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Techno-economic Analysis of Electricity Generation from Biogas Using Palm Oil Waste

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ABSTRACT

In Malaysia, nearly 80 million tons of fresh fruit bunches are processed annually in 406 palm oil mills and are generating approximately 54 million tons of Palm Oil Mill Effluent (POME). This POME is known to generate biogas consisting of methane-a Green House Gas (GHG) identifiable to cause global warming. The amount of methane gas generated annually is equivalent to 19 million tons of carbon dioxide. To meet the regulatory requirement, more than 85% of the mills use solely the lagoon systems in waste water treatment, typically anaerobic first stage followed by facultative treatment. However, these two major palm oil wastes are a viable Renewable Energy (RE) source for production of electricity. In the present paper, an attempt has been made to study the technological parameters for different capacity digester to produce electricity. The cost related data are collected from Serting Hilir Palm Oil Mill. Net present worth, internal rate of return and payback period were calculated. On the basis of the calculated values it has been found that the application of biogas plant for generation of electricity is economically viable in Malaysian perspective and this viability or economic attractiveness increase with the increase of plant size. The findings of this study should be useful to give some directions and guidelines for future planning and implementation of biogas plants in Malaysia.

Key words: Palm oil waste, biogas, techno-economic analysis, electricity generation, plant size

INTRODUCTION

Energy resource is the economic driving force for the industrial world as well as for the developing nation. At the same time energy production and utilization is also blamed for the environmental degradation. In addition, the prospects of long term exhaustibility of the fossil fuel resources, the 'energy crises' of the 1970s and further thrusts towards development and environment concern have promoted the use of renewable resources (such as biomass or hydropower) or inexhaustible resources (such as solar energy or wind power) as the solution. However, the economical and sociological factors are very important for implementation of renewable sources.

The energy need in Malaysia is met by both renewable and nonrenewable energy sources and the country is well endowed with relatively cheap and plentiful supply of conventional fossil fuels such as oil (approximately 3 billion barrels), natural gas (1.61 trillion cubic meters) and coal (776 million tons) as well as nonrenewable energy sources like hydro and solar power and biomass

(Joanta, 1996). However, past and current economic growth in the country is fueled mostly by fossil fuels. The energy need in Malaysia is relatively high (expected to increase at a rate of 9.5% per year) as the economy is projected to grow at a high rate. The maximum electricity energy demand projections are 40,515 MW for the year 2020 (Yusoff, 2006). Figure 1 shows the primary energy demand in Malaysia that indicates a rapid increase and for year 2030, the primary energy demand is expected to increase close to 100 MTOE (million ton of oil equivalent) (APEC, 2006).

Realizing this, The Ministry of Energy, Water and Communications has been promoting energy efficiency and incorporation of renewable energy sources. It has been observed that after the Diversification Policy the need for the use of renewable energy has increased from 6,000 kTOE to 60,000 kTOE since 1971 to 2005 (Zain-Ahmed, 2008). In addition, the government of Malaysia as a Fifth Fuel Policy has incorporated RE since year 1999 and Small Renewable Energy Program since year 2000. RE offers the prospect of increasing energy supply in a self reliant way at national and local levels along with the attended economic, social and security benefits in the process. Long term sustainable development of developing countries like Malaysia, requires the affirmative shift towards renewable sources of energy that are more equivalently distributed and less environmentally destructive than the fossil fuel sources. Nevertheless with all the effort and policy implementation by government, as of 2010, the largest contribution of energy demand is still coming from petroleum products (62%) and electricity (19%) is in next position which has gradual increase from natural gas (16%) and demand for coal and coke is in stable conditions (Gan and ZhiDong, 2008). Though Malaysia is a net exporter of oil and natural gas but they are the nonrenewable and one day will be completely depleted. Moreover, the gradual deregulation of natural gas prices, with price increase from RM 6.40 per MMBTU to RM 14.31 per MMBTU for power sector in 2008 has often brought natural gas to the downside and it is expected that current gas fields to be depleted by 2027 with new fields of higher carbon dioxide content. To make things worse, there is uncertainty on adequacy of gas supply for power generation beyond 2018 (Sulaiman *et al*., 2011). Not only that, there is a proven declination of oil reserves by 3.0 billion barrels in January 2007, which was at a peak of 4.6 billion barrel in 1996 (Mustapa *et al*., 2010; Rotty, 1979). Hence to reserve the nonrenewable sources no new gas-fired power plants are allowed. Though the offshore areas, especially the deepwater zones are being actively explored by

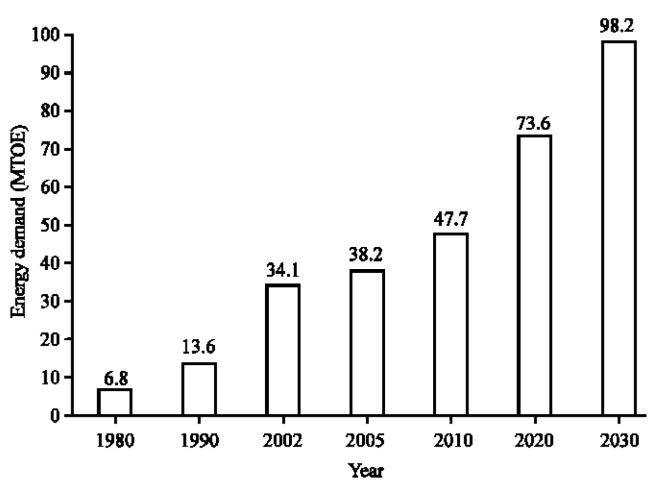

Fig. 1: Energy demand in Malaysia, MTOE: Million ton of oil equivalent

PETRONAS and its partners to ensure the increasing primary energy demand of Malaysia and is continued to be sustained with the support of other energy sources such as coal. According to Gan and ZhiDong (2008), Malaysia's total primary energy consumption and Carbon emissions will triple by 2030, indicating that large amount of the energy demand would have to be supported by coal. The coal deposits in Malaysia are not of very high quality mostly composed of anthracite, sub-bituminous and lignite coals. Consequently, the national dependence on imported coal is more than 97%. Moreover, the supply constraints amongst exporters, e.g., port facilities in Newcastle, Australia and to cope with coal export demand due to escalating coal prices, especially within the region making the situation difficult.

Moreover, during the COP 15, Malaysia has also committed to reduce its carbon intensity by 40% of its 2005 value, which is going to be an uphill task with grow energy intensity of Malaysia and dwindling natural gas resources and increasing coal utilization (Badariah, 2010). One of the solutions would be aggressive and affirmative deployment of available RE energy resources such as biomass and biogas that is abundantly available from the oil palm waste to ensure supply sustainability and environment conservation. This is evident with the upcoming deployment of National RE Policy to be announced soon, whereby the share of RE is expected to be 11 and 17% of total electricity generation mix by 2020 and 2030, respectively. This would translate to cumulative CO_2 avoidance of 42.2 and 145.1 million tonnes for year 2020 and 2030, respectively.

This study explores the potential of biomass and biogas generated form Malaysian palm oil industry, as one of the promising alternative energy source in terms of its techno economic viability.

Biomass and bio-gas: A promising alternative: Biomass energy includes energy from all plant matter and animal dung in the form of gas called biogas. Biogas fuels currently account for about 16% of the energy consumption in the country, of which about 51% is oil palm waste from palm oil industry (Joanta, 1996). Malaysia is the world leader in the production and supply of crude palm oil. The Malaysian palm oil industry is projected to grow steadily (Lee, 2009). This will lead to the plantation of more palm oil trees, consequently processing more palm oil Fresh Fruit Bunches (FFB) and thus more palm oil waste, mesocarp fibres and palm kernel shells will be produced. In 2006, Malaysia had more than 4.16 million hectares of land under palm oil cultivation. Nearly 80 million tonnes of fresh fruit bunches processed from 406 palm oil mills in 2007 and generating approximately 54 million tonnes of Palm Oil Mill Effluent (POME). Based on these figures, the type and amount of biomass generated and their heat value is shown in Table 1 and the potential energy from biogas is presented in Table 2. POME is also high in nutrient containing carbon and organic matter as presented in Table 3 and this can be a great source of biofertilizer (Sulaiman *et al.*, 2011).

The Malaysian Fifth Fuel Policy and the Small Renewable Energy Programme (SREP) launched on May 2001 by the Ministry of Energy, Communication and Multimedia had targeted palm oil wastes as the major form of renewable energy as it contributes 56% of biomass or 10.9%

Table 1: Biomass generated by palm oil mill

Biomass	Quantity (million tonnes)	Moisture content (%)	Oil content (%)	Heat value of dry matter (kJ kg^{-1})
Fresh fruit bunch	18.25	67	5	18,883
Fibre	11.11	37	5	19,114
Shell	5.55	12	1	20,156
Palm oil mill effluent	53.16	93	1	17,044

Table 2: Potential energy from biogas

Year	Palm oil production (million tonnes)	Biomass (million tonnes)	Palm oil mill effluent (million m^3)	Biogas (million m^3)
2002	13.3	14.2	45.63	1,278
2007	15.9	18.5	53.55	1,499
2010	16.9	19.6	57.42	1,607

NKEA (2011)

Table 3: Constituents of palm oil mill effluent (POME)

	Concentration (mg L^{-1}) (except pH)			
	Raw POME		Digested POME (from digested tank)	
Constituents	Range	Mean	Range	Mean
pH	3.0-6.7	4.10	7.1-8.15	7.64
Biological oxygen demand	15750-46000	29500	53-825	312
NH_4-N	1.4-6.9	3.7	82-288	312
Total N	400-993	631	196-926	470
P	80-195	139	20-395	84
K	1225-3365	2246	1117-2530	1714
Mg	203-540	380	193-434	303
Ca	162-540	297	144-667	275
Zn	1.20-4.20	2.74	0.19-4.50	1.30
Cu	0.90-4.40	2.03	3.10-3.20	1.26
Ni	0.10-2.70	1.27	0.14-3.60	1.35
Cd	0.01-0.02	0.01	Trace	Trace
Pb	0.01-0.9	0.5	0.05-2.00	0.60
Cr	0.05-0.4	0.17	Not detected	Not detected

of biogas (Anonymous, 2008). The biogas produced from anaerobic digestion can be captured and utilized as RE to replace fossil fuel/diesel for steam or electricity generation. It has been estimated that a 60 tons FFB/hr mill, will generate about 12,000 m^3 of gas/day and the energy that can be generated is estimated to be 1.04 MW capacity (Joanta, 1996). The total 261.1 MW installed capacity of power from the potential of 406 mills would generate 1.88 MWh of electricity (NKEA, 2011). It is worth to mention that the CO_2 emissions for the generation of electricity by electric power plants by coal or oil is 1100 g of CO_2 per kW h, whereas, the figure is 600 g of CO_2 per kW h for using gas and biomass use can reduce it dramatically to 16 g of CO_2 per kWh (Yusoff, 2006). Hence, the major greenhouse gas is not added to the atmosphere by the utilization of biomass energy and the scenario is quite contrast of the use of fossil fuels (Bazmi *et al.*, 2011).

CAPITAL COST ESTIMATION

The main use of biogas generated from palm oil waste is considered for electricity generation. Three different capacity bio digesters are considered which can handle 30, 60 and 90 tonnes of fresh fruit bunch per hour (tFFB/h). The techno-economic analysis is based on the estimation of cost and cash inflow for a proposed project. The outflow of cost includes the capital cost, set up cost and annual operating cost and the inflow is selling price of the product from the proposed project. As electricity will be generated from the biogas produced from palm oil waste, hence the inflow is comprised of the selling price of the electricity produced.

The total project cost was taken from Biogas Project at Felda Serting Hilir for estimations and it was divided into two phase. The detail of project cost for handling 90 tonnes fresh fruit bunch per

Table 4: Total project cost for processing 90 tonnes fresh fruit bunch per hour (tFFB/h)

	Cost (Ringgit Malaysia)
Capital investment, phase I	7,647,000
Development cost	2,000
Other cost	498, 594
Capital investment, phase II	1,638,000

Table 5: Summary of outflow and inflow of cash for financial analysis

Cash flow	Financial parameters	Value
Inflow	Electricity tariff (Ringgit Malaysia/kWh)	0.21
	Rate of increase of tariff (%/10 years)	12%
	Depreciation	5%
	Costs and Equipment (Ringgit Malaysia)	8,147,594 (Phase I)
		1,638,000 (Phase II)
Outflow	Total Investment (Ringgit Malaysia)	9,785,594
	Operating costs (Ringgit Malaysia/per annum)	238-735k
	Contingencies on operational Expenditure (OPEX)	5%

hour is presented in Table 4 (Saad, 2010) and the summary of key parameters for financial analysis is given in Table 5 (Saad, 2010).

Economic analysis: The economic analysis was carried out based on Net Present Value (NPV), modified internal rate of return (MIRR) and payback period. Different discount rates were taken into consideration and cash flow was considered of with and without clean development mechanism (CDM).

Net present value (NPV): The following formula has been used to calculate net present value along with compound interest (Saad, 2010):

$$\text{NPV} = \sum_{t=1}^{T} \frac{\text{Net cash flow}^t}{(i+1)^t} - \text{initial cash investment} \tag{1}$$

Where:
T = Total net cash flow period/years
I = Interest rate assumption
t = Cash flow period

In Fig. 2, the NPV at different discount rates is presented for project with CDM. The value of NPV at different discount rates without CDM is given in Table 6.

Based on NPV it can be said that the mill capacity at 60 tFFB/h and above is most potential option for investment.

Modified internal rate of return (MIRR): The Modified Internal Rate of Return (MIRR) were used for analysis instead of Internal Rate of Return (IRR) by considering the project future cash flows are reinvested at a lower rate, such as a risk-free rate and the firm's cost of capital. The IRR assumes that all future cash flows are reinvested at the project rate. MIRR better reflects the true economic benefit of a project (Saad, 2010):

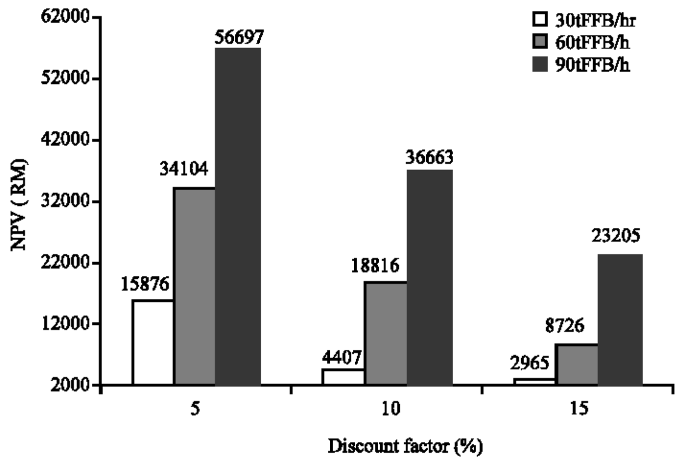

Fig. 2: Net present value (NPV) versus discount factor for clean development mechanism project with different plant capacity

Table 6: Net present value (NPV) at different discount rates without clean development mechanism (CDM)

	Discounts factor (%)		
Mill capacity (tFFB/h)	5	10	15
30	Ringgit Malaysia 5359	Ringgit Malaysia 12,229	Ringgit Malaysia 16,377
60	Ringgit Malaysia 5359	Ringgit Malaysia 12,229	Ringgit Malaysia 16,377
90	Ringgit Malaysia 5359	Ringgit Malaysia 12,229	Ringgit Malaysia 16,377

$$\text{MIRR} = \sqrt[n]{\frac{-\text{FV (positive cash flow,reinvestment rate}}{\text{PV (negative cash flow, finance rate)}}} - 1 \quad (2)$$

Where:

n = No. of equal periods at the end of which the cash flows occur
PV = Present value at the beginning of the first period
FV = Future value at the end of the last period

In Fig. 3, MIRR for different discount factors is presented. MIRR for project without CDM is given in Table 7. The value indicates that cash generated by the investment will be sufficient to repay the principal and the annual interest charged on the project. With the increase of plant capacity the investment becomes more attractive.

Payback period: It can be calculated as:

$$\text{Payback period} = \frac{\text{Intial investment}}{\text{Net annual cash inf low}}$$

Because the cash flow associated with an investment project changes from year to year, the simple payback formula cannot be used. The Payback period is calculated as follows:

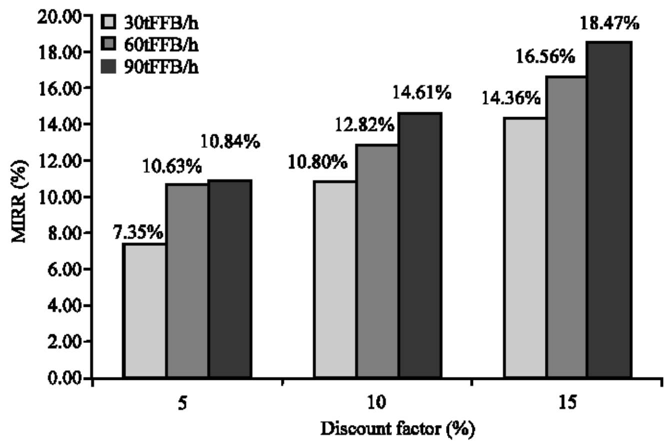

Fig. 3: Modified internal rate of return (MIRR) versus discount factor for clean development mechanism project with different plant capacity

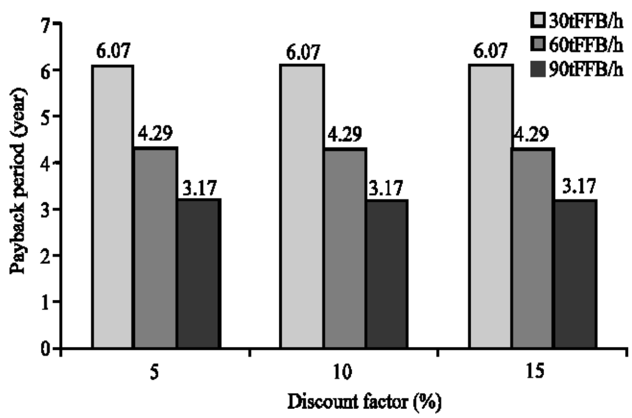

Fig. 4: Payback period at different discount rate for different plant capacity with clean development mechanism

Table 7: Modified internal rate of return calculated at difference mill capacity without clean development mechanism

	Reinvestment rate (%)		
Mill capacity (tFFB/h)	5	10	15
30	3.98	7.12	10.40
60	3.98	7.12	10.40
90	3.98	7.12	10.40

$$\text{Payback period} = A + \frac{|CF_A|}{CF_{A+1}} \quad (3)$$

Where:

A = Last negative number of cumulative cash flow

CF_A = Cumulative cash flow

CF_{A+1} = The next cumulative year

Table 8: Payback periods at difference mill capacity without clean development mechanism

	Net present value		
	discount factor (%) ($years^{-1}$)		
Mill capacity (tFFB/h)	5	10	15
30	13.79	13.79	13.79
60	13.79	13.79	13.79
90	13.79	13.79	13.79

The payback period at different discount rates for different capacity is given in Figure 4 for Clean Development Mechanism (CDM) project. In Table 8 the value for without CDM project is presented. As payback period represents the number of years in which the investment is expected to 'pay for itself' and generation profit. Hence shorter payback period indicates that the investment is viable.

The present results indicated that Payback period for all mill capacity without CDM will take the same amount of time to break even on investment. Comparing results for both with and without CDM it can be said that the investment with CDM is most attractive with less time taken to recover capital investment.

CONCLUSION

The study confirms that the anaerobic treatment plant POME for generating electricity is technically, financially and economically viable. The conclusions are based on the analysis of results of cost economics of biogas plant of three different sizes, with different discount rates. Through the net present value calculation, it is found that the project is viable at all the three discount factor selected (5, 10 and 15%) for a plant capacity of 30 tFFB/h, 60 tFFB/h and 90 tFFB/h. However, 60 tFFB/h and above is more potential for investment. From the calculations, it can be summarized that the initial investment can be recovered in 3.17, 4.29 and 6.07 years for 90, 60 and 30 tFFB/h plant, respectively when the capacity factor is 100. The bigger the plant size, the shorter the payback period. In addition to the direct monetary benefits from the project, the Biogas Project will also gain a few indirect benefits to the nation as well as listed below:

- Utilization of renewable energy from POME
- Improved effluent discharge standard which will protect the water bodies from contamination. Thus complying with the DOE standard discharge limit
- Reduction of palm oil industry contribution to the accelerated global warming or climate change by trapping and utilizing methane as renewable energy

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