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Specific Energy Consumption of Sugar Cane Mills in Thailand

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According to Thai Energy Efficiency Plan (EEP 2015), the government has set the target of 30 % reduction in 2036 compared to the total energy consumption in 2010. The industry sector accounts for approximately 37 % of the total energy consumption. Thai industries have been classified into 11 main sectors, in which food, beverage and tobacco sector is the most energy-consumed sector which consume about 35.7 % of the total energy consumption. Among industries in the food, beverage and tobacco sector, sugar mill industry is the most second energy-consumed industry. Thus, the rational amount of energy saving target will be assigned to the sugar mill industry, for which their baseline energy consumption and their potential energy saving should be known. In this paper, 25 of 55 sugar mills are carefully investigated and audited to determine baseline energy consumption (BEC) and specific energy consumption (SEC) based on plant performance. Factors that effect on BEC and SEC are identified. Equations for predicting baseline BEC and SEC are developed using statistic regression approaches. It is found that the sugar mills can be classified into two groups, i.e. one with own power plant and one without power plant. They are totally different in BEC and SEC. The characteristic of energy consumption within a sugar mill itself is also different between juice extraction season and the others. The regression equations for predicted baseline BEC and SEC are developed based on known factors.

1. Introduction

Energy Efficiency Plan (EEP 2015) (Energy Policy and Planning Office, 2017) is the energy master plan of Thai government. The goal is to reduce energy intensity by 30 % in 2036, compared to 2010, or equal to 56,142 ktoe of final energy consumption. One measure to achieve the EEP 2015 target is the study of energy performance index for each industry sector, i.e., Baseline Energy Consumption (BEC) and Specific Energy Consumption Index (SEC), to support the promotion and regulation of energy efficiency activities. Currently, 5,285 high energy intensive factories consume approximately 21,430 ktoe of final energy consumption and expectedly increase to 11,300 factories with 41,600 ktoe in 2036 (Energy Policy and Planning Office, 2017). The high energy intensive factories will be enforced to meet the stringent energy standards based on either BEC or SEC. The penalty will be charged to those who do not meet the standard.
The existing BEC and/or SEC for an industry sector is usually represented as an average or constant value which is not fair for industries with different production capacities and technologies. The relationship between the BEC and/or SEC and corresponding factors should be developed to obtain a rational value with the actual production conditions and technologies instead of using a constant or average value. Tthis paper presents BEC and SEC correlations for the sugar mill industries based on statistic regression approaches.

2. Industrial background and basic concepts

According to Thailand Energy Efficiency Situation 2013, which is conducted by the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy has reported the energy consumption in the industry sector for approximately 37 % of the total final commercial energy consumption. Thailand industries have been classified into 11 main sectors, food and beverages, textiles, wood and furniture, paper, chemical, non-metallic, basic metal, fabricated metal, stone and mining, power plant and others (unclassified). The food,

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beverage and tobacco sector is the most energy-consumed sector, approximately 35.7 % of industry sector consumption. Sugar mill industry is the most energy-consumed industry subsector which consumes almost 29 % of the food, beverage and tobacco sector.

2.1 Production and energy consumption model of sugar mills

Sugar is a seasonal production which can be defined as the juice extraction season and the melt or non-extraction season. The juice extraction season always begins approximately between November and March which is sugar cane harvesting season. In this period the factories will produce raw sugar as much as they can. When the harvesting season ends, the raw sugar is refined to white sugar, so-called the melt or non-extraction season. There are significant differences in energy consumption between both seasons as shown in Figure 1.

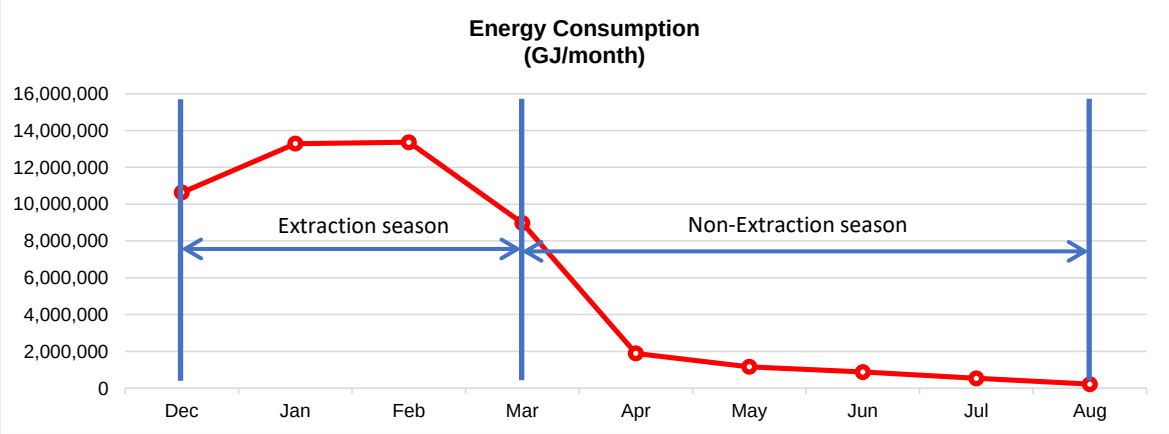
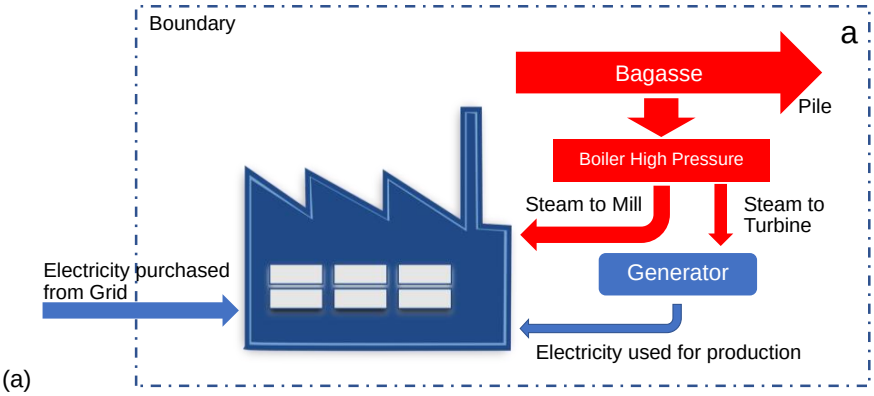


Figure 1: *The energy consumption of sugar plant in extraction and non-extraction season*



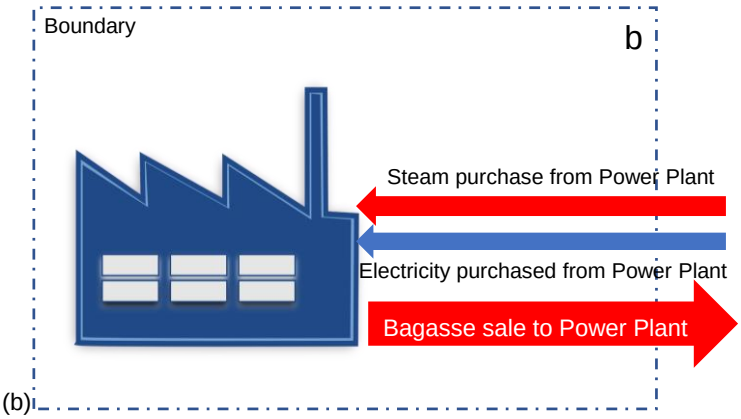


Figure 2: *Analysis boundary of the sugar mill; a) with own power plant and b) without power plant*

The sugar mill demands a huge amount of energy for sugar production, especially heat. Heat is a primary energy that is used for several processes including sugarcane trunk from sugarcane, making sugar cane juice, boiling juice and crystallization until sugar. Currently, there are 55 sugarcane factories operating sugar canes in Thailand, according to the report of the Office of Sugarcane and Sugar Board.

In this paper, 25 of 55 sugar mills are carefully investigated and audited to determine baseline energy consumption (BEC) and specific energy consumption (SEC) based on plant performance (Birru, 2016; Merkl, 2017). Which can be classified into two groups, i.e. one with own power plant (13 of 25) shown in Figure 2a and one without power plant (12 of 25) shown in Figure 2b. Both of them use two types of energy: heat and electricity. Considering that, the source of all energy in sugar mill with own power plant is the steam produced from their own boilers using bagasse and some purchases from electricity when not enough. This steam energy is divided into two parts, the first part is used in the steam as heat energy, which is in the form of steam and hot water. The steam energy is used in the production process from cane crushing using the sugar cane preparation stage before the container is chopped, the sugar cane is clarified by using steam from the heat exchanger and boil syrup. The second part is used for power generation. Steam is used to drive turbines and power generators into production or sales processes. Therefore, the proportion of energy is divided into 3 parts: electricity purchased from Grid 0.39 %, the steam power used in the production of electricity for production 36.43 % and steam power used in the production process 63.18 %, shown in Figure 3a.

While, the source of both energy, heat and electricity, in sugar mill without power plant is clearly separated by the purchase of heat energy in the form of steam and electricity from the power plant (Pippo and Luengo, 2013). The proportion of energy is divided into two parts: electricity 5.62 % and steam 94.38 % in Figure 3b.

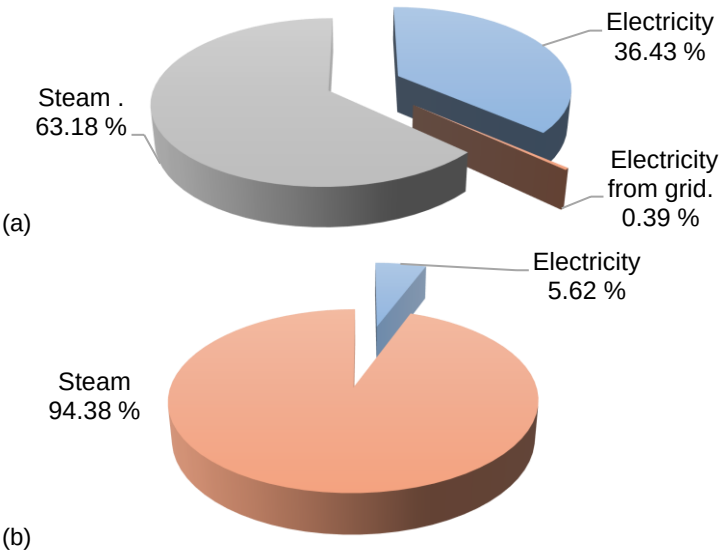


Figure 3: *Energy consumption of sugar mill; a) with own power plant and b) without power plant*

2.2 Preparation concept

Baseline Energy Consumption (BEC) is the amount of energy that should be consumed over the same period or same production volume. While, Specific Energy Consumption (SEC) is the ratio between the amount of energy and production quantity, which indicates the amount of energy required to produce one unit of product. In addition, the evaluation boundary is also important. In this case, both BEC and SEC are based on plant performance. They will be developed in the form of correlation equations with influenced factors instead of using an average or constant value. Energy consumption of sugar mill is difference depend on seasons. Therefore, BEC and SEC are developed for specific season. There are steps to be taken as follows:

- Factory and measurement data are analysed using concept of mass and energy balance to indicate potential independent variables that effects on BEC and SEC. Variables should be ones that are collected on a regular basis.
- Determine independent and dependent variables. In this case, SEC and BEC are dependent variables. Potential independent variables are shown in Table 1.

- Correlation analysis examines the correlation among variables by which independent variables are truly independent and not collinearity or multi-collinearity among them. Independent variables selection shown in Table 2.
- Determine the relationship between independent and dependent variables that could be either linear or nonlinear.
- Using a static tool to determine appropriate BEC and SEC regression equations.

Table 1: *Independent variables*

Variable	Description	Unit
x_1	The fraction of electricity sold compared to total electricity production	kWh/kWh/season
x_2	The fraction of sugar cane input to installed capacity by mass	t/t/season
x_3	Average sugar production per hour	t/h/season
x_4	Sugar yield per tonne per season	t of sugar/t of cane/season
x_5	Raw sugar production per season	t/season
x_6	White sugar and refine white sugar production	t/season
x_7	The fraction of electrical power consumption compared to steam consumption	GJ/GJ/season

Table 2: *Selected independent variable*

Variable	Description	Unit
x_1	The fraction of electricity sold compared to total electricity production	kWh/kWh/season
x_2	The fraction of sugar cane input to installed capacity by mass	t/t/season
x_3	Average sugar production per hour	tons/hour/season
x_7	The fraction of electrical power consumption compared to steam consumption	GJ/GJ/season

3. BEC and SEC regression equations

Finally, there are eight equations for two types of the sugar mill based on energy sources, i.e., one with own power plant and one without own power plant. Each of them will be divided into juice extraction season and non-extraction season. The equations for sugar cane mills with own power plant are as follows:
Juice extraction season;

$$BEC = 192{,}671.510 + 43{,}279.532\,x_3, \qquad R^2 = 0.740 \tag{1}$$

$$SEC = -146.442 + 1.297x_1 + 1.431x_2 + 2.924x_3 - 0.00031x_1x_2x_3 - 0.026x_1^2 + 0.000135x_2^2 - 0.007x_3^2 \tag{2}$$

$$R^2 = 0.949$$

Non-extraction season;

$$BEC = 4{,}297{,}731.45 - 120.44x_1 - 284{,}688.17x_3 + 3{,}537.05x_1x_3 - 901.37x_1^2 + 2{,}116.70\,x_3^2\,, \quad R^2 = 0.990 \tag{3}$$

$$SEC = 81.760 + 0.796x_1 + -5.054x_3 + 0.08446x_1x_3 + -0.031x_1^2 + 0.004809x_3^2\,, \quad R^2 = 0.890 \tag{4}$$

The equations for sugar cane mills without own power plant are as follows:
Juice extraction season;

$$BEC = 944{,}939.448 + 26{,}508.163x_3\,, \qquad R^2 = 0.760 \tag{5}$$

$$SEC = 89.833 - 1.468x_2 + 0.085x_3 - 1{,}056.518x_7 - 0.019x_2x_3x_7 + 0.012x_2^2 - 0.000090x_3^2 + 8{,}353.778x_7^2, \qquad R^2 = 0.948 \tag{6}$$

Non-extraction season;

$$BEC = 24{,}853{,}148.348 - 90{,}849.491x_3 - 831{,}740{,}428.121x_7 + 3{,}389{,}141.656x_3x_7 - 756.388x_3^2 + 6{,}338{,}708{,}287.370x_7^2\,, \qquad R^2 = 0.786 \tag{7}$$

$$SEC = 159.781 - 0.303x_3 - 5{,}130.529x_7 + 20.968x_3x_7 - 0.012x_3^2 + 38{,}139.774x_7^2, \qquad R^2 = 0.790 \qquad (8)$$

The comparisons between actual and predicted values are shown in Figure 5 and Figure 6. They are mostly within the range of ±10 %.

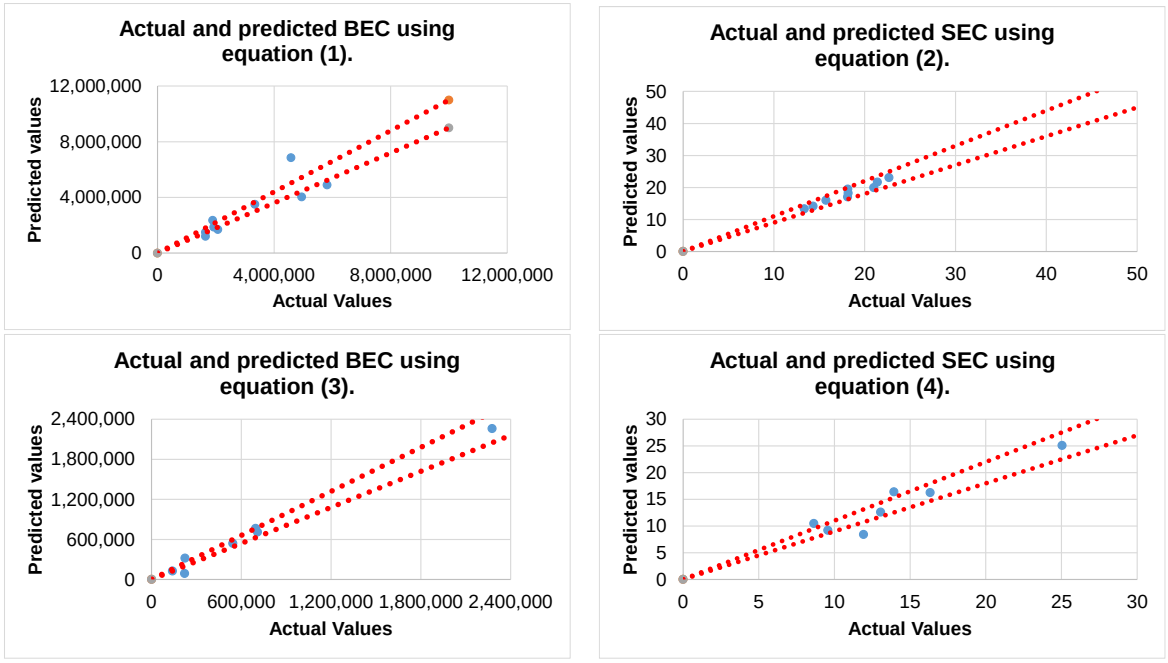


Figure 5: *Comparisons of actual and predicted BEC and SEC for sugar mills with own power plant using a) equation (1); b) equation (2); c) equation (3); and d) equation (4)*

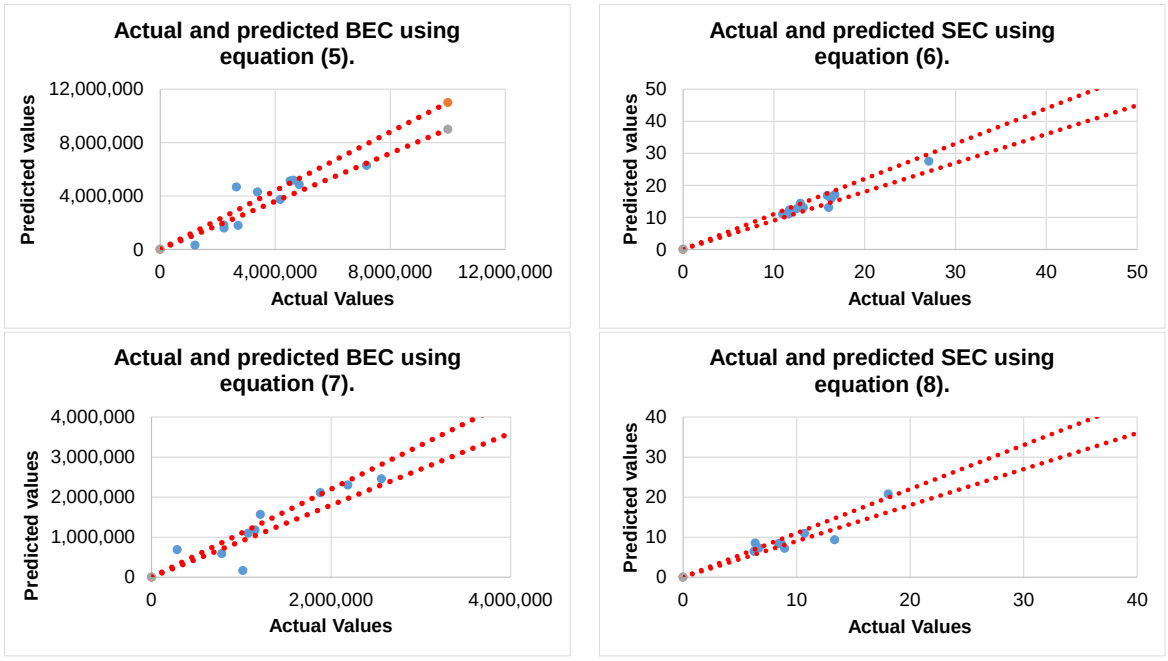


Figure 6: *Comparisons of actual and predicted BEC and SEC for sugar mills without own power plant using a) equation (5); b) equation (6); c) equation (7); and d) equation (8)*

4. Conclusions

The sugar mill industry is the most energy-consumed industry subsector which consumes almost 29 % of the food, beverage and tobacco sector. The sugar mill industry is one of target subsectors to promote and regulate energy efficiency measures to achieve the EEP 2015 target. Processes to produce granulated sugar includes juice extraction, clarification process, preheat and evaporation, syrup treatment, crystallization, centrifugalization and drying. Each process consumes a huge amount of both thermal and electrical energy, especially the juice extraction. However, the juice extraction process does not operate in non-extraction season, so that, the energy consumption is significantly less than extraction season. In this paper, the sugar mill is classified into two types based on its energy source. One is the sugar mill with its own power plant by which steam and electric will be generated using their bagasse. The other is the sugar mill without its own power plant. In this case steam and electric will be purchased from nearby utility suppliers.

Regression equations to determine BEC and SEC are developed for sugar cane mills in Thailand. They can be further used as benchmarks for energy consumption in this sector. Data for analysis and regression are gathered and measured from 25 of 55 sugar mills. The sugar cane mills are divided into two groups, which are one with own power plant and one without own power plant. They are further separated to juice extraction season and non-extraction season. BEC and SEC equations are developed for each of them. The results show that the equation can predict the value within acceptable tolerances. BEC and SEC depend on 4 variables, i.e., the fraction of electricity sold compared to total electricity production, the fraction of sugar cane input to installed capacity by mass, average sugar production per hour, and the fraction of electrical power consumption compared to steam consumption. For each particular year, data for each variable are gathered and substituted into the equations to calculate BEC and SEC that will be used as benchmarking. They will be compared with the actual BEC and SEC of the same year to determine whether the energy usage is effective or not. Even though there were studies using the same approach to obtain the BEC/SEC regression models, this study focuses on the whole plant performance instead of equipment, systems or product performance. Hence, they can be easily implemented and convenient for those involved.

Acknowledgments

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