricity generation process in the case study.

policy to subsidize investment in energy. The FiT price for the amount of energy per-kWh is based upon the cost of technologies used to generate different types of renewable energy. Different technologies are awarded different FiT prices. It allows the government to promote the development of one technology or renewable energy over another.

The Royal Thai Government have legislated a FiT on top of utility avoided costs depending on the technology used and the amount of electricity transmitted to the grid and have guaranteed a FiT for a certain period of time, normally 7 to 10 years [10]. For example, solar energy has awarded the highest amount of 8 Thai Baht per kWh, whereas the large biomass power plant has offered the lowest amount of 0.3 Thai Baht per kWh [10].

2.4 *Methodology for environmental analysis*

There are many methods and tools for environmental assessment. This research aims at assessing and controlling the environmental risks of the 9.9 MW biomass incineration plant as selected for the case study. Five environmental risk factors (air, sound, water, ash and transportation) have been examined in this research project. The environmental analysis is performed under three standards (United States Environmental Protection Agency: USEPA, Thailand's Pollution Control Department: PCD, and Thailand's Department of Industrial Work: WIP) [11], [12]. The comparisons of measured environmental data at the site as appeared in environmental monitoring system and environmental standards are made [13].

2.5 *Business model development of biomass power plant for sustainability*

Another critical consideration of biomass power plants for long-term business management and sustainability is the understanding of the risks presenting in the relationships with all stakeholders (government, suppliers, customers, and other organizations) in business environments. The development of business model is performed into three steps: 1) interview with experts, 2) survey with stakeholders, and 3) validation of the analysis of experts' results. The analysis of business risk management become important and more complicated environment, especially when there are processing costs for coordinating stakeholders involved [14]. Thus, a proposed business risk analysis model with respect to enterprise risk management is necessary for business success and sustainability [7].

3 Results

3.1 *Energy analysis*

The assessment of energy in this study focuses on the general process of electricity generation in the 9.9 MW biomass incineration plant case study as shown in Figure 5. Briefly, the electricity generation system uses raw biomass for combustion to generate steam by boiler to run a stream turbine connecting with a generator to generate electricity before transmitting and distributing it through PEA grid network. In fact, this plant generates approximately 9.3MW in which 8.1 MW is sold to the grid.

Table 1: Characteristics of biomass residue as an input for the power plant – modified data from [15]

Biomass Residue	Cost (Thai Baht/ton)	Calorific Value (kcal/Unit)	Calorific Value (MJ/Unit)	Energy Conversion (ktoe/ton)	Electricity Conversion (kWh/ton)
Bamboo ship	2,500	5,800.00	24.27	0.000579612	6740.89
Palm shell	2,500	4427.19	18.52	0.000442423	5145.38
Sugarcane leaf	600	3858.55	16.14	0.000385597	4484.49
Empty bunch from oil palm	1,300	3,899.23	16.31	0.000389662	4531.77
Rice husk	1,500	3440.00	14.39	0.00034377	3998.04
wood pellets	4,000	3,944.00	16.50	0.000394136	4583.80
wood ship	1,000	3,000.00	12.55	0.000299799	3486.67
Bagasse	900	1,800.00	7.53	0.00017988	2092.00

3.2 *Economic analysis*

Table 1 shows the energy and cost characteristics of biomass feedstock as potential input materials for the biomass power plant. These characteristics are partially considered in economic analysis. The transportation cost for each biomass residue is 200 Thai Baht per ton. In general, 10 tons per hour of biomass residue on average are fed in the plant for electricity generation of approximately 9.3 MW.

The mathematical calculation of the FiT is given in Equation (1):

$$FiT_i = FiT_F + FiT_{V,i-1} * (1 + Core\ inflation_{i-1}) + FiT_{Premium} \quad (1)$$

When:

i = year[th] of electricity transmitted to the grid

FiT_F = Fix Rate for the entire project

FiT_V = Variable rate regards to core inflation

$FiT_{Premium}$ = Power Purchase rate extra (Specific area)

The net present value (NPV) is the economic factor indicating how much value the project adds to the investment and refers to the present values of all costs and associated revenues as presented in Equation (2). The internal rate of return (IRR) as presented in Equation (3) is calculated as the discount rate that makes the NPV equal to 0.00 Thai Baht as given below.

$$NPV = \sum_{n=1}^{t} \frac{CF_n}{(1+i)^n} - C_{IC} \quad (2)$$

$$IRR = \sum_{n=1}^{t} \frac{CF_n}{(1+IRR)^n} - C_{IC} = 0 \quad (3)$$

When:

NPV = the net present value

CF_n = the annual cash flow; the difference between the annual revenue and annual expenditure

C_{IC} = the total of capital cost of investment

i = discount rate (%)

t = the time life of the investment (20 years)

n = timespan (number of years) from time now

In this study, the major costs of biomass power plant operations include 1) capital cost, 2) feedstock cost, 3) transportation cost, and 4) administrative/processing cost. The NPV and IRR are estimated for a biomass feedstock mix. The profit concerns on only from the sale of electricity. The revenue and profit of the plant is generated only from the sale of electricity to PEA on a PPA of 20 years at 4.25 Thai Baht/kWh. With loan financing that comprises of 70% loan, 8% interest, and 7-year tenure, the NPV and IRR are 480 million Thai Baht, 13%, respectively.

3.3 *Environmental impacts*

Five environmental factors (air, sound, water, ash, and transportation) from the biomass power plant in the current study are considered under the standards of Thailand's Department of Pollution Control (Ministry of National Resources and Environment) and Department of Industrial Works (Ministry of Industry) and United States Environmental Protection Agency (USEPA). Details on each factor are presented as follows:

3.3.1 Air

The quality of air emission from the biomass power plant case study is considered under the standards of

Thailand's Department of Pollution Control (Ministry of National Resources and Environment) and Department of Industrial Works (Ministry of Industry) and United States Environmental Protection Agency (USEPA). Four factors (Sulfur Dioxide: SO_2, Nitrogen Dioxide: NO_2, Carbon Monoxide: CO, and Total Suspended Particles: TSP) of air quality at two local communities within a 5-kilometer radius from the biomass power plant case study are collected and evaluated. Average values of SO_2 (1-hour average), NO_2 (1-hour average), CO (1-hour average), and TSP (24-hour average) at two local communities the power plant case study are shown in Table 2.

Table 2: Air quality nearby the plant

Location	Air Quality			
	SO_2 (ppm) (1-hour Avg.)	**NO_2 (ppm) (1-hour Avg.)**	**CO (ppm) (1-hour Avg.)**	**TSP (mg/m^3) (24-hour Avg.)**
Local Community #1	0.003	0.014	0.526	0.150
Local Community #2	0.003	0.014	0.526	0.150
Standards	0.30	0.17	30	0.33

3.3.2 Sound

The sound pressure levels (L_{eq} and L_{max}) at the different two local communities within a 5-kilometer radius from the biomass power plant case study are collected and evaluated. Average values of L_{eq} and L_{max} as measured in dBA as 24-hour average are shown in Table 3.

Table 3: Sound findings around the plant

Location	Sound Levels	
	L_{eq} 24 h (dBA)	**L_{max} (dBA)**
Local Community #1	44.76	84.86
Local Community #2	55.54	92.64
Standard	70	115

3.3.3 Water

Five parameters of water quality are observed at three different locations within a 5-kilometer radius from the biomass power plant. The average sampling is shown in Table 4.

Table 4: Parameters of waste water from the plant

Water Parameters	Average	Standard
pH	8.57	5–9
Temperature (°C)	30.9	40
Suspended Solids (SS)	26	50
Total Dissolve Solid (TDS)	561.67	3,000
Biochemical Oxygen Demand (BOD)	6.33	20

3.3.4 Ash

Ash assessment and management in this study focus on fly and bottom ash. The 9.9 MW biomass incineration plant produces approximately 10 tons per hour or a total of 240 tons of ash per day. There are four major steps for ash management in this case study. 1) selling to the cement plant – as the ash from the boiler matches the ash qualities (Unburnt Carbon < 5%, Bulk Density 150–400 kg/m^3, Grain Size 2–4 mm and moisture content < 5%,) for cement plant, 2) giving to the farmers for making Organic fertilizer, 3) hiring the waste company for ash treatment, and 4) landfilling at the plant spared area of 1,120 m^2

3.3.5 Transportation

The traffic volume utilized around the biomass power plant case study is far below the traffic capability standards as given in Table 5. It can be concluded that the traffic volumes of the four highways (No. 3342, 3472, 333, 321) are in moderate traffic utilization level and have no effects to the biomass power plant case study.

Table 5: Traffic statistics around the biomass power plant case study

Highway No.	Volume of Traffic (PCU/h)	Capacity of Traffic (PCU/h)	V/C Ratio	Average Traffic Volumes per Day	% of Highway Utilization
3342	408	2,000	0.20	11,402	57
3472	330	2,000	0.16	10,128	51
333	422	2,000	0.21	9,782	49
321	475	8,000	0.06	7,906	40

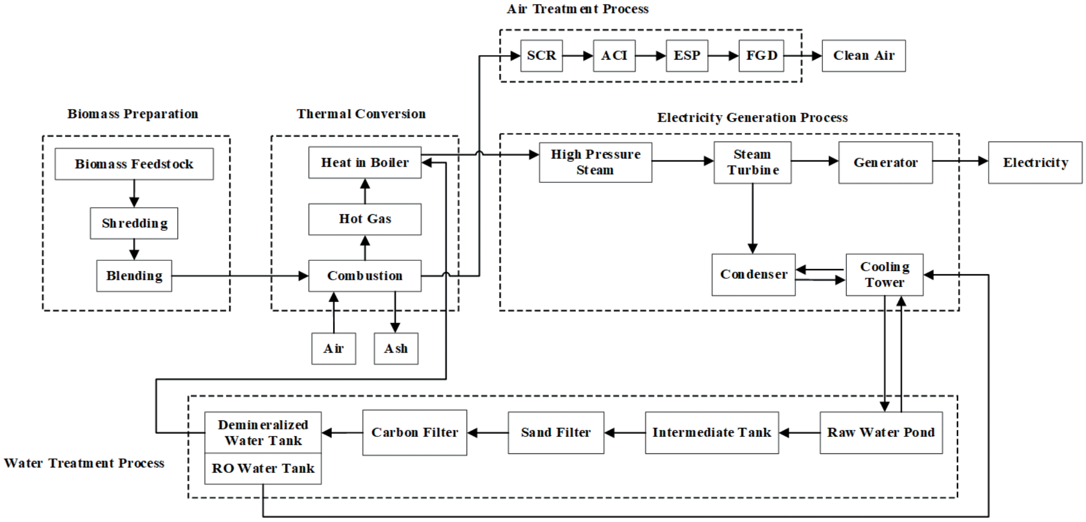

Figure 6: Environmental protection systems of the biomass power plant.

In sum, the environmental analysis on five factors (air quality, sound level, water quality, ash treratment, and transportation) is performed under three standards (United States Environmental Protection Agency: USEPA, Thailand's Department of Industrial Work: DIW, and Thailand's Pollution Control Department: PCD). The comparison of measured environmental data from the site as collected in the environmental monitoring system, and environmental standards are made. Findings indicate that those five environmental factors are under the standards. It is implied that the 9.9 MW biomass power plant case study do not negatively affect the environment and local community. The general concept of environmental systems of the plant is given in Figure 6.

3.4 *Biomass power plant business model for sustainability*

A proposed biomass power plant business model for sustainable development, adapted from the enterprise risks in the environment of value is presented in Figure 7.

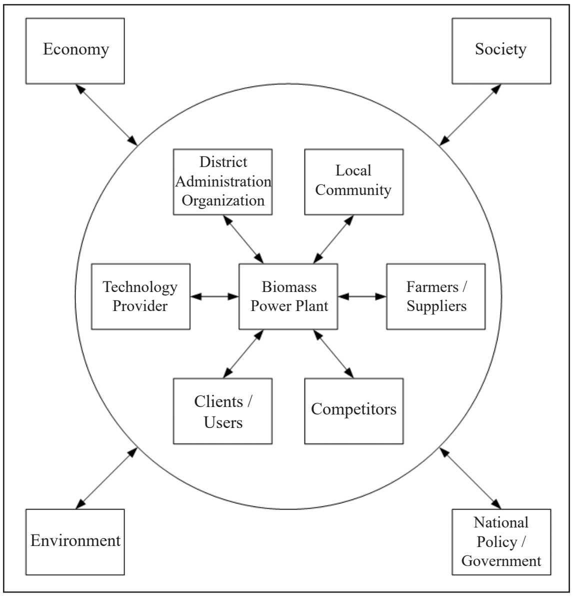

Figure 7: A proposed biomass power plant business model.

4 Conclusions

In this research, the energy as electricity generation, economic perspective and environmental impact of biomass as applied to a 9.9 MW power plant are assessed. The energy assessment focuses primarily on the operating principle of biomass incineration to generate electricity. The biomass feedstock for input materials for the plant is a combination of rice husk, bagasse, sugarcane leaf, palm shell, empty bunch from oil palm, wood pellets, wood ship, and bamboo ship. The most preferable biomass feedstock for the biomass power plant case study in terms of cost, moisture content, heating value, and cost are rice husk and shredded and dried empty bunch from oil palm. The economic analysis is carried out based upon the economic indicators: NPV and IRR, while the major income from electricity sale, which is calculated on FiT payment system. As the NPV > 0 and the IRR ≥ 12%, the biomass power plant project is considered attractive investment opportunity.

The environmental impact from five factors (air, sound, water, ash, and transportation) is evaluated under three standards (United States Environmental Protection Agency: (USEPA), Thailand's Pollution Control Department (PCD), and Thailand's Industrial Works Department (DIP). The comparison of measured environmental realtime data from the site (as appeared in environmental monitoring system) and environmental standards are made. Findings indicate that all five environmental factors in this research project are under the standards. It can be implied that the biomass power plant as selected as case study does not negatively affect the environment [13].

For all these findings, the incineration is a suitable technology for biomass-based electricity generation with considerable profit for all stakeholders, including local community, government, district administrative organization, farmer/supplier, technology provider, client/user, competitor, researcher, and company.

Findings from the current research project are based upon several limitations that should be mentioned. Examples include only one biomass power plant case study having investigated, the major economic benefit deriving from only the sale of electricity as it is greater and more constant as compared to others, such as sale of ash, etc. For the future studies, more biomass power plant case studies with other technologies, besides incineration and more expansions on 3E analysis should be explored.

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