INTEGRATED ASSESSMENT OF PALM OIL MILL RESIDUES TO SUSTAINABLE ELECTRICITY (POMR-SE): A CASE STUDY FROM PENINSULAR MALAYSIA

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ABSTRACT

As the second largest crude palm oil producer in the world, Malaysia is blessed with abundant renewable energy resources from the harvesting and milling process of the palm oil fresh fruit bunches. The quantity of this resources of oil palm fronds and trunks, empty fruit bunches (EFB), palm kernel shell (PKS), palm fibres, and palm oil mill effluent (POME) suggest a high potential for 'green' electricity generation for local and the national electricity grids in addition to meeting the needs of the palm oil mills' own demand for heat and electricity self-sufficiency. Despite having real potential to the economic, environmental and societal benefits, the actual potential that such resources make or could make to Malaysia's renewable energy supply has not been thoroughly evaluated. It is known that the capital expenditure for the renewable energy conversion technology is more costly than the conventional fossil fuel generation; however selecting a suitable resource as the feedstock and optimizing generation plant scale could have a significant impact on the economic viability of the technology. This study presents aspects of our current techno-economic research to identify the optimal configurations for efficient system for palm oil mill residues to sustainable electricity (POMR-SE) generation through the combustion of EFB and/or biogas from anaerobic digestion of POME in Peninsular Malaysia. The factors that influence the optimal scale POMR-SE are outlined and recommendations made on enabling factors and strategic pathways to stimulate the technological progress and wider deployment of POMR-SE.

Keywords: palm oil mills, oil palm residues, electricity generation, techno-economic modelling, Peninsular Malaysia

INTRODUCTION

The use of palm oil mill residues as the feedstock for electricity generation has become of national interest in Malaysia. Since renewable energy (RE) officially became the fifth fuel after oil, gas, coal and hydro in 2000 under the 8th Malaysia Plan, the potential for generating electricity from RE resources has been explored [1-3]. The original aim of this exploration was to diversify the national energy mixture in order to reduce excessive use of fossil fuel, alleviate the effect of the global oil crisis while preserve the finite natural resources and increase the country's energy security (Malaysia is expected to become net oil importer by 2030) [4]. As the second largest crude palm oil producer in the world, the potential for electricity generation from this resource is very promising. In 2012, there were 248 palm oil mills (POM) operated in Peninsular Malaysia. Approximately 60 million tonnes of fresh fruit bunches (FFB) are processed annually for crude palm oil and palm kernel oil which also produces solid biomass residues (notably empty fruit bunches (EFB) and palm kernel shells (PKS)) and a liquid residue/waste palm oil mill effluent (POME) [5]. The high calorific value of the EFB and the high organic content of POME make them very useful energy resources for heat and electricity generation. Hypothetically, a total of about 5,750,000 MWh (800 MW capacity) and 1,200,000 MWh (168 MW capacity) of low carbon electricity could have been generated from combusting the EFB and the biogas extracted from anaerobic digestion of POME in 2012. These amounts, of which only a very small fraction (approx. 288, 000 MWh) were actually generated, are very close to the optimistic goal of having 985MW of green electricity in the 10th Malaysia Plan [6].

Although the potential for the POM to be independent power producers (IPPs) has been scientifically confirmed and approved by the government, the full potential has not been realized and success has been limited [7, 8]. This has been suggested to be due to various economic and technical barriers such as high capital expenditure, unattractive return on investment, low economic potential, inconsistent feedstock availability, non-optimal generation plant size and low overall efficiency of the combined heat and power (CHP) plant [9-11]. There remains considerable uncertainty over these factors and over how to bridge this gap between potential and implementation [12, 13] .

Palm Oil Mill Residue to Sustainable Electricity (POMR-SE)

This study focuses on combined heat and power (CHP) systems which are well-established integrated energy systems that converts the energy resources into useful heat and power. The energy resources commonly used in CHP range from fossil fuel like coal and natural gas to a renewable fuels like biomass and biogas.

Numerous studies focusing on adopting CHP in biomass based power plant has affirmed the appropriateness and suitability of this system to generate sustainable, low carbon heat and electricity. The heat and electricity generated can be used to make the industries self-sufficient and any surplus electricity feed in-to the grid [14-16]. Several CHP configurations to convert different types of biomass fuel to electricity and heat have been described. For example, [17] utilized residues from Jathopha for low carbon heat and electricity, [18] investigated the simultaneous tri-generation of heat, power and cooling from palm based biomass and [19] assessed the technological and economic feasibility of the production of methanol and CHP from various biomass feedstock. These and many other studies demonstrate the versatility of CHP as a platform to convert biomass feedstock to useful heat and power.

In the present study, EFB and biogas from anaerobic digestion of the POME are used as the feedstock for the CHP. As the two major residues from palm oil processing, they creates substantial waste handling and management issues for POMs. Currently, mills often leave surplus EFB to biodegrade informally and although they are introducing covering and methane capture system to treat the POME, with a few exceptions, rather little attention is currently given to recover energy or add value to these residues [20, 21].

Suitable Feedstock for POMR-SE

The selection of suitable feedstock for electricity generation is entirely dependent on the original aim of utilising the resources. Both EFB and biogas capable of generating electricity and each resources has its own advantages. It is illusory to name a single source that can satisfy all the three dimensions (e.g. technical, economic, environment). A summary of a results from a considerable amount of theoretical analysis and modelling of various practical case study to examine the capacity POMs to generate surplus electricity for grid export, both EFBs and biogas from POME is presented in Table 1. This result is for an in-house POMR-SE which it is built within the vicinity of the existing mills having an economic lifetime of 15 years.

POMs Size	Small		Medium		Large	
	EFBs	Biogas	EFBs	Biogas	EFBs	Biogas
Technical Assessment Results						
Generation Capacity (MW)	1.80	7.90	8.90	39.20	21.00	94.00
Total Electricity Generated (GWh/y)	14.20	62.80	70.70	131.80	169.80	753.20
Net Electricity to Grid (GWh/y)	10.20	53.70	52.20	86.50	125.20	644.40
Economic Assessment Results						
ROI (%)	-107	-141	1	-288	60	-273
Payback Period (years)	>15	>15	8.00	>15	6.30	>15
Environmental Assessment Results						
GHG Emission Saving (t CO_{2eq}/y)	8,000	36,000	41,000	184,000	99,000	443,000

Table 1. In-house POMR-SE assessment result

The available amount of EFBs and biogas from small-, medium- and large- scale mills are capable of generating adequate electricity for the mill electricity self-sufficiency, parasitic load of the electricity generation infrastructure and to supply to the local and national grid. Altogether, it can be seen that biogas has higher technical potential with capability to generate more electricity as compare to EFBs in all mills. This is due to the proportion of POME produced from the production of CPO is higher than EFB and it is in line with the results previously discussed by [22]. The EFB on the other hand has higher economic viability than biogas when the ROI value increases with increasing generation plant size until it reaches a maximum value at 60%. The same trends can be observed for the payback period when larger scale system takes less time to make profit. The ROI was found to be at negative value for all biogas system suggesting the revenues obtained from the system is not enough to cover the cost of the investment. The payback period for the system is found to be beyond the system economic lifetime.

It is evident from the environmental assessment result, biogas appear to have higher cumulative greenhouse gas (GHG) emission saving as compared to the EFB as a result of having higher electricity generation capacity.

Optimal Capacity of POMR-SE

Since capital expenditure for the technology for renewable electricity generation from biomass residues is generally greater than for conventional fossil fuel generation, optimizing the generation plant capacity has a significant impact on the economic competitiveness of the renewable technology. Renewable energy technologies are still evaluated primarily from commercial rather than environmental or social responsibility perspective, the optimisation process in this work has sought ROI of 20% for the project in order for it to be considered as financially sustainable and sufficiently remunerative. This level is clearly somewhat less than the ROI of 74% and payback period of 6.75 years noted by [23] for palm oil cultivation. Assuming 100% usage of a POM's EFB and based on the current economic and regulatory setting, this study identifies that the electricity generation plant at a 12.4 MW scale is able to provide a 20% ROI; this also falls within the current mill production capacities of some 22 mills in Peninsular Malaysia (see Table 2). Details comparison between EFB and biogas are also presented in Table 2 for a 20% ROI in Table 3 for a 75% ROI. Under the biogas option, no eligible mills can operate at the necessary t EFB /hr production capacity to achieve a 20% ROI because the current maximum mill production capacity in Peninsular Malaysia is 120 t FFB/hr.

In this instance, POMR-SE generation systems utilising biogas as the feedstock are unable to achieve the minimum optimisation criterion of 20% ROI and neither EFB nor biogas system achieve a 75% ROI. Our analysis suggests that EFB shows the greatest potential to be the more economically viable feedstock for POMR-SE.

Figure 1 shows the proportion of the optimal size mills for POMR-SE using EFB as (out of 235 active mills in Peninsular Malaysia), the proportion of the total amount available EFB (11,852,602 tonnes) and proportion of the policy target for electricity generation capacity from palm residues for year 2020 (800 MW) that can be achieved.

Table 2. Size of generation plant to achieve a 20% ROI

Parameters	EFB	Biogas
Mill Production Capacity (t FFB/hr)	70	500
Electricity Generation Capacity (MW)	12.4	392.0
Payback Period (years)	7.4	7.4
Eligible Mills (nos)	22	0*
Cumulative Generation Capacity (MW)	272.8	0

*current max. mill production capacity in Peninsular Malaysia is 120 t FFB/hr

Table 3. Size of generation plant to achieve a 75% ROI

Parameters	EFB	Biogas
Mill Production Capacity (t FFB/hr)	147	1000
Electricity Generation Capacity (MW)	26.0	784.5
Payback Period (years)	6.0	6.0
Eligible Mills (nos)	0*	0*
Cumulative Generation Capacity (MW)	0	0

*current max. mill production capacity in Peninsular Malaysia is 120 t FFB/hr

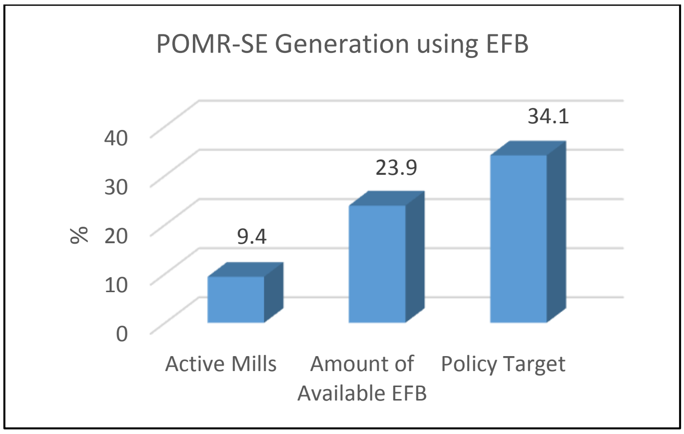

Figure 1. Contribution of economically optimal PO mills and capacity for POMR-SE using EFB in Peninsular Malaysia.

The results of this study indicate that less than 10% of the active mills in Peninsular Malaysia would be able to participate in an economically viable way (20% ROI) utilising approximately 24% of the available amount of EFB. The potentially eligible POMs are also limited only to the large scale mills. It is also clear that only 34% of the policy target in 2020 would be achieved if all these mills participated.

This study has also suggested that there is scope to develop new POMR-SE electricity generation capability that is economically viable. One approach to increasing capacity for this could be via 'cooperative generation' in a technology sharing concept whereby appropriate scaled generation plant is shared by numbers of the existing mills as suggested in some published studies [23, 24, 3]. However, to date such proposal have been unable to demonstrate their economically viability due to various factors such as high influences of the feedstock transportation cost, lack of heat demand from the mill's routine operations to maximising the economic return and limited quota made available to supply the surplus electricity to the local and national grid. The predictive modelling of the 'cooperative generation' POMR-SE system is developed and tested to assess its technical and economic feasibility. The model includes the feedstock cost and feedstock transportation cost to the variable operational cost of the POMR-SE. The technical and economic feasibility of the model is assessed according to the procedure as describe for in-house electricity generation. The result from two case studies indicate that 'cooperative generation' will required bigger generation scale (26 MW- 30 MW) in order to meet the optimization criterion. It also has longer payback period and to certain extend are practically not feasible. Several factors have been identified as the blockade for the realization of the 'cooperative generation' such as severe impact of the additional feedstock cost and feedstock transportation cost, drastic reduction of saving from surplus heat optimisation and the revenue from selling the electricity to the grid is inadequate to recover the cost of the investment. It should be mentioned at this point that the economic performance of the POMR-SE were relatively sensitive to any changes in either the capital or operational cost as well as fluctuation of the revenue streams [25, 26]. Therefore, more detail work need to be carried out to further improve the feasibility of the 'cooperative generation'.

A scalability test was therefore conducted in our study to find an appropriate optimal size for the in-house electricity generation in order to stimulate the uptake of POMR-SE technology and to increase the number of eligible mills, to better use the available resources and to achieve the policy target. The first test was relevant to medium scale mills with a processing capacity of 50 tonne FFB/hour since most of the active mills in Peninsular Malaysia fall into this category. At a 90% utilisation rate of the available EFB from the mill (previously was 100% utilisation rate), using the same assessment methodology, the new optimal scale size now reduced to 6.90 MW.

With this new optimal scale, the number of eligible mills increased to 95 mills (40% of all Peninsular Malaysia mills) and a 66% utilisation rate of available EFB. Hypothetically, the cumulative generation capacity from the eligible mills rises to 655 MW which is more than double from the previous contribution from the 12.40 MW optimal size. On top of significantly improve the performance of POMR-SE, the new optimal size also contributes to a 16% reduction in the capital expenditure of the generation system. From Figure 2, there is a clear increase in the cumulative generation capacity with a significant improvement on the policy target achievement to approximately 82%.

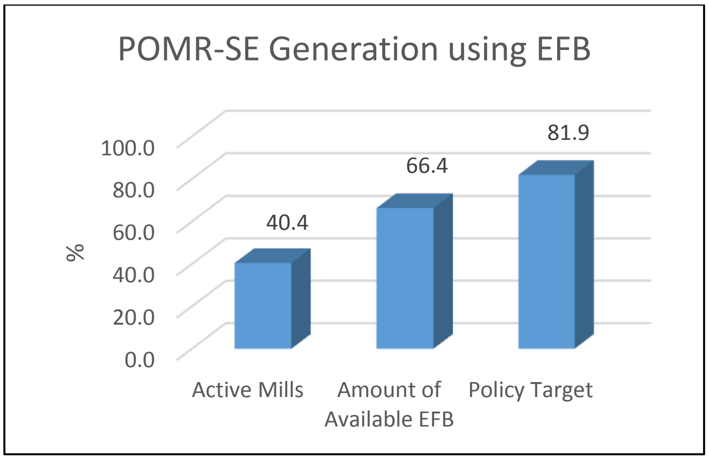

Figure 2. Contribution of revised optimal scale of POMR-SE using EFB on Medium Scale Mills

CONCLUSION

The present study was designed to determine the potential for POMR-SE in Peninsular Malaysia, the optimal size of the POMR-SE to achieve 20% ROI and the number of mills that could participate in economically viable generation of renewable electricity, the feedstock utilisation rate and contribution towards the national renewable energy policy target. The following initial conclusions can be drawn from the present study:

1. Selection of suitable feedstock, appropriate technology and operation at the optimal size improves the economic feasibility of the system
2. EFB POMR-SE has better economic performance while biogas POMR-SE is more environmental friendly
3. Eligibility to become designated independent power producers (IPP) in Peninsular Malaysia is only limited to medium to large scale palm oil mills.

These findings have important implication for the selection of appropriate technological and investment opportunities to help reduce the gap between aspiration for, and implementation of, renewable, sustainable electricity generation from palm oil mill residues in Peninsular Malaysia.

REFERENCES

[1] Yusoff, S., (2006). Renewable energy from palm oil – innovation on effective utilization of waste. *Journal of Cleaner Production*, 14(1), 87–93.

[2] Sumathi, S., Chai, S.P. & Mohamed, A.R. (2008). Utilization of oil palm as a source of renewable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, 12(9), 2404–2421.

[3] Aghamohammadi, N. (2016). An Investigation of Sustainable Power Generation from Oil Palm Biomass: A Case Study in Sarawak. *Sustainability*, 8(5), 416.

[4] Ahmad, S., Kadir, M.Z.A.A. & Shafie, S. (2011). Current perspective of the renewable energy development in

Malaysia. *Renewable and Sustainable Energy Reviews*, 15(2), 897–904.
[5] Loh, S.K. (2016). The potential of the Malaysian oil palm biomass as a renewable energy source. Energy Conversion and Management.
[6] KeTTHA (2008). National Renewable Energy Policy and Action Plan - Malaysia. *National Renewable energy Policy*, (November), 90.
[7] Ali, R., Daut, I. & Taib, S. (2012). A review on existing and future energy sources for electrical power generation in Malaysia. *Renewable and Sustainable Energy Reviews*, 16(6), 4047–4055.
[8] Seong, C. & Lalchand, G. (2014). A review on sustainable power generation in Malaysia to 2030 : Historical perspective , current assessment , and future strategies. *Renewable and Sustainable Energy Reviews*, 29, 952–960.
[9] Trudgill, S. & Richards, K. (1997). Environmental science and policy: Generalizations and context sensitivity. *Transactions of the Institute of British Geographers*, 22(1), 5–12.
[10] Richard, T.L. (2010). Challenges in scaling up biofuels infrastructure. *Science (New York, N.Y.)*, 329(5993), 793–796.
[11] Akhtari, S., Sowlati, T. & Day, K. (2014). The effects of variations in supply accessibility and amount on the economics of using regional forest biomass for generating district heat. *Energy*, 67, 631–640.
[12] Alam, S.S. (2016). A Survey on Renewable Energy Development in Malaysia: Current Status, Problems and Prospects. *Environmental and Climate Technologies*, 17(1), 5–17.
[13] Yatim, P. (2016). Energy policy shifts towards sustainable energy future for Malaysia. *Clean Technologies and Environmental Policy*.
[14] Broek, R. Van den, Faaij, A. & Wijk, A. van, (1996). Biomass combustion for power generation. *Biomass and Bioenergy*, 11(4), 271–281.
[15] Wood, S.R. & Rowley, P.N. (2011). A techno-economic analysis of small-scale, biomass-fuelled combined heat and power for community housing. *Biomass and Bioenergy*, 35(9), 3849–3858.
[16] McIlveen-Wright, D.R. (2013). A technical and economic analysis of three large scale biomass combustion plants in the UK. *Applied Energy*, 112, 396–404.
[17] Martinez-hernandez, E. (2014). Process integration , energy and GHG emission analyses of Jatropha -based biorefinery systems, 105–124.
[18] Andiappan, V. & Ng, D.K.S. (2016). Synthesis of tri-generation systems : Technology selection , sizing and redundancy allocation based on operational strategy. *Computers and Chemical Engineering*, 91, 380–391.
[19] Ng, K.S. & Sadhukhan, J. (2011). Process integration and economic analysis of bio-oil platform for the production of methanol and combined heat and power. *Biomass and Bioenergy*, 35(3), 1153–1169.
[20] Madaki, Y.S. & Seng, L. (2013). Palm Oil Mill Effluent (Pome) From Malaysia Palm Oil Mills : Waste or Resource. *International Journal of Science, Environment and Technology*, 2(6), 1138–1155.
[21] Ehsan, S. & Wahid, M.A. (2014). Utilization of palm solid residue as a source of renewable and sustainable energy in Malaysia. *Renewable and Sustainable Energy Reviews*, 40, 621–632.
[22] Jaye, I.F.M., Sadhukhan, J. & Murphy, R.J. (2016). Renewable, local electricity generation from palm oil mills: a case study from Peninsular Malaysia. *International Journal of Smart Grid and Clean Energy*, 44(Cop 15), 106–111.
[23] Umar, M.S., Jennings, P. & Urmee, T. (2014). Sustainable electricity generation from oil palm biomass wastes in Malaysia: An industry survey. *Energy*, 67, 496–505.
[24] Ahmed, A., Zahedi, G. & Hashim, H. (2015). Design of decentralized biopower generation and distribution system for developing countries. *Journal of Cleaner Production*, 86, 209–220.
[25] Cameron, J.B., Kumar, A. & Flynn, P.C. (2007). The impact of feedstock cost on technology selection and optimum size. *Biomass and Bioenergy*, 31(2-3), 137–144.
[26] Miao, Z. (2012). Lignocellulosic biomass feedstock transportation alternatives , logistics , equipment confi gurations , and modeling, 351–362.