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Techno-economic Analysis of Biogenset and Hybrid Solar-Diesel-Battery for Rural Electrification

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As one of world lead exporter palm oil, Malaysia has generated a lot of waste from the production of palm oil. One of the high produced waste is palm oil mill effluent (POME). POME can be utilized as fermentation media, fertilizer, and biogas. Biogas is produced through the process of anaerobic digestion. It has the potential as energy sources because biogas is a mixture of gas consists of CH_4 and CO_2. It can be used for cooking; vehicle fuel and also can operate the generator. To generate electricity, Malaysia still highly dependent on fossil fuel which is far from the concept of sustainable development. There is some part of the rural area still do not have electricity. The government has taken action in solving the issue by installing solar panel to generate electricity. However, solar is intermittent energy source. Therefore, biogas can be one of alternatives to solve the intermittent problem. Compressed biogas will be used as fuel for biogenset. In this study, techno-economic analysis of biogenset and hybrid solar-diesel-battery for rural electrification is performed. The economic assessment is conducted in term of profit and payback period by using the extracted data. Based on the economic assessment result, it shows that using biogenset for electricity generation is more profitable compare to hybrid solar-diesel-battery due to its high capital cost. The total profit of biogenset is 77,708.05 MYR and the payback period for biogenset also shorter than hybrid solar-diesel-battery which is 8.65 y.

1. Introduction

As the world's leading exporter of palm oil, Malaysia has exported more than 18 Mt of palm oil in 2016 (Malaysian Palm Oil Board, 2017). The extractions of palm oil from palm fruits have generated around 70 Mt of waste such as empty fruit bunches (EFB) and palm oil mill effluent (POME) (Zafar, 2015a). POME is waste water from sterilization process, crude oil clarification process and cracked mixture separation process (Sarawak Energy, 2013). It is hot (temperature 60 – 80 °C), acidic (pH 3.3 – 4.6), thick, brownish liquid with high biochemical oxygen (BOD) and chemical oxygen demand (COD) (Castermans et al., 2015).

Palm oil industry in Malaysia has produced about 58 Mt of POME annually. Without proper waste management, the huge quantity of POME will pollute the waterway nearby the palm oil mills. In order to control pollution, regulatory control over discharges from palm oil mills is instituted through Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977 promulgated under the Environmental Quality Act, 1974 and enforced by the Department of Environmental (DOE). The palm oil mills are required to comply with prescribed regulations included laws governing the discharge of mill effluent into waterway and land (Ahmad et al. 2003). Therefore, effective treatment process has to be implemented by palm oil mill in order to achieve the standard requirement on effluent discharge constantly.

Anaerobic digestion is one of the preferable methods to treat POME. It is a biological process happens between microbes and the organic waste (Castermans et al., 2015). The end product of this process is biogas. With the availability of POME in Malaysia, the production of biogas can reach 15 Bm^3 (Zafar, 2015b). Biogas is a mixture of CH_4, CO_2 and small amount of hydrogen sulfide (H_2S), moisture and other gases (Wilkie, 2015). It has potential to be fuel due to the energy release when undergoing combustion process. Biogas can be used for cooking, vehicle's fuel and also for power generation.

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Regarding the generation of electricity, Malaysia still highly depended on the non-renewable sources to generate electricity. In efforts to attain the status of a developed country through achieving sustainable development, Malaysia required to comply with all components of sustainability such as economy, environment and society (Ross, 2009). In 2012, almost 80 % resources for power generation are non-renewable resources like petroleum, natural gas and coal.
There is some part of Malaysia still have no electricity access which is the vital utility that people need. The database from World Energy Outlook 2016 also proved that the electrification rate for rural area is 99% from the population of Malaysia resident which is around 31 M people (International Energy Agency, 2016).
Based on report made by Shiun (2016), there are 1,919 of villages with 41,100 households still having no 24 h access of electricity in Sarawak. Government has done much effort in order to solve this problem by installing the solar panel and build micro-hydro dam (Sarawak Energy, 2014). However, all those renewable energies (RE) are unstable energy plus the progress of installing the RE is taking time due to lacks of collaboration and partnership between government and public entities.
This paper focuses on the economic analysis of biogenset and hybrid solar-diesel-battery for rural electrification. Capital costs and operation and maintenance costs for both technologies are utilized to study the viability of using biogenset instead of hybrid solar-diesel-battery.

2. Renewable energy in Malaysia

In 2015, Malaysia has achieved 5.5 % of renewable energy from the total of energy production and by 2020; the target has increased to 7.8 % of energy production. Malaysia's government has put various initiatives in order to accomplish that target (Geotech, 2016). For example, the government has established National Renewable Energy Policy and Action Plan 2010, National Biomass Strategy 2020, Renewable Energy Act 2011, etc.
The growth of utilizing renewable resources in generating power has also increased in Malaysia. In order to make sure all the rural areas of Sarawak have 24 h electricity, State and Federal Government have spent 500 million MYR to fund a program called Sarawak Alternative Rural Electrification Scheme (SARES). The SARES team is responsible to design, build and install solar or micro-hydro systems at these villages before handing over to the community to operate. Solar energy becomes a viable alternative for electricity because of the connection to the main power grid will take time and is not practical in settlements with a population that is not crowded (Sinyang, 2015).
However, generating electricity using solar energy is more expensive compared to traditional methods which are using coal, natural gas and petroleum. One of the reason is photovoltaic (PV) panels have a limited ability to transform all the energy of sunlight into electricity. A large area is needed to collect more sunlight. Solar energy is also weather dependent and the output of energy is different from day to day. It's not a very reliable energy source especially during the raining season which the sky always cloudy (ElectroCity, 2010).
Other than solar and hydro energy, biogas also can be the alternative for rural electrification. It is also a sustainable, clean and secure source of energy for the society (Mohtar et al., 2017). In order to support the government's goals which are achieving 5.5 % of renewable energy from the total of energy production, there are already 113 palm oil mills have generated biogas into electricity. 12 of them are connected to the national power grid network while 79 are still in the process of being connected (Geotech, 2016).

3. Literature review

3.1 Properties of biogas

Biogas is a gas that generated from anaerobic degradation of organic matter by a consortium of bacteria. It is a mixture of gases such as CH_4, CO_2 and small amount of H_2S, moisture and other gases. The percentage of CH_4 in biogas is depending on the source of organic matter and conditions of degradation (Wilkie, 2015).
Table 1 shows the chemical composition of raw biogas. Due to the high content of CH_4, biogas can be used as a fuel for the engine. The heating value for biogas is 21 MJ/m^3 and the density is 1.22 kg/Nm^3 which is quite similar to the air's density (1.29 kg/Nm^3) (Al Seadi et al., 2008).

Table 1: Chemical composition of biogas

Elements/ Sources	CH_4 vol%	CO_2 vol%	H_2S mg/m^3	References
POME	60 - 65	30 – 35	375 – 750	(Othman, 2015)
Wastewater Treatment Sludge	60 – 75	33 – 19	1,000 – 4,000	(Naskeo Environnement, 2009)
Agricultural Waste	60 – 75	33 – 19	3,000 – 10,000	(Naskeo Environnement, 2009)

3.2 Application of biogas

The application of biogas is limited to the usage on-site. The consumer will directly use the biogas for heating, cooling, lighting, and cooking. According to Hoo and co-workers, there are many successful implementations of biogas as a source of energy with the support from government (Hoo et al., 2017). The utilization of biogas can also be widened by compressed it into the cylinder. The advantage of bottling the biogas is making the process of storage and transportation become easier.

Vijay and co-workers have reported a study about bottling the biogas for vehicle's fuel. The enriched biogas was compressed after moisture removal at 20 MPa. The compressed biogas was filled in special high pressure seamless steel cylinders same like cylinder used in compressed natural gas (CNG). Then the compressed biogas is tested on operated Maruti-800 car and it showed a good performance as good as CNG. The starting part is easy and quick plus the car ran smoothly after the engine tuning and restriction in air intake (Vijay et al., 2006).

Nallamothu and co-workers have also made a research about the bottling of biogas for cooking purpose. In this study, the researcher used a hermetic reciprocating type refrigerant compressor and compressed the biogas into normal LPG cylinder. To compress 5 bars of biogas, the needed time is 12 – 14 min. In order to validate the purification of biogas on heating value, purified and raw biogas was used to heat 500 ml of water. The finding of this research is purified biogas need a shorter time to heat 500 ml water compare to raw biogas and it has higher calorific value than raw biogas. The recorded time for purified biogas is 4.54 ± 0.03 min while time for raw biogas is 5.62 ± 0.02 min (Nallamothu et al., 2013).

There is also a study proven that bottled biogas can be used to generate electricity, particularly in the rural area. Ilyas has constructed a biogas bottling system in a village with a capacity 60 m^3/d biogas plant. The system has two mechanisms which are water scrubbing for the removal of CO_2 and compression unit for bottling the purified biogas in cylinders. The purified biogas is compressed using a three-stage compressor at 10 x 103 kPa and stored in 0.0215 m^3 water capacities CNG cylinders. By using compressed biogas instead of diesel for electricity, it can save the cost of operation from 147 USD which is diesel worth cost per day to USD 140 which is the cost of compressed biogas. The usage of compressed biogas also can ensure continuous energy supply (Ilyas, 2006).

4. Availability of excess biogas

In Malaysia, 75 palm oil mills already have biogas facilities (Othman, 2015). Some of the produced biogas will be injected into the gas engine to generate electricity, then the generated electricity will be injected into the grid network. While the excess biogas will be used at the mills or flared.

Kekayaan Palm Oil Mill, Paloh, Johor is the specific location for data collection on the availability of excess biogas. The data collected is the amount of excess of POME that not utilized for biogas. The capacity of this palm oil mill is 120 Mt/h and can process up to 450,000 MT fresh fruit bunch (FFB). In this mill, the biogas generated is based on demand. Generally, the mill can be generated 3 MW electricity/d. 2 MW electricity to the grid and 1 MW for the mill's usage.

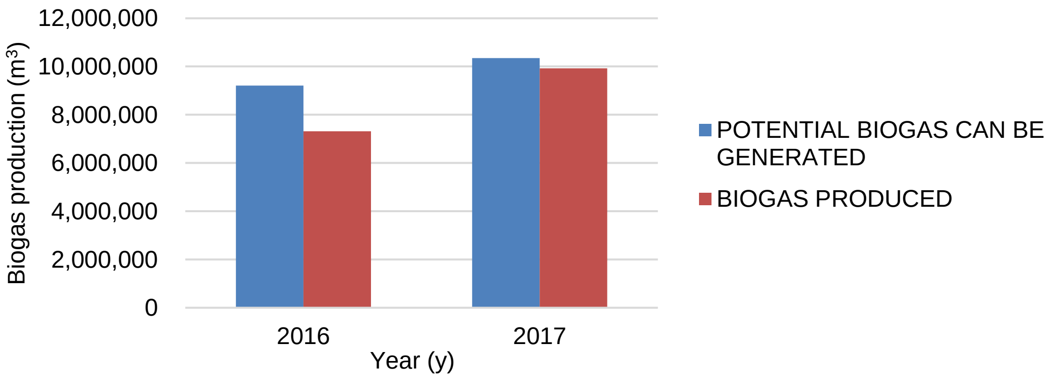

Figure 1: Annual Comparison between Produced Biogas and Potential Biogas

Figure 1 shows the annual comparison between the produced biogas at the mill with the potential biogas that can be generated at the palm mill. The potential biogas is calculated using the conversion (1 m^3 POME = 30 m^3 biogas). Based on the graph, it shows that the volume of potential biogas can be generated is higher than biogas produced yearly. The value of excess biogas for year 2016 and 2017 is 1,885,594 m^3 and 416,919 m^3. This analysis has proved that the mill has excess availability of biogas that can be utilized for other purposes such as rural electrification.

5. Case study

The selected area for a case study is at Rumah Dau, Sri Aman, Sarawak. This region has 26 houses and a school. The demand for electricity is 245.6 kW. At this area, the government has installed the solar system, diesel generator and battery for electricity generation. The power of installed solar panel is 129.6 kW while the rated power of diesel generator is 2 x 58 kW.

Solar energy is one of the clean technology for power generation. However, it is intermittent energy. The mean daily sunshine hours in Malaysia ranges from 4 to 8 h. Plus Johor and Sarawak received the least amount of radiation compared to the northern states (Mekhilef et al., 2012). Malaysia also has the raining season. During this season, there is less sunlight compared to a normal season. In this study, the total revenue for solar energy and biogas is different due to different rates for feed in tariff (SEDA, 2018).

By using the available data, comparison analysis between the solar system and biogas is performed in order to know which renewable energy gives higher profit and the result from this outcome can be used for future development. The red pin in Figure 2 shows the location for case study.

Figure 2: Location of case study

6. Economic analysis

The economic assessment is conducted in term of profit and payback period by using the data listed in Table 2. The basis for this calculation is 245.6 kW which is the demand for electricity at the case study area. The economic analysis is done by comparing the profit value and the payback period for bio-genset and hybrid solar-diesel-battery. The profit is calculated using Eq(1). The value for total revenue is obtained from the multiplication of selling price of RE with the amount of electricity produced. While the total cost is the addition of the capital cost and the operation cost.

$$\text{Profit (MYR)} = \text{Total revenue (MYR)} - \text{Total cost (MYR)} \quad (1)$$

The payback period is calculated using Eq(2). For hybrid solar-diesel-battery system, only considered the capital and operation cost of solar in order to know the payback period of solar panel.

$$\text{Payback period (y)} = \frac{\text{Initial cost}}{\text{Net annual cash inflow}} \quad (2)$$

6.1 Assumption

The basis for this calculation is 245.6 kW. For solar energy, the daily sunshine is 6 h while the diesel generator operating hours is 18 h. While the operating hours for biogenset is 24 h. Both system will be operated for 365 d annually.

6.2 Results and discussion

Based on the calculation tabulated in Table 3, the biogenset has higher profit compared to hybrid solar-diesel-battery which is RM 77,708.05/y. Due to the high capital cost and the high cost of raw material, using hybrid solar-diesel-battery has negative profitability. The biogenset also has lower payback period than hybrid solar-diesel-battery which is 8.65 y.

Table 2: Economic parameters

Parameters	Classification	Value	Unit	Reference
Electricity (Solar)	Selling Price	0.5435	MYR/kWh	SEDA, 2018
Electricity (Biogas)	Selling Price	0.3485	MYR/kWh	SEDA, 2018
Compressed Biogas	Raw material price	40.00	MYR/MMBtu	Raof, 2014
Diesel	Raw material price	80.00	MYR/MMBtu	Raof, 2014
Solar panel	Capital cost	10,752	MYR/kWh	Nippon Koei Co., Ltd and ORIX Corporation, 2012
	Operating cost	12,960.00	MYR/y	Nippon Koei Co., Ltd and ORIX Corporation, 2012
Battery	Capital cost	19,900.00	MYR/unit	Alibaba.com, 2018
Diesel generator	Capital cost	123,972.70	MYR/unit	Ultimate Washer, 2018
	Operating cost	60,664.75	MYR/y	Homer Energy, 2018
Biogenset	Capital cost	207,402.00	MYR/unit	Alibaba.com, 2018
	Operating cost	171,255.90	MYR/y	Homer Energy, 2018

The system is more suitable for a long term project to recover the capital cost. The solar hybrid scheme is the combination system between solar panel and diesel generator. If the government only use solar energy, it will be more profitable compare to the solar hybrid scheme. However, it is impossible to supply for 24 h electricity if depend on the solar energy due to its limitation.

Table 3: Economic Assessment Results

Type of Renewable Energy	Total Capital Cost (MYR/y)	Total Operation Cost (MYR/y)	Total Raw Material Cost (MYR/y)	Revenue (MYR/y)	Profit (MYR/y)	Payback Period (y)
Solar Hybrid Scheme	1,740,904.60	73,624.75	207,876.49	154,258.34	-1,868,147.50	10.57
Biogenset	207,402.00	171,255.90	293,416.47	749,782.42	77,708.05	8.65

7. Conclusion

In this study, the economic potential of using biogenset for rural electrification is promising in term of profit and payback period. Based on the economic assessment, the profit using biogenset is higher compared to hybrid solar-diesel-battery which is 77,708.05 MYR/y. This is because solar energy has higher capital cost and raw material cost. The payback period for biogenset also shorter which is 8.65 y compared to solar hybrid scheme, 10.57 y. The solar energy is more suitable for the long term project to retrieve the capital cost. Further studies can be extended by assessing the environmental aspects for a better future.

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