IOP Conf. Series: Materials Science and Engineering **358** (2018) 012002 doi:10.1088/1757-899X/358/1/012002

Integrated Assessment of Palm Oil Mill Residues to Sustainable Electricity System (POMR-SES): A Case Study from Peninsular Malaysia

I F Md Jaye, J Sadhukhan and R J. Murphy*

Centre of Environment and Sustainability, University of Surrey, UK

i.mdjaye@surrey.ac.uk, j.sadhukhan@surrey.ac.uk, *rj.murphy@surrey.ac.uk

Abstract. Generating electricity from biomass are undeniably gives huge advantages to the energy security, environmental protection and the social development. Nevertheless, it always been negatively claimed as not economically competitive as compared to the conventional electricity generation system using fossil fuel. Due to the unfair subsidies given to renewable energy based fuel and the maturity of conventional electricity generation system, the commercialization of this system is rather discouraging. The uniqueness of the chemical and physical properties of the biomass and the functionality of the system are fully depending on the availability of the biomass resources, the capital expenditure of the system is relatively expensive. To remain competitive, biomass based system must be developed in their most economical form. Therefore the justification of the economies of scale of such system is become essential. This study will provide a comprehensive review of process to select an appropriate size for electricity generation plant from palm oil mill (POM) residues through the combustion of an empty fruit bunch (EFB) and biogas from the anaerobic digestion of palm oil mill effluent (POME) in Peninsular Malaysia using a mathematical model and simulation using ASPEN Plus software package. The system operated at 4 MW capacity is expected to provide a return on investment (ROI) of 20% with a payback period of 6.5 years. It is notably agreed that the correct selection of generation plant size will have a significant impact on overall economic and environmental feasibility of the system.

1. Introduction

The transition towards non-fossil electricity has been an inspiration for many countries of the world for many years. Factors such as the finite nature of fossil fuels, volatility of the global oil market prices, electricity supply security and limiting global warming to no more than 2˚C are among the main drivers for this transition. Lignocellulosic plantation residues (e.g palm oil empty fruit bunches, rubber, sugar cane baggase, forestry and timber processing residues) and their availability, indicate a high potential for use as an alternative fuels for sustainable electricity generation [1]. This potential encompasses several other advantages e.g carbon footprint reduction from electricity generation, facilitating 'waste to resources' transition, supporting integrated waste management system and contributing to local social-economic development [2]. In Malaysia, palm oil reported to be the major commodity harvested between 2000-2014 compared to rice, cocoa and rubber. According to the Malaysia Economic Statistics Time Series 2015 report, 72.7 million tonnes of palm oil fresh fruit bunch (FFB) was harvested from 4.6 million hectares of palm oil cultivation in 2014 [3]. This makes the oil palm industries the largest contributor of plantation residues with more than 95% of the country's total accumulated value. In 2015, it has been further estimated that 175.6 million tonnes wet of field and processing residues was produced from 95.38 million tonnes of FFB [4]. The potential electricity generation capacity from empty fruit bunch (EFB) and biogas from the anaerobic digestion of palm oil mill effluent (POME) in 2015 has been estimated to be 9.7 million MWh and 3.3 million MWh respectively. However, only a very small fraction of these amounts (approx. 13,600 MWh) were actually generated, showing that a substantial gap exists in delivering the full potential of this biomass feedstock for electricity production. To date, relatively few attempts have been made to provide suitable business cases to identify the economies of scale of the generation plant to optimize delivery of both economic and environmental benefits. Such business cases can serve as an appropriate technological and investment solutions to reduce the gap between aspiration for, and implementation of, renewable, sustainable electricity generation from palm oil residues.

2. Objective

The research undertakes a detailed resource and system analysis to identify the opportunities and constraints in developing the maximum potential for electricity generation from the combustion of palm oil EFBs and biogas from POME.

3. Methodology

A comprehensive technical, economic and environmental evaluation for a combined heat and power (CHP) system has been conducted based on the process flowchart in Figure 1. The works has been conducted in five different stages begins with the resource scoping activities to establish the full range of potential generation plant size according to the amount of available residues. The scaling process is based on a combination of top-down and bottom-up resource assessment of the current availability of EFB and POME residues from palm oil mill operations in Peninsular Malaysia. A well-established CHP system was selected for this work due to its capability to co-generate heat and power in the same generation plant and having better overall efficiency as compared to only generating electricity [5,6]. A conventional CHP configurations using multiple combination of input fuels as listed below are used in this work to extend the versatility of the technology.

- Configuration 1 – Conventional CHP configuration using EFB as a single input fuel to the boiler.
- Configuration 2 – Conventional CHP configuration using biogas as a single input fuel to the boiler.
- Configuration 3 – Conventional CHP configuration using EFB and biogas as an input fuels to the boiler.
- Configuration 4 – Conventional CHP configuration using EFB as an input fuel to the boiler and biogas as an input to a gas turbine.

The amount of potential electricity generation from EFB and biogas are obtained from theoretical calculation and simulation process using Aspen Plus software taking consideration of stoichiometric condition of full combustion process as suggested in reference [7]. Such techniques are also been adopted in other CHP technical performance evaluation studies [8,9]. In order to determine the amount of potential electricity generation, the extractable heat from the biomass boiler is first to be quantified using Eq. (1).

$$H_{i,n}^{Out} = M_i^{In} \, CV_i \, n_n^{boiler} \tag{1}$$

where $H_{i,c}^{Out}$ is the total extractable heat from biomass i via biomass boiler in configuration n, M_i^{In} is the fed rate of the biomass i , CV_i is the calorific value of dried biomass i and n_n^{boiler} is the efficiency of the boiler in configuration n. The efficiency of biomass based boiler can reach 80% - 90% when it is installed in a CHP system [10]. For this work, an average boiler efficiency of 80% is used throughout the analysis. The extractable heat from the biomass boiler is then used as the input to produce high pressure superheated steam (50 bar, 500˚C) to full fill the mill's routine operation steam demand and for electricity generation purposes.

IOP Conf. Series: Materials Science and Engineering **358** (2018) 012002 doi:10.1088/1757-899X/358/1/012002

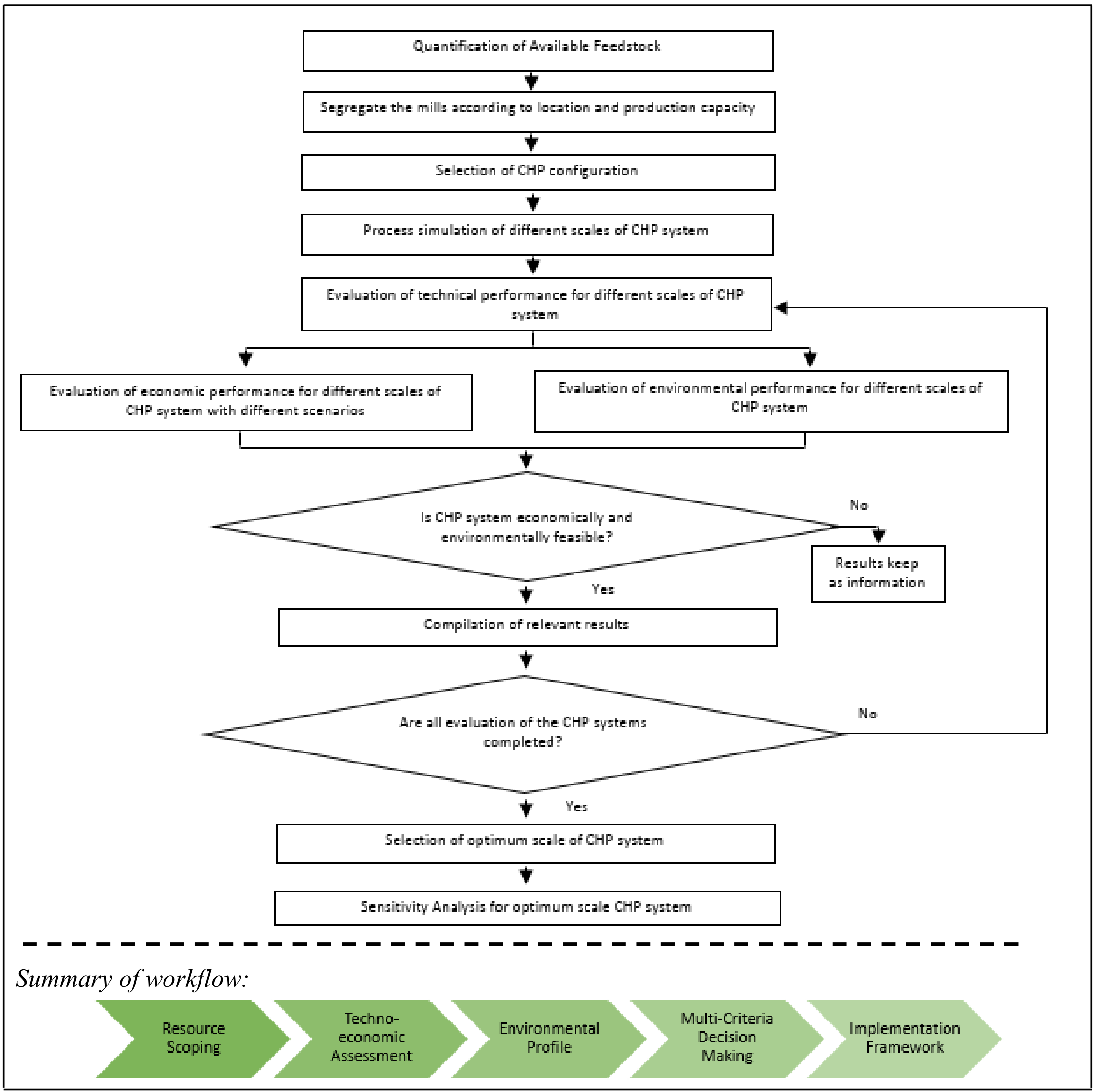

Figure 1: Technological assessment framework for optimizing CHP for oil palm residues

From the amount of extractable heat quantified from Eq. (1), the total mass flow rate of the steam generated (m_{steam}) can be calculated using Eq. (2).

$$H_{i,n}^{Out} = m_{steam}\left[C_p(T_{sat} - T_{BWF}) + \Delta h_{vap} + (h_{sup} - h_v)\right] \quad (2)$$

The operating condition of steam generation given as:

- Specific enthalpy of superheated steam (h_{sup}) = 3433.7 kJ/kg.
- Specific enthalpy of saturated steam (h_v) = 2794.2 kJ/kg at 50 bar.
- Saturation temperature of steam (T_{sat}) = 264˚C at 50 bar.
- Temperature of BFW (T_{BFW}) = 105˚C.
- Heat vaporization of water (Δh_{vap}) = 1639.6 kJ/kg.
- Heat capacity of water (C_p) = 4.187 kJ/kg/˚C.

The available steam flow rate for electricity generation (m_{elec}) can be derived from Eq. (3) where m_{mill} is the steam demand from the mill.

$$m_{elec} = m_{steam} - m_{mill} \quad (3)$$

Note that, the mass flow rate of the steam fed back to the mill must be not more than 50% of the total flow rate of the steam generated to adhere the condensate steam turbine requirement for electricity generation. In due course to maximize the electricity generation potential for this study, the heat from the combustion flue gas is used to dry the EFB from 60% to 11% moisture content [11,12]. Drying the EFB is needed to maximize the recoverable energy from the fuel, improve the efficiency of the boiler and to reduce the air emissions.

A techno-economic assessment spreadsheet is used as a tool to measure the economic and investment feasibility of the CHP system as described in detail in Ng & Sadhukhan and Patel et al. [13,14]. Two different scenarios pertaining the existence of grid connection from the proposed generation location to the national grid is used to represent the actual implementation conditions of such system in Peninsular Malaysia. This scenario will evaluate the volatility of capital and operational expenditure of the CHP system. The assessment method suggested in Wan et al. is adopted for plant lifetime of 15 years and interest rate of 12% [7]. The total capital expenditure (CAPEX) for the CHP is the summation of direct capital cost, indirect capital cost, working capital and cost of installation of the new electricity distribution inter-connection cost. For solid-liquid based electricity generation plant, the summation of direct capital cost, indirect capital cost and working capital can be specified as 5.03 of the total delivered cost of equipment (DCoE). In order to estimate the DCoE, list of required equipment with the designated size is prepared and the concept of economy of scale and capital cost index is used to calibrate the cost to the present DCoE. The operational expenditure (OPEX) for the CHP can be define as the gross value of direct production cost (fixed OPEX + variable OPEX) and miscellaneous cost. The development of POMR-SES will be within the mill compound thus the feedstock will be supplied by the mill with no cost. The number of workers employed is based on the generation plant scale. The workers worked 10 hours per day and paid on the basis of USD 10 per hour. ROI and simple payback period (SPP) and discounted payback period (DPP) are used as an economic and investment indicators to measure the economic and investment competitiveness of the system. The revenue counted for this analysis are coming from selling the surplus electricity to the grid, claiming the eligible FiT rates and the saving from the mill's steam and electricity self-sufficiency. The CHP system was then co-evaluated using life cycle assessment method to establish the CHP individual environmental profile by quantifying the carbon emission saving (CES) per year as compared to the conventional fossil generation [15]. The value of carbon emission saving from the electricity generated in the CHP ($Elec$) can be identified using Eq. (4):

$$CES = Elec\ x\ EF_{grid}\ x\ OH \quad (4)$$

Given the carbon emission factor of electricity from the grid (EF_{grid}) = 0.899 kg CO_2 / kWh and operating hours of the CHP is 8000 hours/year [7]. Multi criteria decision making analysis is employed to justify the appropriate scale of generation for various cases to meet combined/optimized economic and, environment (and, less formally social) constraints to foster future decision making and planning on potential implementations of POMR-SES [16,17]. This equitable assessment results is then compiled and proposed as an effective operational and/or business plan to assist in the implementation of the POMR-SES schemes considering business risk and an equalable balance between human development and sustainable technology.

4. Results & Discussion

4.1 Resource Scoping

The amount of potential electricity generation from EFB and biogas are accounted based on the residues production report obtained from series of visit to selected mills across Peninsular Malaysia and from a full residue production report of 236 POM operated in Peninsular Malaysia obtained from a reliable data base. This allows the full-range of potential electricity generation been translated more accurately. The statistics are then further anticipated using a standard waste-to-energy conversion method demonstrated in [15,16]. These references treated EFB and biogas as a stand-alone fuel for combustion (similar to Configuration 1 and Configuration 2 in this study). The full-range of potential electricity generation is classified into small (< 3 MW), medium (3-10 MW) and large (>10MW). Table 1 summarized the result for the resource scoping phase. From the tabulated results, it was found that Configuration 3 which is combusting EFB and biogas in the same boiler giving the largest potential of electricity generation (25 MW) followed by Configuration 4 (20 MW), Configuration 1 (15 MW) and Configuration 2 (5 MW). However, any mill intended to employ Configuration 1 and/or Configuration 2 to generate electricity must ensure the availability of 4500 tonne EFB and 20000 tonne POME every year to obligate Eq.(3) and the note that following the equation about the mass flow rate of the steam for electricity generation. Therefore, the minimum size for Configuration 1 and Configuration 2 is 0.28 MW and 0.68 MW respectively.

Table 1: Full-range of potential electricity generation from EFB and biogas in Peninsular Malaysia

Items	Standard (MW)	Theoretical Calculation (MW)	Aspen Plus Simulation (MW)
Configuration 1	0.08 – 16.00	0.07 – 15.00	0.08 – 15.00
Configuration 2	0.00 – 4.00	0.00 – 5.00	0.00 – 5.00
Configuration 3	-	1.00 – 20.00	1.00 – 25.00
Configuration 4	-	1.00 – 18.00	1.00 – 20.00

4.2 Techno-economic Assessment

In this work, the techno-economic assessment was conducted for two scenarios to find the optimal scale of the POMR-SES that provide at least 20% ROI, reasonable SPP and DPP. The scenario was selected because the POMR-SES will required a new electricity distribution inter-connection to supply the surplus electricity to the national grid. This will allow an evaluation of the significant effect of new electricity distribution inter-connection cost on the economic performance of the POMR-SES. It was quoted that, the installation cost of new electricity distribution inter-connection is USD 312,500 per kilometer. The distance of the new electricity inter-connection is kept at 5 km. Table 2 illustrates the result of the selected indicator for both scenarios. In order to operate above reasonable chance of being economically viable, the plant should be operated at the optimum size of 4 MW for Scenario 1 and 4.5 MW for Scenario 2. In favor of coping with the ROI and payback period of palm oil mill cultivation, the plant should be running at a scale of 7.5 MW. It was found that, there are a significant effect of new electricity distribution inter-connection cost on the overall economic performance of the system.

Table 2: POMR-SES optimal size economic performance

	Scenario 1			**Scenario 2**		
Plant Size (MW)	ROI (%)	SPP (years)	DPP (years)	ROI (%)	SPP (years)	DPP (years)
0.28	-193.00	5.50	>15.00	-249.00	5.50	>15.00
4.00	20.00	3.00	6.50	3.20	3.00	7.00
4.50	31.00	3.00	5.50	21.00	3.00	6.50
7.50	90.00	2.50	4.50	80.00	2.75	4.50

4.3 Environmental Profile

The environmental profile of the POMR-SES is the measure of the amount of carbon dioxide (CO_2) saving as compared to the conventional central generation that been dominated by fossil fuel. The amount of CO_2 saving based on the optimal size of POMR-SES is shown in Table 3.

Table 3: CO_2 saving from electricity generation from EFB and biogas in Peninsular Malaysia

Plant Size (MW)	Standard (tonne CO_2/y)
0.28	2014
4.00	28800
4.50	32400
7.50	54000

4.4 Multi-Criteria Decision Making
Multi criteria decision making technique is applied to identify the most convincible optimize solution(s) for POMR-SES based on multiple criteria set from the economic and environmental perspectives. In the interest of promoting an effective operational and/or business plan and to attract the stakeholder engagement, the main criteria to be met is providing a ROI of 20% within a reasonable timeframe with admissible amount of CO_2 saving. A dedicated multi criteria decision tree from the two scenarios assessed before can be internalized through Figure 2.

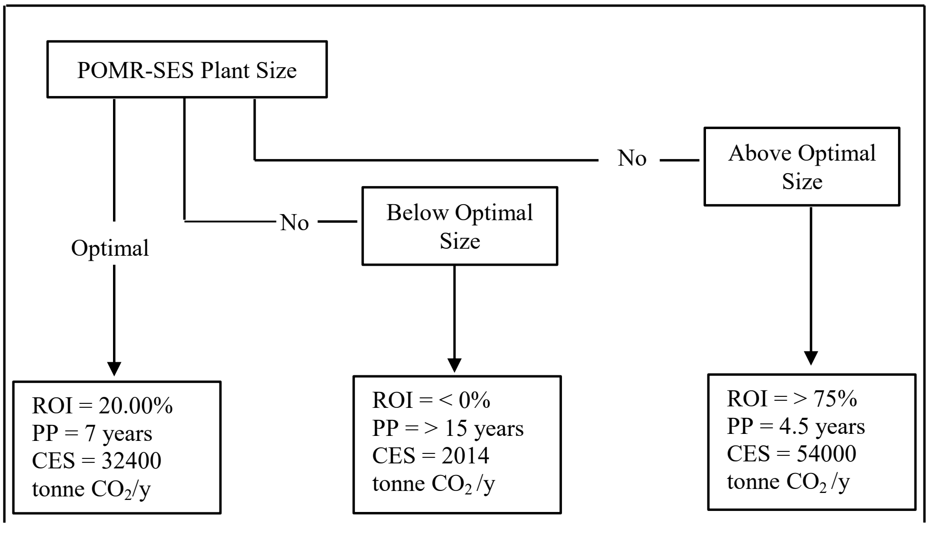

Figure 2: Multi-criteria decision tree

4.5 Implementation Framework
A compilation result of an extensive techno-economic and environmental assessment for site specific optimal size POMR-SES can use as a standard implementation framework to stimulate the good business environment for the investor and other stakeholders to get in to the renewable energy electricity generation based business.

5. Conclusion
The relatively slow pace of implementation of electricity generation from PO mills in Peninsular Malaysia does not appear to be due to a lack of available technologies, specific scientific data or even some supportive policies. Rather is seems to result from shortage of systematic, techno-economic and risk modelling and demonstration of specific benefits and uncertainties on a case-by-case basis and on inertia by the industry to enter the space due to understandable priority focus on meeting demand in robust primary markets for crude palm oil. From the perspective of economic viability, only medium size and large size POMR-SES are eligible to become the independent power producers (IPP) in Peninsular Malaysia. To qualify as one of the IPP, the mill should produce at least 65,000 tonnes of EFB and about 136,000 tonnes of POME every year. The research that described in this paper to identify the optimal business, environmental and societal cases for POMR-SES scheme should be consider as the necessary steps in encouraging the PO industry and government institutions to develop investment and support mechanism that will enables this important potential resources of sustainable, low carbon electricity to be tapped effectively.

References
[1] Shafie S, Mahlia T, Masjuki H 2012 A review on electricity generation based on biomass residue in Malaysia *Renewable and Sustainable Energy Reviews*, **16(8)**, pp.5879-5889
[2] Sadhukhan J, Martinez-Hernandez E, Ng KS 2016 Biorefinery value chain creation, *Chemical Engineering Research and Design*, **107**, pp. 1-3

[3] Department of Statistics Malaysia 2015 *Malaysia Economic Time Series*, pp. 1-277
[4] Loh SK 2016 The potential of the Malaysian oil palm biomass as a renewable energy source, *Energy Conversion Management*
[5] Wood S R, Rowley P N 2011 A technoeconomic analysis of small scale, biomas-fueled combined heat and power for community housing, *Biomass and Bioenergy*, **35(9)**, pp.3849-3858
[6] McIlveen-Wright D R, Huang Y, Rezvani S, Redpath D, Anderson M, Dave A, Hewit N J 2013 A technical and economic analysis of three large scale biomass combustion plants in the UK, *Applied Energy*
[7] Wan Y K, Sadhukhan J, Ng D K S 2015 Techno-economic evaluation of intergrated bioethanol plant for sago starch processing facility, *Chemical Engineering Research and Design*
[8] Hunpinyo P, Narataruksa P, Tungkamani S, Pana-Suppamassadu K, Chollacoop N 2013 Evaluation of techno-economic feasibility biomass-to-energy by using ASPEN Plus: A case study of Thailand, *Energy Procedia*, **42(August)**, 640-649
[9] Ying T, Lam G, Zhang Y, Wai C 2014 Chemical engineering research and design an optimization of biomass power plant, *Chemical Engineering Research and Design*, **92(8)**, 1412-1427
[10] Thornley P, Upham P, Huang Y, Rezvani S, Brammer J, Roger J 2009 Intergrated assessment of bioelectricity technology options, *Energy Policy*, **37(3)**, 890-903
[11] Gebreegziabher T, Olajire A, Yu Z 2014 Biomass drying for an intergrated power plant: effective utilization of waste heat, *European Symposium on Computer Aided Process Engineering*, **Vol 33** gbfg
[12] Li H, Chen Q, Zhang X, Finney K N, Shari V N, Swithenbank J 2012, Evaluation of a biomass drying process using waste heat from process industries: a case study, **35**, 71-80
[13] Ng K S, Sadhukhan J 2011, Process intergration and economic analysis of bio-oil platform for the production of methanol and combined heat and power. *Biomass and Bioenergy*, **35(3)**, 1153-1169
[14] Patel C, Lettieri P, Simons S J R, Germana A 2011, Techno-economic performance analysis of energy production from biomass at different scales in the UK context, *Chemical Engineering Journal*, **171(3)**,986-996
[15] Rahim K A 2014, Towards low carbon economy via carbon intensity reduction in Malaysia, **5(16)**, 123-133
[16] Catrinu M D 2006, Decision aid for planning local energy system: application of multi-criteria decision analysis, *Electrical Power Engineering*
[17] Scott J A, Ho W, Dey P K 2012, A review of multi-criteria decision-making methods for bioenergy system, *Energy*, **42(1)**, 146-156