Application of Energy Return on Investment (EROI) Analysis to Biogas Production

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Abstract: Energy plays a vital role to the industry of developing countries. Producing clean renewable energy is one way of mitigating the effects of pollution generated by the industry in using conventional fossil fuels. Biogas is a renewable fuel which can be produced anaerobically using agricultural waste and food waste materials. A net energy analysis is one way of assessing the quality of different fuels by accounting the differences between the energy conveyed to society and the energy endowed. This system will help to analyze the flow of energy in a society associated with the growth. This paper presents the results of the application of Energy Return on Investment (EROI) analysis in the biogas production of Jatropha press-cake (JPC) and Pig manure (PM). Jatropha press-cake used in the biogas production was taken as a by-product from the biodiesel production. The EROI indicator was used in this study to provide a numerical quantification on the pathways being compared in utilizing Jatropha press-cake as feedstock for renewable energy generation. The analyses of EROI were able to assess the different substrate mixture ratio used in the biogas production whether it is viable or not. A comparison of EROI analysis between biogas production and thermal gasification were also undertaken in order to assess its viability as a feedstock for renewable energy generation. Results show that utilizing the Jatropha press-cake as feedstock for thermal gasification is much better than biogasification. However, it should be made clear that the by-product of biogas production was not covered in the analysis of EROI. A further study of the EROI analysis on the biogas by-product is recommended for future investigation.

Key Words: EROI; Net Energy; Biogas; Renewable Energy; Thermal Gasification

1. INTRODUCTION

1.1 Net Energy Analysis

Is a technique in evaluating energy systems which evaluates the amount of energy being delivered in society through technology to the total energy required to find, extract, process, and develop that energy into socially useful form (Herendeen, 2004). Primarily the net energy analysis seeks to measure the direct and indirect energy required to produce a unit of energy. A direct energy is the fuel being used directly in extraction or generation of a unit of energy. Indirect energy is the energy that is being used elsewhere in economy in order to produce goods and services. Basically, both direct and indirect energy use are called embodied energy. The energy products and embodied energy is expressed in a common physical unit of measurement, such as Btu (Cleveland, 2010).

According to Zhang and Colosi (2013) energy ratio is one of the significant classes of energy-related LCA metrics. The LCA metrics basically accounts the energy (in or out) on a given system in order to assess the production efficiency on a particular energy system evaluated. Energy ratio metrics basically applied into a particular study for practical purposes: to asses overall sustainability on a particular system and aid of comparison to another alternative system (Zhang and Colosi, 2013). While the reports of Hall et al., 2009; Mulder and Hagens, 2008; Murphy and Hall, 2010; Murphy et al., 2011, all say that energy ratio is one of the most interesting topic in theoretical studies that focused in assessing the impacts of hypothetical system boundaries of energy return on investment (EROI) calculations.

2. METHODOLOGY

2.1 EROI for biogasification and thermal gasification

An EROI formulation basically differ primarily in the treatment specifically on the system boundaries set in quantifying net energy creation or consumption. In this study, evaluation of the energy return on investment (EROI) is governed by the following assumptions:

- The energy used in fabrication of the bioreactor and gasifier is not covered in the system boundary.
- It is assumed that the materials needed in biogasification and thermal gasification is within the plant site.
- The energy used of the blower for thermal gasification is 15,218.4 kJ (Vyas and Singh, 2007; Varshney et al., 2011).
- The gasifier has the following of efficiency 65.90% and 68.31% with a gas flow rate of 4.5 and 5.5 m^3 / h and continuously operated in 340 min. (5.666 hrs.) respectively (Vyas and Singh, 2007).

$EROI_{BP}$ of biogas production: (Eq. 1)

$$EROI_{BP} = \frac{\left((A_{mix}\ x\ X_{jpc})\ x\ (B_m)\right) - \left(\left(C_{pm}\ x\ Y_{pm}\right)\ x\ (B_m) + (E_w)\right)}{(F_{jpc}\ x\ G_{jpc})}$$

$EROI_{TG}$ of thermal gasification: (Eq. 2)

$$EROI_{TG} = \frac{\left((H_{pg}\ x\ J_{pg}) - (I_{tg})\right)}{(F_{jpc}\ x\ G_{jpc})}$$

where:

A_{mix} = methane gas produced from jatropha press-cake and pig manure mix, L/kg
B_m = heating value of methane gas, kJ/L
C_{pm} = methane gas produced from pig manure, L/kg
E_w = energy used of water supplied, kJ
F_{jpc} = amount of jatropha press-cake used, kg
G_{jpc} = heating value of jatropha press-cake, kJ/kg
H_{pg} = amount of producer gas produced from thermal gasification of jatropha press-cake, m^3
I_{tg} = energy used by gasifier system in producing producer gas, kJ
J_{pg} = heating value of producer gas, kJ/m^3
X_{jpc} = percentage of jatropha press-cake loaded, kg
Y_{pm} = percentage of pig manure loaded, kg

3. RESULTS AND DISCUSSION

The data from master's thesis of Gonzaga (2013) were used in EROI analysis for this particular study. Results of EROI analysis of the two alternative pathways in utilizing jatropha press-cakes are shown in tables 1 and 2 respectively. Energy return on investment was calculated using the equations 1 & 2 which are shown above. The EROI analysis revealed that the following substrates 80JPC:20PM / 1:3WDR, 90JPC:10PM / 1:4WDR and 90JPC:10PM / 1:3WDR of the two different scenarios shows significant results. Differences in EROI value of the two scenarios are observed to be slightly small. The substrate 80JPC:20PM / 1:4WDR shows a positive EROI but less significant as compared to the other results.

Table 1: EROI for Biogas production in different scenarios

Substrates compositions	EROI (Scenario 1)	EROI (Scenario 2)
90JPC:10PM/1:4WDR	0.31816	0.31822
80JPC:20PM/1:4WDR	0.09365	0.09372
50JPC:50PM/1:4WDR	-0.15665	-0.15654
90JPC:10PM/1:3WDR	0.30799	0.30803
80JPC:20PM/1:3WDR	0.30557	0.30562
50JPC:50PM/1:3WDR	-0.12549	-0.12540

In figure 1 it is clearly exhibited there that EROI of the substrates 50JPC:50PM with 1:4 and 1:3WDR shows negative results which means that we cannot get a descent energy value on this. A negative EROI value primarily indicates that it's not a suitable substrate composition for biogas production. The substrate composition that has a negative EROI value should be rejected for biogas production. An EROI evaluation results as compared to the gas production analysis shows a relatively consistent results specifically in the following substrates 80JPC:20PM / 1:3WDR, 90JPC:10PM / 1:4WDR and 90JPC:10PM / 1:3WDR of the two different scenarios.

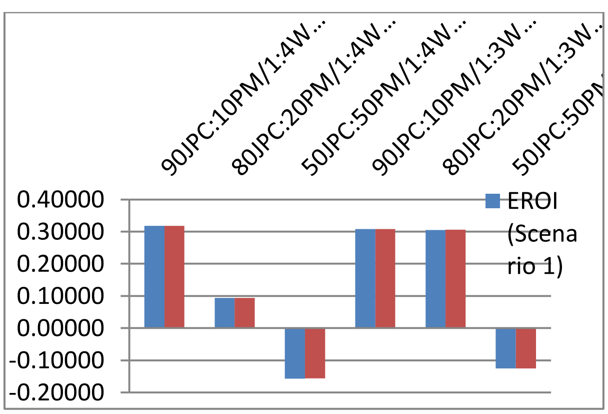

Figure 1: EROI for Biogas production in different scenarios

However EROI results of thermal gasification exhibits better results over the biogasification. As shown in table 2, thermally gasified jatropha press-cake at different gasifier efficiencies and gas flow rates reveals higher EROI compared to the biogsification. Table 2 further illustrates that thermal gasification compared to the biogasification is less susceptible to the mathematical variability of EROI. This clearly indicates that utilizing the jatroph pres-cake as feedstock for gasifier is much relatively better to biogasification.

Table 2: EROI for Gasifier with different gasification efficiencies and gas flow rates respectively

Substrates compositions	EROI @ Gas. Eff. 65.96%	EROI @ Gas. Eff. 68.31%
90JPC:10PM/1:4WDR	1.98749	2.09846
80JPC:20PM/1:4WDR	2.23593	2.36077
50JPC:50PM/1:4WDR	3.57748	3.77723
90JPC:10PM/1:4WDR	2.67966	2.81529
80JPC:20PM/1:4WDR	3.01462	3.16721
50JPC:50PM/1:4WDR	4.82339	5.06753
90JPC:10PM/1:3WDR	1.58999	1.67877
80JPC:20PM/1:3WDR	1.78874	1.88862
50JPC:50PM/1:3WDR	2.86198	3.02178
90JPC:10PM/1:3WDR	2.14373	2.25224
80JPC:20PM/1:3WDR	2.41170	2.53377
50JPC:50PM/1:3WDR	3.85871	4.05402

4. CONCLUSIONS

The energy return on investment (EROI) was able to provide a numerical quantification on the pathways being compared in utilizing jatropha press-cake as feedstock for renewable energy generation. It is highly recommended that the by-products of the biogas production must be also taken into consideration on EROI analysis.

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