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Research paper

Business Sustainability Analysis of On-Grid POME-Based Biogas Power Plant; A Resource-Based Theory Approach

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Abstract

The purpose of paper is to estimate the electricity generated from palm oil mill with fresh fruit bunch processing capacity of 45, 60 and 90 ton/h and analyse the business sustainability of grid connected POME-based biogas power plant using resource-based theory (RBT). The process of biogas formation and generation of electricity from palm oil mill effluent (POME) is described. Biogas is formed from anaerobic digestion of POME (organic materials). Biogas mainly consists of 50% to 75% methane (CH_4). Methane (CH_4) has larger impact to the global warming then CO_2. Therefore, the use of methane-capture technology and conversion of CH_4 into electricity will significantly reduce greenhouse gases (GHG) emissions to the environment. Various methods of anaerobic digestion on POME have been studied. However, commercial installations of anaerobic digestion normally use pond and tank systems due to performance and cost consideration. A mathematical method is used to calculate electricity generation potential from the palm oil mills (POMs) based on COD (chemical oxygen demand) of POME and the mill capacity in processing fresh fruit bunch (FFB) per hour. Business sustainability of biogas power plant from POME will depend on the level and durability benefit created from combination of resources against other alternatives. This paper also provides a model for validating sustainability of on-grid POME-based biogas power plant using resource-based theory (RBT). The validation using case studies from operational on-grid POME-based biogas power plant is a subject for future research.

Keywords: *biogas, biogas from pome, electricity from biogas, business sustainability, alternative energy.*

1. Introduction

At present, Indonesia is the largest producer of crude palm oil in the world. The energy value organic wastes produced by palm oil industry has yet been fully utilized. Some palm oil industries have been successful in utilising palm oil mill effluent (POME) to generate on-grid electricity. In 2014, the total production of crude palm oil (CPO) was about 31 million tons and it came from nearly 700 palm oil mills (Statistik Kelapa Sawit, BPS 2014; Zul 2014). Palm oil mills in Indonesia hold a huge of biogas energy potential from POME. While processing the POME (liquid waste) to meet the environment regulations, biogas generated from anaerobic digestion process is potential for generating electricity. If every mill generates in average of 2 MWe, then the total contribution of the 700 palm oil mills for electrification will be 1400 MWe.

Indonesia is a net importer of crude oil and the import will be growing due to more energy demand in the future (Badan Pengkajian dan Penerapan Teknologi, 2016). Contribution of alternative energy form POME-based biogas power plant will help in providing additional energy supply. The electricity generation capacity of POME-based biogas power plant from a certain mill and its sustainability are analysed in this paper.

Biogas mainly consists of methane and the impact of released methane (CH_4) to the global warming is about 21 larger than that of CO_2. Therefore, the use of methane-capture technology and conversion of CH_4 into electricity will significantly reduce greenhouse gases (GHG) emissions to the environment.

2. Literature Review

2.1. Anaerobic Digestion of POME

Biogas mainly consists of methane (50-75%), CO_2 (25-45%) and small amount of other gases such as H_2S (Handbook POME to Biogas). Biogas is produced from anaerobic digestion of organic material, measured as Chemical Oxygen Demand (COD). In the anaerobic digestion process, long-chain organic material is decomposed step by step with the help of bacteria into short-chain organic material in the absence of oxygen and it takes time to produce biogas (Deublein & Steinhauser, 2011). To be able to grow, microorganism requires macro and micronutrients. Nitrogen (N), Phosphorous (P) and Potassium (K) are examples of macronutrients and examples of micronutrients are Zinc (Zn), Iron (Fe), Molybdenum (Mo) and Selenium (Se). Bacteria produce protein from nitrogen. However, too much nitrogen will inhibit biodegradation process. The Nitrogen content in the form of carbon to nitrogen ratio (C/N) is expected about 25/1 (Gerardi, 2003). POME has enough nutrients for bacteria.

POME has been considered polluting the environment. Therefore POME has to be treated until it is considered safe for the environment. Various methods for treating POME has been introduced and anaerobic digestion system using pond and digester has been considered cost effective and valuable for recovering renewable energy (Poh & Chong, 2009; Ahmad et al, (2016), Kumaran et al, 2016).

To generate an optimum production of biogas, anaerobic bacteria require nutrients, suitable temperature, pH and retention time. The parameters for a typical commercial biogas plant are provided in table 1.

Table 1: Values of process parameters in a typical commercial biogas plant

Parameter	Unit	Range	Remarks
Temperature	° C	35 – 38	Mesophilic process
		55 – 57	Thermophilic process
pH Value		6.5 – 7.5	During anaerobic digestion
Retention Time	days	20 – 60	Effluent and technology dependent
COD	mg/L	< 90,000	Palm Oil Mill dependent
POME/FFB	m^3/ton FFB	0.6 – 1	Palm Oil Mill dependent
Methane Concentration	% biogas	50 – 75	Substrate dependent

2.2. Resource-based Theory (RBT)

Resource-based theory (RBT) is a theory of sustainable competitive advantage and a theory of rents (Peteraf & Barney, 2003). RBT is about maximizing benefits produced per unit cost (competitive output) through efficient production, operation, organization, effective adaptation to maintain durable heterogeneity and elimination of wastes (Barney, 1997; Teece et al., 1997). Competitive advantage in RBT is initial position or initial advantage and it is an independent variable that explains performance differences among competing firms based on differences in their resources and capabilities. Superior resources are characterized by value, scarcity and durability of resources (Newbert, 2007; Collis and Montgomery, 2008). Resources and internal capabilities can be physical, human or organization (Barney, 1991). Factory, machines, process, raw materials, money, patent, permits are examples of physical resource. Skill, knowledge and attitude are the example of the human resources. While capabilities to organize resources, access to resources of others such as information, loan, technical support and management system to generate superior product are example of organization resources.

Valuable (or expensive because of high demand) and rare resources are source of competitive advantage. Imperfect mobility of resources capable of generating products with more economic value such as patent, permit, ownership of material, process and systems are source of competitive advantage (Peteraf, 1993). Collis and Montgomery (2008) explained that valuable resources created by demand, scarcity and capacity to retain value added. Performance differences derived from rent differential among competing firms attributable to the differences in their resources with intrinsic differential level of efficiency (Barney, 1991; Peteraf, 1993). Competitive advantage of the firms can be built based on productivity superiority by producing products with less cost or by producing better products with the same cost and rent exists because of scarcity (demands exceed supply) on valuable resources. Natural restrictions or resource limitations creates scarcity and rents (Hart, 1995). Scarcity of critical resources may be short-lived because it is inherently imitable or a temporary phenomenon due to limitation in the replication in rapidly changing conditions (Schumpeterian) or longer–lasting due to barriers to imitation and substitution in stable environment (Ricardian). RBT is internal oriented activity and concerns with efficiency either lowering cost or improving benefits. Superior resources, capabilities and combination of resources and capabilities are capable of generating and maintain rent advantage or more economic value (Peteraf and Barney, 2003; Newbert, 2008).

3. Method

This paper uses a mathematical model to calculate electricity generated from a typical palm oil mill (POM) and a qualitative method for analyzing the business sustainability of on-grid biogas power plant. The mathematical model is based on the flow rate of POME, COD concentration in the POME, operating hour of the mill, efficiency of COD conversion into biogas, methane concentration in the biogas and electrical efficiency of the gas engine.

4. Results and Discussion

4.1. Modeling of Biogas Electricity Generation from POME

Palm oil mill (POM) produces crude palm oil (CPO). The steam used for sterilizing fresh fruit bunch (FFB) and the water separated from the crude palm oil, during pressing and clarification process, is released as palm oil mill effluent (POME). The quantity of POME discharged from palm oil mill is in the range of 0.6 – 1 m3 per ton of fresh fruit bunch (FFB) processed. Based on some measurements, the COD (Chemical Oxygen Demand) of POME is in the range of 35000 to 90000 ppm (mg/l). COD is an indirect method to measure amount of pollution based on oxygen requirement to decompose organic and inorganic pollutants into water (H2O) and carbon dioxide (CO2). Before released into the environment or to be used for land application, POME is treated in a wastewater treatment system, normally in the form of ponds, to meet the environmental standards.

For calculation of electricity generation capacity from POME, COD of POME is the most important parameter. Using stoichiometric analysis of complete oxidation of methane, it can be derived that 1 kg COD generates 0.35 Sm3 of methane (Deublein & Steinhauser, 2011, p. 80) and described as follows:

$$CH_4 + 2O_2 \text{ -----------à } 2H_2O + CO_2 \quad (1)$$

1 kmol CH4 (= 16 kg) requires 2 kmol of O2 or Oxygen Demand (=64 kg); 64 kg of Chemical Oxygen Demand (COD) will produce 16 kg of Methane (CH4); At 0oC and 1 bar (STP-IUPAC), 1 kmol of CH4 has a volume of 22.4 Sm3. Therefore 1 kg of O2 oxidizes 0.35 Sm3 or 0.25 kg of methane.

The temperature, pH and retention time in the digester are controlled to achieve an optimum digestion process. H2S and moisture contents in the biogas from the digester require treatment to meet the operational requirement of a gas engine, H2S < 200 ppm and dry biogas.. Depending on the brand and the size of a gas engine, the electrical efficiency the gas engine is in the range of 38 to 42%.

Revenue from the sales of electrical energy (kWh) to customers depends on the electricity demand profile and grid capability to distribute electricity. Base load (continuous) operation the biogas power plant will absorb all the electrical energy generated and give maximum revenue for the business. If the demand is lower than the generating capacity, the biogas power plant operates at partial loads and consequently the revenue generated is not optimum. On-grid biogas power plants from POME can be found in Sumatera and Belitung.

The steps of POME conversion into electricity and sales of electrical energy is described by a business process diagram in figure 1 as follows:

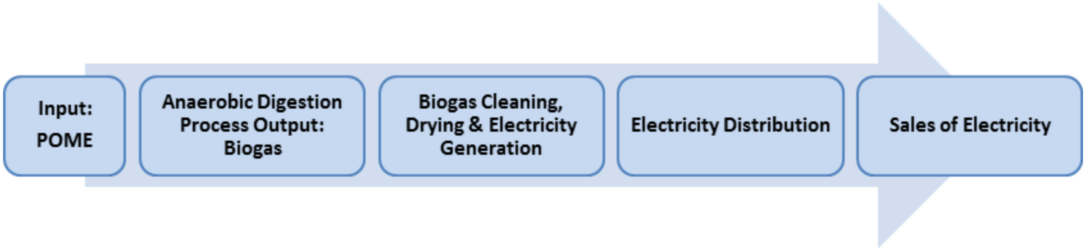

Fig 1: Business process diagram of POME conversion into electricity

In general, palm oil mills (POMs) installed in Indonesia has capacity to process fresh fruit bunch (FFB) in the range of 45, 60 and 90 ton/h. Assuming 1 ton of fresh fruit bunch (FFB) generates 0.7 m3 of palm oil mill effluent (POME) and mills operate at 20 h/day, COD of 65000 mg/l, efficiency of COD conversion into biogas of 85%, methane concentration of 55%, electrical efficiency of gas engine at 38% and yearly operation at 7200 h. The calculation of electricity generated from a mill with capacity of 45 ton/h fresh fruit bunch is as follows:

Daily POME Flow; 45 ton FFB/h x 20 h/d x 0.7 m3 POME/ton FFB = 630 m3/d

COD Loading; 65000 mg/l x 630 m3/d x (1/1000000) kg/mg x 1000 l/m3 = 40950 kg/d

CH4 production; 40950 kg/d x .35 Sm3/kg x 0.85 = 12182.625 Sm3/d

Power Generation Capacity; 12182.625 Sm3/d x 35.7 MJ/Sm3 x .38 x 1/(24x60x60) d/s = 1.91MWe

The potential of electricity generated by 45, 60 and 90 ton/h palm oil mills (POMs) is provided in table 2.

Table 2: Potential electricity generated by palm oil mills with 45, 60 and 90 ton/h

Mill Capacity	**POME Ouput**		**Electricity Generated**
FFB ton/hour	m^3/hour	m^3/day	MWe
45	32	630	1.91
60	42	840	2.55
90	63	1260	3.83

4.2. Business Sustainability Analysis of POME-based Biogas Power Plant

According to resource-based theory (RBT), the competitive advantage of biogas power plant business is characterized by their heterogeneity of resources and internal capabilities. Some firms are able to generate more value than others. Many resources and capabilities are involved in sustaining competitive advantage of biogas power generation business. Sustainability of on-grid biogas power plant business is dependent on value, scarcity (rare) and durability of POME supply, productive anaerobic digestion process, efficient electricity generation, distribution, favorable government policy in feed in tariff and fiscal policy (Kumaran et al, 2016), high electrical energy consumption and efficient revenue collection. Proven technology, competence of manpower and organization effectiveness in the various processes in the on-grid biogas power plant business are essential to business sustainability. A Model for business sustainability analysis of on-grid biogas power plant is described in figure 2 as follows:

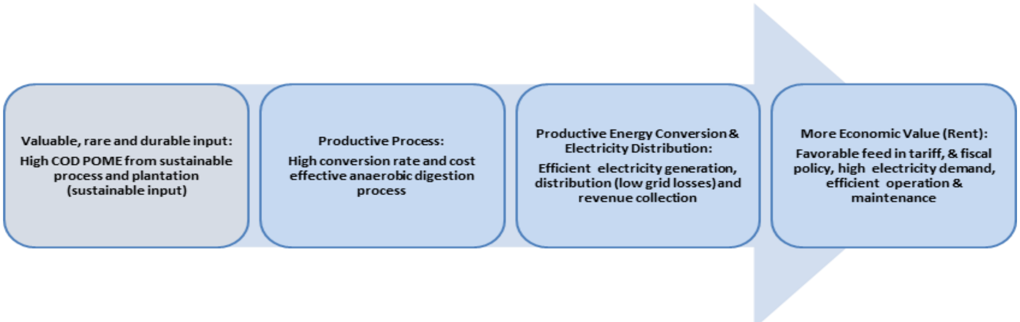

Fig 2: Business model for sustainability analysis of on-grid biogas power plant

Based on data of renewable energy statistics in 2016, in Indonesia, there are 5 on-grid POME-based biogas power plants operational with electricity generation capacities in the rage of 1 to 2.4 MWe (Direktorat Jenderal Energi Baru, Terbarukan dan Konservasi Energi, 2016). A model for validating sustainability of on-grid POME-based biogas power plant using resource-based theory (RBT) has been developed and discussed in this paper. Business sustainability validation of POME-based biogas power plant using the model proposed needs to use data from the operational biogas power plants and it is a topic for future research. In Germany, anaerobic digestion technology has been well established and Germany is a leader in anaerobic digester implementation with about 10,000 biogas power plants operational (Kumaran et al, 2016). According to Kumaran et al (2016), the implementation of biogas power plants in Malaysia has some barriers due to lack of awareness and experience of investors and local financial institutions on renewable energy projects, low feed in tariff, the location is far from electricity grid, high construction cost and high risk premium requirement from foreign investors. Understanding the causes of success and failure of biogas power plants implementation is an interesting research subject for providing more capacity of renewable energy into the grid.

5. Conclusion

On-grid generation of electricity utilising palm oil mill effluent (POME) has been successfully implemented by some palm oil mills (POMs) in Indonesia and it can be replicated in appropriate areas. As described in resource-based theory (RBT), the evaluation of resources and capabilities such as POME as raw material, electrical supply capability, demand of electricity, financial, technology, expertise, organization and supportive policy in feed in tariff and fiscal incentive are required to analyse how more economic value created and guarantee sustainability of the business. The use of methane-capture technology for POME and conversion of CH4 into energy are effective in reducing greenhouse gases (GHG) emissions to environment. The impact on global warming from methane (CH4) is about 21 larger than CO2. The potential of electricity generated from biogas power plant is about 1400 MWe from approximately 700 palm oil mills in Indonesia. From the perspectives of social, economic and environment, the use of POME to generate electricity is an interesting business as long as it creates and sustains higher net benefit against other alternatives. Valuable, rare and durable resources of palm oil industry are essential factors for sustaining the business of POME-based biogas power plants. The validation of business sustainability model for POME-based biogas power plants developed in this paper needs will require the use of data from operational POME-based biogas power plants and it is proposed as a subject for future research.

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