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Bagasse - A Sustainable Energy Resource from Sugar Mills

Daranee Janghathaikul and Shabbir H. Gheewala*

The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

*Author to whom correspondence should be addressed, email: Shabbir_g@jgsee.kmutt.ac.th

Abstract. During sugar production, bagasse (waste) is produced which is used as energy resource in the sugar mill. Cogeneration power plants using bagasse as the feedstock are attached to several sugar factories in Thailand. These produce steam and electricity for use in the sugar mills and also sell the excess power to the grid. Bagasse, being a by-product of sugar production as well as of biomass origin seems to be a suitable candidate for sustainable energy production. However, the environmental impacts of power production from bagasse must be quantified to evaluate whether it is really advantageous for the environment. This study considers a 25 MW bagasse-fired power plant at a sugar mill in Nakorn Ratchasima province of Thailand. The study shows that the bagasse-fired power plant has lower emissions of NO_x and SO_x than conventional (fossil) power production in Thailand. The environmental problem of the bagasse-fired power plant is the emission of substantial amount of CO and Total Suspended Particulates (TSP or dust) which contribute to local impacts. However, on the whole power production from bagasse utilizes a waste from the sugar mill and also has lower potential for global warming, acidification, and nutrient enrichment as compared to conventional power production. Thus power production from bagasse promises to be a good sustainable energy source in Thailand.

Keywords: Bagasse, Biomass Energy, Sustainable Energy, Sugar Industry in Thailand.

Introduction

Today, 80% of worldwide energy use is based on fossil energy sources, and this share is rising [1]. Burning these fuels releases emissions to the environment, where they cause climatic changes, air pollution and human disease. The world environmental problems of recent concern are: [2]

- 6 million mile2 hole in the ozone layer over Antarctica or 4.5-5% loss of ozone over north hemisphere.
- The planet has warmed at least 1^{0}C in the last century and given the annual carbon, CO_2, CFC and methane transmission into the atmosphere, it is predicted rise another 2.5-5.5^{0}C in this century.
- In Europe, Estonia and Lithuania acid rain has damaged over 122.6 million acres of forest.

These problems are mainly caused by emissions from fossil energy production. One of the solutions is to find alternative energy sources which are sustainable and friendly for the environment. Renewable resources such as solar, biomass, hydro, geothermal energy are promising alternative energy

Renewable Energy
Renewable energy technologies are being developed and applied alongside conventional, i.e. fossil fuel and nuclear source for electricity, heat and transportation [3]. The renewable electricity generation technologies such as small roof-top photovoltaic (PV) installations to multi-MW wind farms also feed electricity into the grid, thus displacing conventional fuels in Europe.

In Thailand solar and biomass energy are the two renewable energy sources that receive high priority for support by the government [4]. However, considering the relatively high cost of investment and imported components of solar systems, providing support to widen applications of solar energy, especially PV, will be limited. In the case of a major food producing and agricultural country like Thailand, biomass is considered a renewable source with the highest potential [5].

Biomass Eenergy
The use of biomass residues to generate electricity and thermal power and to support weak grids is therefore important for the economic sustainability, as well as a key component of sustainable energy demand growth.

Biomass energy potential in Thailand has been projected at 715.5 and 1,769 PJ in year 2005 and 2010 respectively [6]. Thailand has high biomass yields such as agricultural residues; rice husks, bagasse from sugar cane and residues from palm oil or wood production which could be used as bioenergy resources. The use of agricultural residues as bioenergy resource represents an appropriate option to be considered.

The anticipated advantages of using agricultural residues for energy production are reduction in air emissions, especially CO_2, NO_x and SO_x. Their utilization also contributes to waste management, reduction in electricity purchase at the generating facility (e.g. rice or sugar mills) and even profit from selling surplus electricity to the grid.

The problems are their low energy density leading to increased transportation requirements if they are not utilized at the generation point, high moisture content leading to incomplete combustion and seasonal variability. However, these difficulties may be partly overcome by proper management such that the overall advantages prevail.

Since Thailand is the world's sixth largest sugar producer, bagasse could be the one of the major resources of biomass energy. According to the Office of Agricultural Economics, agricultural production increased by about 1.9 % in 2000. Thai sugar production in 1999/2000 was a record 5.72 million tons [7]. Moreover, as per the 5-year strategic plan (2004/08) for the sugar industry, developed recently to strengthen industrial competitiveness, the production target aims to improve cane yields from the current 60 tons per hectare to 88 tons per hectare [7-8].

Bagasse
Bagasse is the crushed remaining of sugarcane stalks left after the extraction of juice. Normally, it is used as fuel for supplying the energy need of the sugar mills. It is a fuel of varying composition and heating value. Its characteristics depend on the climate, type of soil upon which the cane is grown, variety of cane, harvesting method, amount of cane washing, and the efficiency of the milling plant. In general, bagasse has a heating value between 7-9 MJ/kg. Most bagasse has moisture content between 45 and 55% by weight which would affect the efficiency of combustion system [9-10]. Table 1 shows the average characteristics of bagasse.

Table 1 Characteristics of Bagasse [11]

Analysis Method	Value (%)
Proximate	
• Fixed carbon	11.1
• Volatile	35.9
• Moisture	50.0
• Ash	3.0
Ultimate	
• Carbon	22.9
• Hydrogen	2.8
• Sulphur	0.0
• Nitrogen	0.0
• Oxygen	21.3
• Moisture	50.0
• Ash	3.0

In South East Asia, bagasse furnaces and boiler arrangements have been around for quite some time and many bagasse furnaces are quite old [12]. There are four principal types of bagasse furnaces which are the step-grate furnace, the cook or horseshoe furnace, the ward furnace, and the spreader-stoker furnace [13]. In more recently built sugar mills, bagasse is burned in spreader stoker boilers [14]. Bagasse fed to these boilers enters the furnace through a fuel chute and is spread pneumatically or mechanically across the furnace, where 80-90% of the fuel burns while in suspension, according to the size of the particles. Simultaneously, large pieces of fuel are spread in a thin, even bed on a stationary or moving grate. The flame over the grate radiates heat back to the fuel to aid combustion. The combustion area of the furnace is lined with heat exchange tubes (waterwalls). The spreader stoker makes ash removal easy, is easy to clean, and, has no separate furnace.

In general, combustion of standard fossil fuels in commercial and industrial boilers results in the following emissions, CO_2, N_2, O_2, H_2O, CO, NO_x, SO_2, volatile organic compounds, and particulate matter [15]. The latter five products of combustion are considered pollutants and are known to, either directly or indirectly, cause harmful effects on humans and the environment. In case of bagasse-fired boilers, the pollutants emitted are CO_2, CO, TSP, SO_x, and NO_x of which the latter two products are emitted in small amount [16]. Emissions of SO_2 and NO_x are lower than conventional fossil fuels due to the characteristically low levels of sulphur and nitrogen associated with bagasse. However, if auxiliary fuels are used during startup of the boiler or when the moisture content of the bagasse is too high to support combustion, then SO2 and NO_x emissions will increase [10].

This study will evaluate whether bagasse is an environmentally friendly and sustainable energy resource by using “Life Cycle Assessment” (LCA), an environmental management system (EMS) tool which concerns the environmental effects of a product processing from cradle to the grave or since raw material extraction until disposal including all services during the processe

Methodology

Study site

• Sugar Factory

The Ratchasima Sugar Factory is located in Nakorn-Ratchasima province, Thailand. The factory has been in operation for 10 years. The mill capacity is 30,000 tons of sugarcane per day every day during the crushing season December to May). Total sugar processing capacity is 172,000 tons per year (approx. 180 days). Bagasse, the waste from the sugar processes, is used for power generation.

- Power Plant

The power plant is of cogeneration type with 2 water-tube boilers (each of capacity 300 ton/hour) and 2 steam turbines (each of capacity 15 MW). The power plant stores bagasse from the milling process for utilization in power processes appropriate for 8 months and for the remaining 4 months, other residues (i.e. rice husks and wood waste) are purchased from elsewhere to generate electricity. The power plant generally operates at approximately 25.5 MW, utilizing 17.5 MW for the sugar factory and power plant itself and selling the excess 8 MW to the grid under the Small Power Producers (SPPs) scheme. Figure 1 shows the flow diagram of the power plant.

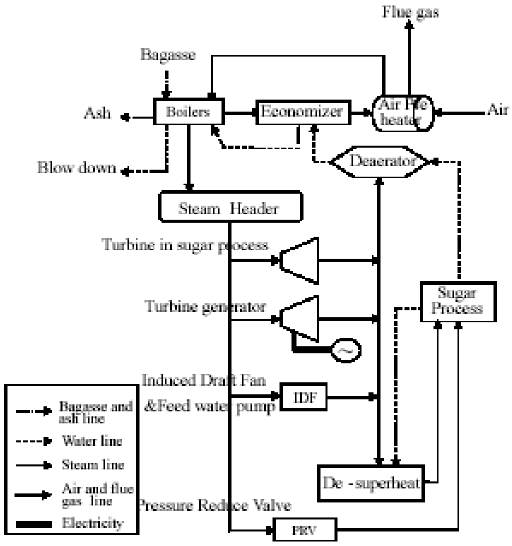

Fig. 1 Ratchasima Sugar Factory's power plant.

Demineralized water is used in the boilers at start-up and condensate water from sugar processes is reused thereafter. Therefore, water consumption for this power plant is closed-loop, recycling water. Normally, the factory has to make up water less than one time per year. Steam generated in the boilers is used in the sugar processes and steam turbines. Heat from the flue gas is utilized in air-preheater and economizer. A multi-cyclone collects dust and ash from the final flue gas before releasing it from the stack. Bottom and fly ash from the combustion are dumped on land. Wastewater from the power plant is only the blow down water, which is about 5% of feed water, sent to wastewater pond. Oxidation pond is used to manage all the wastewater of the factory.

Research Procedures

The LCA methodology comprises 4 stages: Goal & Scope definition, Inventory analysis, Impact assessment and Interpretation. The procedure for conducting the study is shown in Figure 2.

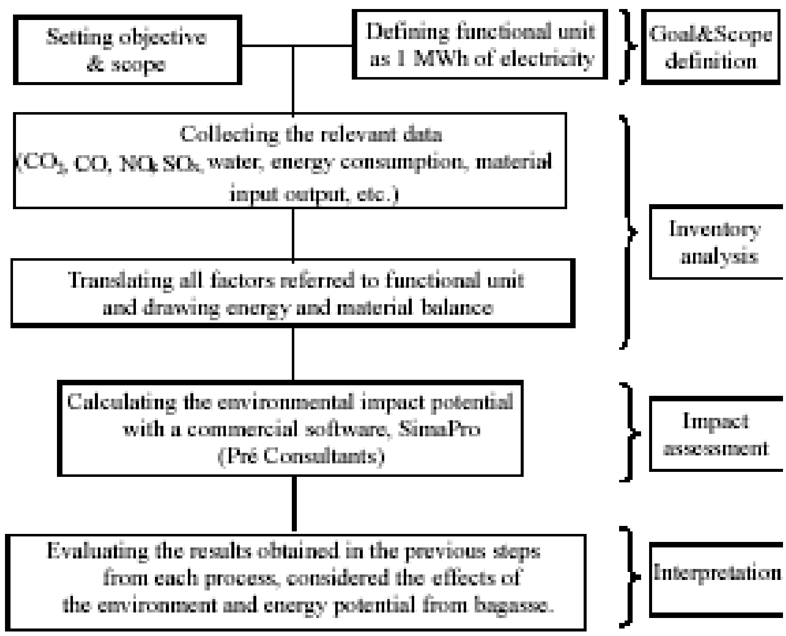

Fig. 2 Methodology of the study.

- Goal & Scope definition

The study analyzed the environmental impact potentials of energy production from bagasse in a sugar factory's power plant. The functional unit, which quantifies the function of the product (electricity) used for normalizing the data in the inventory and impact assessment steps, is defined as 1 MWh of electricity.

- Inventory analysis

In this step, the relevant data from the power plant was collected either from daily reports of the power plant or experimental analysis. The relevant data consist of all of materials consumed and emissions to the environment. Table 2 shows the data collection methods for this study. Energy, water and material balances were drawn in this step which are useful to account for all the energy and material flows in the system.

- Impact assessment

The commercial software, SimaPro 5.0, was used for the impact assessment. The environment profiles of interest are global warming, acidification, photochemical ozone formation, nutrient enrichment and solid waste to be landfilled. The environmental impacts of the conventional power plants in Thailand have been considered as a baseline for evaluating the environmental friendliness of the bagasse power plant.

- Interpretation

Finally, useful results from the inventory analysis and impact assessment steps were analyzed according to the goal and scope of the study. Recommendations have been made for improvement of the bagasse power plant.

Table 2 Data collection methods

Data requirement	Collection Method
• Power generation system of the study site	• Daily report
• Material (bagasse and water) consumption	• Daily report
• Energy and electricity generated	• Daily report and analysis
• Waste generated	
- Gas emissions[1]	• USEPA method[3]
- Wastewater	• Daily report
- Solid waste	• Daily report
• Characteristics of fuel (bagasse) and solid waste(ash)[2]	
- Proximate analysis	• Bomb calorimeter and oven[4]
- Ultimate analysis	• CHONS analyzer[5]
• Water, wastewater, and flue gas management	• Daily report
• Chemical, steel, and lubricant oil utilization	• Daily report

Note :

[1] Emissions measurement was done by CMS technology on January 23, 2004. The values obtained represent the average values of the operation.

[2] Each sample has been analyzed in triplicate.

[3] *USEPA Method 5* uses isokinetic and gravimetric methods to determine particulate matter (TSP). In addition, this method obtains the CO_2 intensity which is one of the parameters. *USEPA Method 6* uses midget impingers and titrimetric methods to determine sulphur dioxide (SO_2).

USEPA Method 7 uses absorbing solution in 2 L vacuum flask and spectrophotometry methods to determine nitrogen dioxide (NO_2).

USEPA Method 10 uses tedlar sampling bag and non-dispersive infrared (NDIR) detection method to determine carbon monoxide (CO).

[4] *Bomb Calorimeter* : LECO : AC-350 model, USA *Oven* : MAMERT, USA

[5] *CHONS analyzer* : Thermo Finnigan : FLASH EA 1112 SERIES model, Italy

Results

The results of this study are shown in 3 stages; inventory analysis, impact assessment and interpretation to achieve the goal of the study.

Inventory analysis

The relevant data for power plant operation have been collected from the daily report, by calculation, and direct measurements. On average, 258.60 ton/h of bagasse are combusted to produce 600 ton/h of steam at 400°C. The energy flows of the overall power plant are shown in Figure 3. Energy input and output are 1,788.95 GJ/h and 1,446.83 GJ/h, respectively, and electricity generated is 24.88 MWh per hour. The data were measured hourly and the values averaged over 1 day. The heating value of bagasse was measured to be 7.5 MJ/kg at a moistur content of about 50%. The energy calculations revealed that boiler efficiency of this power plant is 87.13%, steam turbine efficiency works out to 43.23% and cogeneration power plant efficiency is 42.72%. The energy balance reveals an energy loss of 234.40 GJ/h. This is due to energy loss with flue gas, blow down water, radiation, ash and others. Flue gas contributes 185.59 GJ/h or 79.17% of the total loss. This result indicates that the flue gas could be used for drying bagasse which would improve the efficiency of the power plant.

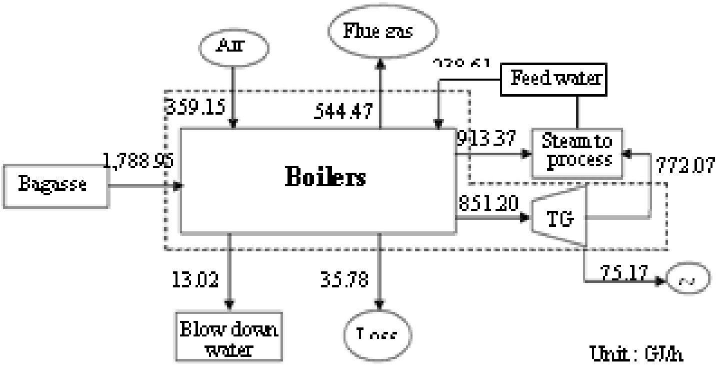

Fig. 3 Energy balance of the power plant.

Table 3 shows the emissions data collected during 5 hours in normal operation condition. Multiple samples were collected for the analysis. The data are assumed to represent emissions from the normal condition of power plant.

Table 3 Emission of gases per MWh of electricity production

Parameter	Average amount	kg/MWh
CO_2	13.8% by volume	7,264.21
CO	1,526 mg/m^3	44.64
SO_2	11.3 mg/m^3	0.33
NO_2	91.57 mg/m^3	2.68
TSP	1,006.29 mg/m^3	29.43

The emissions intensity of conventional power plants in Thailand is shown in Table 4 [17]. The emissions intensity report came from the combustion emission of coal, oil and natural gas power plants in Thailand. In addition, the weighted average of coal (23.56%), oil (0.02 %) and gas (76.42%) fired power plants are shown for comparison with the emissions from the bagasse power plant. However, conventional power plants have an advanced technology which the biomass power plant still lacks. For example, NO_X and SO_X removal, grinding and drying process before feeding to the chamber is attached in conventional power plants.

Table 4 Emission intensities of each substance from power stations in Thailand in fiscal year 2001 [17]

Parameter	Coal	Oil	Gas	Combined
CO_2	1,269.52	812.61	568.88	733.98
CO	0.197	0.27	0.197	0.197
SO_2	2.77	1.28	0.0003	0.65
NO_2	5.84	2.86	1.36	2.42
TSP	0.037	0.927	0.036	0.036

Note : Combined - Weighted average of coal, oil, and gas-fired power

From Table 3 and 4 it can be seen that CO_2 emissions from bagasse power generation are higher than fossil-based power generation. But CO_2 generated from combustion of bagasse is part of the natural carbon cycle and thus does not contribute to global warmin CO emission is mostly due to incomplete combustion due to high moisture content (50%) and dense packing of bagasse which hinders the burning. On the other hand, fossil fuels normally have low moisture and can be powdered which is good for the combustion. One solution of this problem might be drying bagasse before burning.

NO_2 and SO_2 from bagasse power plant are less than coal and oil power plants even though conventional power plant use NO_x and SO_x removal. Due to the small nitrogen and sulphur content in bagasse and lower combustion temperature of bagasse power plant, less NO_2 and SO_2 is produced.

Total Suspended Particulate (TSP) is formed by turbulent movement in the chamber and due to some particulate matter or soil from sugarcane. In this power plant, only multi-cyclone is used unlike fossil-based power plants which have more sophisticated dust control such as electrostatic precipitators (ESP) and bag filters.

The other options that were considered in this study are material and chemical usage in the power plant facilities, such as lubrication oil for gears, chemical utilized in water and wastewater treatment and steel usage for equipment in the power plant. Since life time of power plant's facilities is very long, the effects from them was small based on the functional unit of 1 MWh electricity production as shown in Table 5.

All the relevant data from the inventory analysis step have been used to calculate the potential environmental impacts in the next step.

Table 5 Mass of facilities per MWh of electricity production in the bagasse power plant

Facility	Unit	Amount	Unit/MWh
Fossil fuel utilization			
Lubrication oil	Liter	12,800 per 2 years	0.03
Save valve oil	Liter	5,000 per year	0.01
Chemical utilization			
$Al_2(SO_4)_3$	kg	45 per year	$4.0x10^{-4}$
NaOH	kg	7,920 per year	0.04
HCl	kg	820 per year	$2.7x10^{-3}$
$Ca(OH)_2$	kg	15 per month	$1.5x10^{-3}$
Steel parts			
Total weight	kg	1,242,084 per 30 years	0.21

Impact assessment

This study covers the impact categories having significant environmental influence in Thailand, i.e. global warming (GW), acidification (AC), photochemical ozone formation (PO), nutrient enrichment (NE), and solid waste to be landfilled (SL). Environmental impact potentials were calculated by SimaPro 5.0 software using Environmental Design of Industrial Products (EDIP) as the impact assessment method. The relevant data from inventory analysis was used for impact assessment while some of background data of materials production is from European databases provided in the software.

Table 6 shows the impact potentials of power plants fuelled by various feedstocks. It shows that coal fired power plants contribute maximum to global warming whereas bagasse is the least contributor to GW. Acidification could be reduced via using bagasse as energy source. Nevertheless, CO is one such of contributor for photochemical ozone formation so even though the NO_2 is less but CO is high which affects the photochemical ozone formation.

Due to low nitrogen and sulphur content, waste from bagasse power plant do not contribute to NE. Since the data of solid waste from conventional power plant is not available, the impact category SL could not be compared.

Table 6 Impacts potential of bagasse power plant and conventional power plants per MWh of electricity production

Fuel / Category	Bagasse	Coal	Oil	Gas	Combined
GW	89.28	**1,269.91**	813.15	569.27	734.36
AD	2.21	**6.86**	3.28	0.95	2.34
PO	**1.79**	0.008	0.011	0.008	0.006
NE	3.62	**7.88**	3.86	1.84	3.27
SL	783	na.	na.	na.	na.

Note: na.= not available

Interpretation

According to the results from the previous sections it is evident that bagasse as energy source is friendly to global environment but affects local environment adversely. GW, AC and NE are lesser from bagasse power plant than conventional power plant while PO is higher. Incomplete combustion process and high moisture content of bagasse result in high CO emission. Also, TSP from bagasse power plant is high due to turbulent movement in the chamber during combustion process and soil or particulate matter from sugarcane. Tables 7 and 8 summarize the interpretation and environmental problems of the bagasse power plant. The problem of high TSP emission can be addressed by installing dust control equipment such as ESP or bag filter in addition to the existing multi-cyclone. CO emissions might be reduced by pre-drying the bagasse using waste heat from the flue gas and also by improving the operation control. Thus, bagasse could become a sustainable and benign energy source for Thailand.

Table 7 Interpretation summary of bagasse power plant

Category	Effect to environment	Reasons
Global warming (GW)	+	CO_2 emission is a part of the global carbon cycle.
Photochemical ozone formation (PO)	-	High CO emission due to high moisture content and lack of adequate operation control.
Acidification (AC)	+	Low SO_2 and NO_2 emissions.
Nutrient enrichment (NE)	+	Low N as NO_2 emission to air and wastewater and ash do not have any N and P
Solid waste to be landfilled (SL)	+	It is good for waste management in sugar industry to utilize bagasse rather than dumping to landfill.

Table 8 Problems from power generation using bagasse

Problems	Effect to environment	Reasons
High CO emission	-	Incomplete combustion because of the varying moisture content of bagasse and inadequate operation control.
High TSP emission	-	Turbulent movement of gases during bagasse combustion and not sufficient flue gas treatment.

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