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Performance Assessment and Optimization of Biomass Steam Turbine Power Plants by Data Envelopment Analysis

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ABSTRACT

As rice husk is abundantly natural resource in Thailand, it has been used as the biomass energy resource in the stream turbine power plants, in particular to very small power producers (VSPPs). The VSPPs' plants produced by rice husk is generally found in many regions of Thailand, however its performance efficiency and optimization has never been assessed at any level. This study aimed to fulfill this gap by adopting the method of data envelopment analysis (DEA) to relatively measure the performance efficiency of the decision making units, as well as to adjust input surpluses found in order to maximize the overall efficiency scores. The secondary data recorded in 2012 were collected from the power policy bureau of Thailand and Energy for Environment Foundation, totally 47 rice husk steam turbine power plants. The empirical results showed that a constant return to scale-DEA and variable return to scale-DEA model performed efficiency scores at 0.874 and 0.882, respectively. The input surpluses of capacity and purchasing cost of rice husk were emphasized to increase its unit efficiency. Achieving the Thai government's aim of sustainable, renewable energy would boost up many utility plants to use rice husk for electricity generation in the nearer future.

Keywords: Biomass, Data Envelopment Analysis, Stream Turbine
JEL Classifications: Q420, M110

1. INTRODUCTION

In 2001, the Thai government initiated the very small power producers (VSPP) program that mostly generates electricity from renewable energy materials. Previously, the capacity of a VSPP plant was ≤1 megawatt (MW). However, the Electrical Generating Authority of Thailand (EGAT) expanded the VSPP capacity to 10 MW in 2006. Notably, the VSPP plants are less complex than large scale fossil fuel power plants. To encourage investment in VSPP, a reasonable rate of return is guaranteed by EGAT's net metering calculation method. Furthermore, the Thai government has supported the additional production subsidies to the VSPPs that mainly generate electricity from the rice husk renewable source (DEDE, 2012).

Driven by technology and the increasing cost of fossil fuels, renewable energy for power generation includes solar energy, wind energy, hydropower, waste energy (municipal solid waste), biogas, and biomass. Currently, most biomass is primarily converted into liquid fuels. In totality, biomass includes sugarcane leaves, bagasse, rice straw, rice husk, etc. Using biomass for electrical generation has increased, but has varied by region, dependent on the source, availability and volume of material and associated costs.

Biomass power plants, such as rice husk power plants, offer three main advantages over traditional fossil fueled plants:

1. Economic, by reducing energy import values (about 460,000 million Thai Baht in 2022), encouraging more private power production investment (about 382,240 million Thai Baht per year), providing more job opportunities (about 40,000 job positions), and reducing the government's fossil fuel plants investment (about 100,000 million Thai Baht)
2. Societal, by discouraging labor migration from rural to urban areas and by increasing farmer's incomes

3. Environmental, by reducing pollution emissions and promoting the development of a low carbon society (Ueasin et al., 2012).

Since the rice husk VSPPs generated have been playing an increasingly important role in the Thai energy industry each year, it has become necessary to measure the technical efficiency of rice husk power generation. Hence the gestation of this this study which is intended to measure the technical efficiency of rice husk power generation throughout Thailand using the concepts of data envelopment analysis (DEA).

2. LITERATURE REVIEW

Regarding studies on renewable energy efficiency, there have been several researches focusing on energy efficiency and renewable energy such as Wongchai et al. (2012) who conducted an efficiency assessment of Thai energy industries by adopting the rational two-stage DEA with 24 energy companies. Cross section data were obtained from the stock exchange of Thailand in 2010. The empirical results showed that the average score of 0.7592 for production acquisitions was higher than the average score of 0.3376 for profit earning, implying that the inefficiency in the whole process was caused by the profit earning process.

Later, Liu et al. (2011) conducted a productive performance analysis of Taiwan's energy companies by using the DEA Malmquist index. The DEA Malmquist index is a distinguished research method employed to measure productivity change over time. Panel data were collected from Taiwan's Stock Exchange Market recorded from 2008 to 2011. The average technical efficiency score was relatively high at 0.938. Moreover, the trend in productivity change regressed due to the lack of technological improvement.

Likewise, Houston et al. (2014) evaluated energy efficiency and renewable energy generation opportunities for small scale dairy farms in Prince Edward Island, Canada. They found that the energy efficiency and renewable generation opportunities have been exciting in the studied area. Moreover, the entire energy need can be fulfilled by installing an anaerobic digester and a 25 kW wind turbine.

Jablonski and Tarhini (2013) assessed the selected energy efficiency and renewable energy investment in Mediterranean partner countries (MPCs) over 2011-2020. The main results showed that the MPCs need to accelerate the development process in order to achieve their national targets. Furthermore, significant investment costs and subsidies need to be fully supported for the deployment of energy efficiency and renewable efficiency investments to reach the envisaged 2020 targets.

Rausch and Mowers (2014) examined the efficiency and distribution impacts of clean and renewable energy standards for electricity in America. The empirical results showed that electricity standards are 2-4 times more costly than a market-based carbon pricing policy. Its trends are more regressive and can produce uneven regional impacts. In addition, there is no revenue that can be utilized to adjust an unintended distributional consequence.

Ueasin and Wongchai (2014) assessed the operating efficiency scores of registered energy companies in the Taiwan Stock Exchange recorded during 2003-2012. The empirical results showed that seven decision making units (DMUs) performed efficiently, ranking from 7.29 to 1.02. The company with the best operating performance was Taiwan Cogeneration Corporation, while the Great Taipei Gas Corporation revealed the worst efficiency score. Furthermore, the Tobit regression model explained that the higher number of local employees, the greater were the efficiency scores and the lower the number of shareholders, the greater were the efficiency scores.

Unfortunately, there is no research that studies the efficiency measurement of rice husk biomass power plants of the VSPPs at either national or international levels. Therefore, the purpose of this research is to assess the technical efficiency of VSPPs throughout Thailand. The research scope is limited to only the power plants that use rice husk for the main biomass in the process of electricity generation.

3. MATERIALS AND METHODS

3.1. Data Collection

The secondary data were collected from the power policy bureau, the energy policy and planning office, at the Ministry of Energy, Thailand recorded in 2012 and Energy for Environment Foundation recorded in the same year. The type of information was cross-sectional data. Theoretically, the capacity of VSPPs is considered as ≤10 MW. The VSPPs have always generated electricity by using rice husk as the main biomass material. Therefore, in this study, there were a total of 47 DMUs located throughout the country in 2012. Notably, almost steam turbine VSPP statistics are from the metropolitan electricity authority and the provincial electricity authority of Thailand.

3.2. Output Produced and Inputs Used

Generally, there are two sides in the production process of electricity generation. The left side denotes the production factors that can be used to generate electricity, while the right side represents the quantity of output for power producers. This study considers 1 output and 2 inputs that are related to the power production process. Notably, this study limited the capacity of steam turbine power plants more than 110 MW.

For output, a sales contract for VSPPs is a legal contract that outlines the rules, regulations, and obligations for the buyer and sellers during an electricity-transaction. The volume of electricity supplied on the sales contract is always shown in MW. The power production inputs consisted of two productive factors: the different sizes of capacity and the purchasing cost of rice husk. The capacity is the total amount of electricity that each VSPP can produce, normally, measured in KW. Electrical production capacity in terms of management refers to the maximum possible output of a system.

3.3. Analytical Approaches

DEA is defined as a non-parametric method that is exclusively applied to measure the efficiency scores of a DMU or firm/unit (Charnes et al., 1978). Later, Charnes et al. (1981) used a linear programming approach to transform the quantity of inputs used and the quantity of outputs produced into an efficiency score. This distinctive method is an un-functional conceptual model that has the ability to deal with multi-inputs and multi-outputs. Furthermore, the DEA is assumed to be a function of the frontier to measure the relative performance of a firm/unit towards the benchmark production frontier.

An efficiency value derived from the DEA model has to range from 0.00 to 1.00. The maximum score (1.00) represents the highest efficiency while scores of 0.00-0.99 show a firm's inefficiency, indicating the relative displacement from the frontier (Wongchai et al., 2011). The two-ways to consider efficiency are output-oriented and input-oriented approaches. Output orientation is the way to produce a greater quantity of output with a given number of inputs. On the other hand, input orientation is the way to use lower levels of input with a given quantity of output (Wongchai et al., 2012).

Since the VSPP firms try to minimize the quantity of inputs used for the given output level, this study chose only the concept of input-orientation with two aspects, constant return to scale (CRS) and variable return to scale (VRS) in order to compare the efficiency scores derived from both approaches.

Firstly, a description of the input-orientated CRS model is discussed at this stage because it is considerably utilized in several researches. For example, Cook and Bala (2007) studied performance measurement and the classification of data in an input-oriented DEA model. Wei et al. (2011) researched developing an input-oriented ratio-based comparative efficiency model. Liu et al. (2011) conducted a study of input-oriented CRS-DEA models without explicit inputs.

The linear programming program is conducted to derive an equivalent envelopment form of the CRS-DEA model as shown in equation 1.

$$\text{Min}_{\theta,\lambda}\,\theta$$

Subject to $-y_i + y\lambda \geq 0$

$$\theta x_i - x\lambda \geq 0$$

$$\lambda \geq 0, \qquad (1)$$

Where θ depicts a scalar;

λ depicts a $I \times 1$ vector of constants;

y_i depicts the quantity of outputs of the i^{th} firm;

x_i depicts the quantity of inputs of the i^{th} firm.

Notably, the efficiency score for the i^{th} firm can be shown by the obtained value of θ in which conforms θ≤1. The value of 1.00 performs a maximum efficiency score lined on the frontier, indicating a technically efficient firm. Remarkably, the linear programming model is necessary to compute the non-parametric problem *I* times. Each firm/unit needs to be solved for one time. Consequently, the value of θ is obtained in every firm/unit.

Therefore, the production technology function, as associated with the linear programming model referred to in equation (1), can be defined as $T = T\{(x,q) : q \leq \lambda, x \geq X\lambda\}$ (Luh et al., 2008). This technology function defines a production set that is convex and closed. Moreover, its function is a CRS with strong disposability.

Secondly, the definition of input-orientated VRS-DEA model is assumed when not all firms are operating at the optimal scale of a production function due to rules and regulations, imperfect competition, financial conditions, etc. Several researches, for example, Ouellette et al. (2012), Thanassoulis et al. (2012); and Gerdessen and Pascucci (2013) made a suggestion to adjust the input-oriented model from the condition of CRS to VRS.

The VRS-DEA model will be used when not all firms/units produce at the optimal scale. As a result, the calculation of technical efficiency considers none of these scale efficiency effects. Later on, the VRS-DEA model can be easily computed by adding the terms of $I1'\lambda \leq 1$ into equation (1). The VRS-DEA model is used to assess the efficiency in the case of uncompetitive markets. This is the cause of an un-optimal scale for a firm/unit. Moreover, the VRS-DEA model can identify whether the firm/unit has a decreasing return to scale or an increasing return to scale. Therefore, the VRS-DEA model can be written as equation (2).

$$\text{Min}_{\theta,\lambda}\,\theta$$

Subject to $-y_i + y\lambda \geq 0$

$$\theta x_i - x\lambda \geq 0$$

$$I1'\lambda \leq 1$$

$$\Lambda \geq 0, \qquad (2)$$

Where *I*1 displays an $I \times 1$ vector of ones. Notably, the VRS-DEA model curves outwards to envelop the data points more tightly than the CRS-DEA model. The technical efficiency scores obtained by this method are probably equal to or greater than the efficiency scores derived by the CRS-DEA model.

4. RESULTS AND DISCUSSION

The results showed that the average scores for all 47 VSPPs were very high, because the rice husk biomass power plants had a high technical efficiency. The VRS-DEA model is 0.882 and the CRS-DEA model is 0.874 as shown in Table 1.

In the conditions of the CRS-DEA model, there was 5 firms that performed efficiently. The main group (33 firms) was found to be in the range of 0.80-0.89. The maximum score of the CRS-DEA model was 1.000, while the minimum score was 0.707.

Table 1: Descriptive statistics of efficiency scores, categorized by model

Efficiency score	Number of VSPPs (DEA)	
	CRS	VRS
1.00	5	6
0.90-0.99	7	8
0.80-0.89	33	31
0.70-0.79	2	2
<0.70	0	0
Number of VSPPs	47	47
Average efficiency score	0.874	0.882
Maximum efficiency score	1.000	1.000
Minimum efficiency score	0.707	0.707

VSPPs: Very small power producers, CRS: Constant return to scale, VRS: Variable return to scale, DEA: Data envelopment analysis

The VRS-DEA model found that 6 firms performed efficiently. The residual 41 firms functioned inefficiently. The majority of firms (31) were in a range of 0.80-0.89. With this distinguishing method, the maximum efficiency boundary was 1.00, while the minimum efficiency boundary was fairly high at 0.707.

According to the DEA model, the input surplus demonstrates an ability to decrease the quantity of inputs used for VSPPs' electricity generation with a given quantity of output. Table 2 presents the descriptive statistics of an input surplus for capacity and purchasing cost of rice husk. The study found that the ratio of input surpluses for capacity and purchasing cost of rice hush were 0.12 and 5.66, respectively. The average technical inefficiency was caused by the input surpluses of capacity 0.12%, together with the purchasing cost's surplus of rice husk at 5.66%. The findings concluded that if the VSPP's producer tried to decreases these two inputs as equal to the ratio of input surpluses, its average technical efficiency will increase definitely.

To succeeding their sustainable energy aims, the Thai government emphasis on renewable energy use which will increase the economy and the country providing for energy security through the efficient use of sustainable resources. A practical way should be found to launch valuable policies for the rice husk biomass power plants. The Thai government should boost more biomass production from rice husk and emphasis on small scale farmer-cooperate rice mills, especially in rural areas. This approach would not only could diminish the cost of producing electricity for their own use, but could also be environmentally beneficial and increase farmers' incomes.

It would seem that biomass technology and supply chain development are beneficial policies that the government should emphasize in order to decrease production costs and increase the generation capacity in the near future. Since the initial capital investment for generation of rice husk biomass is high, research and development (R and D) is a useful strategy to improve technical efficiency, as well as to sustain renewable electricity for VSPPs. An intensive R and D project could find alternative ways to increase the technical efficiency of rice husk biomass power generation. This R and D should involve cooperation with other energy-related organizations at both national and international levels.

Table 2: Descriptive statistics of the input surplus

Input	Average input surplus (1)	Average input used (2)	Ratio of input surplus $\left[\frac{(1)}{(2)}\right]\times 100$
Capacity (KW)	0.01	8.67	0.12
Purchasing cost of rice husk (Thai Baht)	444,544.68	7,859,981.72	5.66

5. CONCLUSIONS

Thailand has increased electricity demand and has been trying to produce more electricity while encouraging environmental protection, by increasing energy supply reliability and energy sovereignty and by maintaining efficient energy demand management. Consequently, the Thai government has launched a variety of energy policies that aim to encourage sustainable development in electricity consumption and generation by using renewable biomass energy sources.

This study assesses the technical efficiency of the VSPPs that are found in Thailand by using DEA models. These power plants have utilized rice husk as the main raw material in the process of electricity generation. The findings indicated that the technical inefficiency was widely found in the DMUs of VSPPs. The average efficiency scores were in the range of 87-88%, implying that technical efficiency can increase by around 13-12% by reducing input surpluses with the same technology.

The results of input surplus showed insufficient production factors. In order to achieve the maximum scores for technical efficiency, the VSPPs' producers must adjust the production factors by decreasing the capacity by 0.12% on average, as well as reducing the purchasing cost of rice husk by 5.66%. New adjustments in the production factors can surely provide better average technical efficiency score. This technique is called as the input-orientated approach.

Increasing efficiency scores for the VSPPs not only means adjusting the production inputs, but also sustainable development in renewable energy needs to be promoted at all power production plants located throughout the country. An owner of a firm should learn how to manage effectively by making more effort to minimize production cost, to get rid of surplus inputs, to increase output, and to maximize net profit.

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