

# A study of palm biomass processing strategy in Sarawak

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**Abstract.** In the past decades, palm industry is booming due to its profitable nature. An environmental concern regarding on the palm industry is the enormous amount of waste produced from palm industry. The waste produced or palm biomass is one significant renewable energy source and raw material for value-added products like fiber mats, activated carbon, dried fiber, bio-fertilizer and et cetera in Malaysia. There is a need to establish the palm biomass industry for the recovery of palm biomass for efficient utilization and waste reduction. The development of the industry is strongly depending on the two reasons, the availability and supply consistency of palm biomass as well as the availability of palm biomass processing facilities. In Malaysia, the development of palm biomass industry is lagging due to the lack of mature commercial technology and difficult logistic planning as a result of scattered locality of palm oil mill, where palm biomass is generated. Two main studies have been carried out in this research work: i) industrial study of the feasibility of decentralized and centralized palm biomass processing in Sarawak and ii) development of a systematic and optimized palm biomass processing planning for the development of palm biomass industry in Sarawak, Malaysia. Mathematical optimization technique is used in this work to model the above case scenario for biomass processing to achieve maximum economic potential and resource feasibility. An industrial study of palm biomass processing strategy in Sarawak has been carried out to evaluate the optimality of centralized processing and decentralize processing of the local biomass industry. An optimal biomass processing strategy is achieved.

## 1. Introduction

In a few decades time the area of oil palm plantation have increased drastically in Malaysia. The main product of oil palm is crude palm oil (CPO) which is extracted from palm fresh fruit bunch (FFB). FFB is typically processed in palm oil mill (POM). Along with FFB processing, waste is produced. The organic wastes generated are collectively termed palm biomass. The quantity of palm biomass increases in proportion with the increasing number of POM, POM processing capacity or amount of FFB being processed.

With the increasing volume of palm biomass, the disposal of palm biomass has become one source of pollution which has raised the concern of environmentalists and citizens. Due to the increased concern on environmental impacts and sustainability performance, researchers are contributing efforts to investigate the utilization of palm biomass for recovery and conversion through waste-to-wealth strategy to convert biomass into bio-energy and value-added products. Despite numerous researches that have been carried out by individuals, research institutions and universities, there is only limited number of



palm biomass technologies being commercialized due to the lack of confidence towards palm biomass value-added products as well as the lack of investment from investors. Besides, the scattered location of palm biomass sources has also needs to be tackled if biomass processing plant were to be set-up and operated efficiently. Biomass availability has to be secured and these processing facilities have to be logistically connected. The low density of biomass and its high moisture content have contributed to the infeasibility of logistic activity to collect biomass for centralize processing or product distribution in most countries. These factors have resulted in the slow development of biomass industry in Malaysia.

The key issue for the production system is the transportation of biomass, storage as well as supply chain system design. Centralize and decentralize processing of biomass is a major concern for effective supply network design and biomass industry development. [1] asserted that the general decomposition scheme was proposed for the generation of smaller sub-systems for the solution of worldwide optimality. The study aims to solve for each decentralized problem to the optimality as well as the original problem by integration of optimal schedule of each sub-system [1].

[2] had carried out a study on the economic evaluation of decentralized and centralized gasification plant. It was concluded that the decentralized strategies results in the high capital and operating costs of fast pyrolysis process and was hindering any benefits from the cost-effective transportation of the bio-oil from biomass plant to the gasification plant [2]. Then, [3] made comparison between the centralized and decentralized strategy on the processing system of the cellulosic biomass biorefining systems. The cost analysis showed better performance for centralized small-scale biorefineries and decentralized large-scale biorefineries [3]. Whereas, the environmental impact of the processing plant increased proportionally with the size of factory [3].

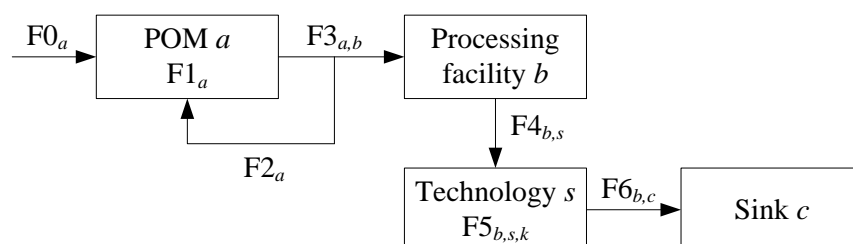
Research works have been done on the economic evaluation on the centralized and decentralized on the processing plant. However, the performances of cases vary with the properties of biomasses and localized scenario. None or less local study on the performance centralized and decentralized strategies towards palm biomass industry in Sarawak, Malaysia. In this work, the local performance of centralized and decentralized strategies and feasibility of the palm biomass processing strategy is simulated and evaluated.

## 2. Problem statement

The problem to be stated in this work is addressed as follows: FFB are processed in a set of palm oil mill source  $a \in A$  and the biomass is send to a set of centralized or decentralized processing hubs  $b \in B$  and eventually to sink  $c \in C$ . The problem is divided into two parts: (i) industrial study of the feasibility of decentralized and centralized palm biomass processing in Sarawak, and (ii) development of an optimized palm biomass processing strategy for the development of palm biomass industry in Sarawak, Malaysia.

## 3. Model formulation

Figure 1 denotes the summary of the methodology which the processed FFB is processed in POM  $a$  and the biomass is sent to processing hub  $b$  for conversion of value-added product and eventually to sink  $c$  for exportation purpose. The details formulation is shown in the following section.



**Figure 1.** Summary of Methodology.

### 3.1. Flowrate of biomass in POM $a$

Palm biomass consists of multicomponent, such as empty fruit bunch (EFB), palm oil mill effluent (POME), palm kernel shell (PKS), oil palm frond (OPF) and so on. The availability of the biomass in POM is represented as below.

$$F1_a = F0_a \times COM_i \quad a \in A, i \in I \quad (1a)$$

where  $a$  is POM,  $a \in A$ ,  $A = \{1, 2, 3, \dots, 39\}$ ;  $F1_a$  is the flowrate of EFB in the POM  $a$  (t/h);  $F0_a$  is the flowrate of FFB in POM  $a$  (t/h); and  $COM_i$  is the fraction of the fraction of multicomponent of palm biomass  $i$  generated from FFB processing.

However, EFB is the only raw material used in the case study. Therefore, equation (1a) can be simplified to the following:

$$F1_a = F0_a \times COM \quad a \in A \quad (1b)$$

where  $COM$  is the fraction of FFB to generate EFB.

Typically, palm biomass is either dumped for mulching or recovered for further utilization. Biomass can be incinerated directly as fuel source to generate heat and/or electricity or recovered for value-added product generation. The amount of palm biomass recovered for further processing is represented below:

$$F2_a = F1_a \times REC \quad a \in A \quad (2)$$

where  $F2_a$  is the flowrate of EFB retained for consumption in POM  $a$  (t/h); and  $REC$  is the fraction of palm biomass (assumed to be 0.8) retained for POM's self-consumption.

### 3.2. Flowrate from POM $a$ to processing hub $b$

The remaining palm biomass from POM  $a$  is sent to the processing facility  $b$  for further processing. The centralized palm biomass processing facilities, processing hub  $b$  are planned to be located in the center of a cluster of POM  $a$ .

$$\sum_{b \in B} F3_{a,b} = F1_a - F2_a \quad a \in A, b \in B \quad (3)$$

where  $F3_{a,b}$  is the palm biomass flowrate from POM  $a$  to processing hub  $b$  (t/h).

### 3.3. Conversion of EFB into value-added product

In the palm biomass processing facilities, palm biomass is sent to selected biomass processing technology with flowrate  $F4_{b,s}$  (t/h) for additional processing to convert the biomass into value-added products.

$$F4_{b,s} \times PR_{s,k} = F5_{b,s,k} \quad b \in B, s \in S, k \in K \quad (4)$$

where  $s$  is the technology for biomass processing,  $s \in S$ ,  $S = \{\text{Drying, Densification}\}$ ;  $k$  is the palm biomass products,  $k \in K$ ,  $K = \{\text{Dry Long Fibre (DLF), Pellet (PLT)}\}$ ;  $PR_{s,k}$  is the rate of conversion of technology  $s$  to produce product  $k$ ; and  $F5_{b,s,k}$  is the flowrate of product in palm biomass processing hub  $b$  produced from technology  $s$  (t/h).

The amount of palm biomass is sent to technology  $s$  and the amount is limited with an upper boundary for a maximum operating capacity as well as a lower boundary to constraint for the minimum operating capacity to achievement an optimal operating efficiency of the equipment:

$$F4_{b,s} \leq UB_s \quad b \in B, s \in S \quad (5a)$$

$$F4_{b,s} \geq LB_s \quad b \in B, s \in S \quad (5b)$$

where  $UB_s$  and  $LB_s$  are the upper boundary and lower boundary of the operating capacity for technology  $s$ . 25% of the maximum operating capacity is taken as the lower boundary as the minimum operational flowrate of the equipment; while the upper boundary of the maximum operating capacity is taken to be 2.5 t/h.

### 3.4. Flowrate of value-added product to port

The final product will be sent to sink  $c$  for exportation which is represented below:

$$\sum_{b \in B, s \in S, k \in K} F5_{b,s,k} = \sum_{c \in C} F6_{b,c} \quad b \in B, c \in C, s \in S, k \in K \quad (6)$$

where  $c$  is the set index of sink,  $c \in C$ ,  $C = \{1, 2, 3, 4\}$ ; and  $F6_{b,c}$  is the flowrate of product from palm biomass processing hub  $b$  to sink  $c$ .

### 3.5. Flowrate from POM $a$ to processing hub $b$

The distance travelled to deliver EFB from source  $a$  to hub  $b$  is considered in this work. The great-circle distance of EFB delivered from source point to the processing facilities to the sink  $c$  is estimated using Spherical Law of Cosines. Consideration of the location of processing hub  $b$  is based on the two aspects, i) location of POM  $a$ , which its location is within 150 km from the processing hub, and ii) capacity of processing hub  $b$ , which its capacity is not higher than the upper bound set.

$$\text{Distance}_{a,b} = \text{acos}[\sin(\text{lat}_a) \times \sin(\text{lat}_b) + \cos(\text{lat}_a) \times \cos(\text{lat}_b) \times \cos(\text{lon}_b - \text{lon}_a)] \times r \quad a \in A, b \in B \quad (7a)$$

$$\text{Distance}_{b,c} = \text{acos}[\sin(\text{lat}_b) \times \sin(\text{lat}_c) + \cos(\text{lat}_b) \times \cos(\text{lat}_c) \times \cos(\text{lon}_c - \text{lon}_b)] \times r \quad b \in B, c \in C \quad (7b)$$

where  $\text{lat}_a$ ,  $\text{lat}_b$ ,  $\text{lon}_a$  and  $\text{lon}_b$  are the latitude and longitude coordinates of the corresponding POM  $a$  and the centralized processing hub  $b$ ;

The upper boundary is estimated to be 150 km due to large coverage area of Sarawak, Malaysia;  $\text{lat}_c$  and  $\text{lon}_c$  are the latitude and longitude coordinates of sink  $c$ ; and  $r$  is the radius of earth (6371 km).

### 3.6. Economic evaluation

The transportation cost of EFB,  $C_d$  (MYR/d), is estimated and represented by the equation below:

$$C_d = (\sum_{a \in A, b \in B} \text{Distance}_{a,b} \times F3_{a,b} + \sum_{b \in B, c \in C} \text{Distance}_{b,c} \times F6_{b,c}) \times (\text{TCP}/30) \times t^h \quad (8)$$

where  $C_d$  is the total transportation cost to deliver biomass from POM  $a$  to processing facility  $b$  to sink  $c$  per day (MYR/d);  $t^h$  is the operating hour per day of the processing facility (8 h/d); and TCP is the transportation cost parameter (172 MYR/t for a distance of 30 km [4]).

The total cost of the palm biomass processing facilities with accountability of capital and logistic cost can be represented with the equation below:

$$CT = C_c + 10 y \times \sum_{a \in A, b \in B} (F3_{a,b} \times C_r \times t^d + F3_{a,b} \times C_{op} \times t^h \times t^d + C_d \times t^d + C_m) \quad (9)$$

where  $CT$  is the total cost incurred to set up and operate the palm biomass processing facility which considers the capital cost, raw material cost, operating cost, logistic cost and maintenance cost in 10 years duration (MYR);  $C_c$  is the capital cost (MYR);  $C_r$  is the raw material cost (MYR/t);  $t^d$  is the number of operating days of the processing facility per year (d/y);  $C_{op}$  is the operating cost (MYR/t); and  $C_m$  is maintenance cost which is assumed to be 10% of the capital cost and is imposed once every three years as (MYR/3y) [5].

The calculation for payback period is represented as below:

$$P_b = CT/AR \quad (10)$$

where  $P_b$  is the payback period (y); and  $AR$  is the annual revenue (MYR/y).

## 4. Model illustration

Three scenarios are investigated in this work: (i) centralized palm biomass processing facility with single product, (ii) centralized palm biomass processing facility with multiple products, and (iii) decentralized palm biomass processing facility with single product. The generation rate of palm biomass from FFB in Sarawak is listed in Table **Error! Reference source not found.** 1. Four ports are identified as product sinks and the locations of the sinks are listed in Table 2. Thirty-nine out of seventy-six POMs are identified in Sarawak, Malaysia. The locations and the capacities of the generalised sources of POMs are listed Table 3.

**Table 1.** Palm Biomass General Composition in Sarawak [6].

Palm Biomass Component	Biomass Generation Rate (% from FFB)
EFB	15.07
OPF	8.90
PKS	3.77
POME	44.52
Others	27.74

**Table 2.** Location and Capacity of Sink *c*.

No.	Latitude (°)	Longitude (°)
<i>c1</i>	1.615826	110.452764
<i>c2</i>	2.289373	111.823615
<i>c3</i>	3.267837	113.078303
<i>c4</i>	4.563727	114.040497

**Table 3.** Location and capacity of POMs *a*.

No.	Latitude (°)	Longitude (°)	Capacity (t/h)	No.	Latitude (°)	Longitude (°)	Capacity (t/h)
<i>a1</i>	2.855475	112.444793	45	<i>a21</i>	3.316018	113.450317	30
<i>a2</i>	2.414777	111.826769	60	<i>a22</i>	2.140779	112.103255	60
<i>a3</i>	3.810816	113.845825	40	<i>a23</i>	4.137053	113.977446	90
<i>a4</i>	3.390203	113.345417	60	<i>a24</i>	3.809446	113.859558	80
<i>a5</i>	3.822167	114.025194	45	<i>a25</i>	1.334718	112.000122	60
<i>a6</i>	3.507938	113.609619	90	<i>a26</i>	2.906984	112.313262	60
<i>a7</i>	1.153186	110.676056	60	<i>a27</i>	3.400940	113.347730	60
<i>a8</i>	3.163611	113.599750	30	<i>a28</i>	2.463753	111.928695	40
<i>a9</i>	1.444549	110.121460	40	<i>a29</i>	1.499153	109.905671	45
<i>a10</i>	3.191754	113.039500	40	<i>a30</i>	2.593907	112.338923	40
<i>a11</i>	3.585771	113.431968	60	<i>a31</i>	3.182660	113.505036	60
<i>a12</i>	2.487052	112.225823	60	<i>a32</i>	3.768750	113.696250	30
<i>a13</i>	2.850447	112.335189	60	<i>a33</i>	1.257834	111.445313	60
<i>a14</i>	3.872687	113.862575	120	<i>a34</i>	3.448807	113.769950	40
<i>a15</i>	3.610556	113.661667	60	<i>a35</i>	3.524878	113.747263	60
<i>a16</i>	1.669686	109.819336	40	<i>a36</i>	3.031650	113.882551	60
<i>a17</i>	1.062866	110.895996	60	<i>a37</i>	3.638889	113.504444	40
<i>a18</i>	1.397469	110.446100	45	<i>a38</i>	4.034047	114.303772	90
<i>a19</i>	3.260240	113.671980	30	<i>a39</i>	4.839639	115.257353	40
<i>a20</i>	3.727067	114.281073	45				

Dried long fibre (DLF) is taken as the prior product for the conversion of biomass into value-added product while DLF and biomass pellet (PLT) are taken into consideration for multiple products biomass processing facility. DLF is highly demanded for mattress and fibre mat production; while the increasing demand of EFB pellet for utilization as fuel in biomass power station. They are opted for the product choice due to their demand.

In the first scenario, single product production facility is studied and DLF is the sole product being produced in the biomass processing facilities. The feasibility of the centralized processing hub *b* with single product generation in Sarawak is investigated.

In the second scenario, multiple products production in centralized processing facilities is investigated. DLF and PLT are the products generated in the centralized processing facilities. Therefore, the consistent demand of PLT is secured and it is then suitable to be taken as one value-added products to be produced practically.

In the third scenario, decentralized processing facility of single product production is investigated. DLF is the lone product in this case. The feasibility of the decentralized processing hub *b* with single product generation in Sarawak is investigated.

The lifespan of each processing facility is taken to be 20 years. However, the payback period is calculated using the gross profit of the palm biomass processing facility. The upper boundary of the palm biomass processing facility taken to be 2.5 t/h due to the less production of EFB in Sarawak. Furthermore, the absence of highway also becomes one of the factor of capacity limitation. In addition, the real time market prices of DLF and PLT are the major factor that influences the economic potential of the plant. The fluctuation of the market price is mainly affected by the FFB yield which controls the raw material availability and the consistency supply of products which affects the stabilisation of products' market prices. As such, palm biomass processing facilities with 2.5 t/h is taken to be the optimum capacity. The parameters used to simulate the case studies are tabulated in Table 4 and Table 5.

**Table 4.** Parameter for Case Studies.

Parameters	Value
EFB (%)	15.07
Recovery Fraction (%)	80
DLF Conversion Rate (%) *	37.52
PLT Conversion Rate (%) **	26.64
Earth's Radius (km)	6371
Transportation Cost Parameter (MYR/km)	5.73
USD to MYR Exchange Rate	4.03
Operating Day per year (d)	330
Operating Hours per day (h)	8
Plant Life Span	10

\* The conversion rate of raw EFB to DLF is 1 ton of raw EFB is required to produce 0.67 ton of wet long fiber (WLF) and 0.24 ton wet short fiber (WSF), while 1 ton of WLF is required to produce 0.56 ton of DLF [7] with the assumption that all WSF is screened out to be disposed.

\*\* The conversion rate of raw EFB to PLT is 1 ton of raw biomass consists of EFB and WSF, is needed to produce 0.33 ton of PLT, while 1 ton of WLF is needed to produce 0.11 ton of WSF [7] and it is assumed that all WSF is recovered for PLT production.

**Table 5.** Raw materials and products selling prices, production costs, operating costs and capital costs [7].

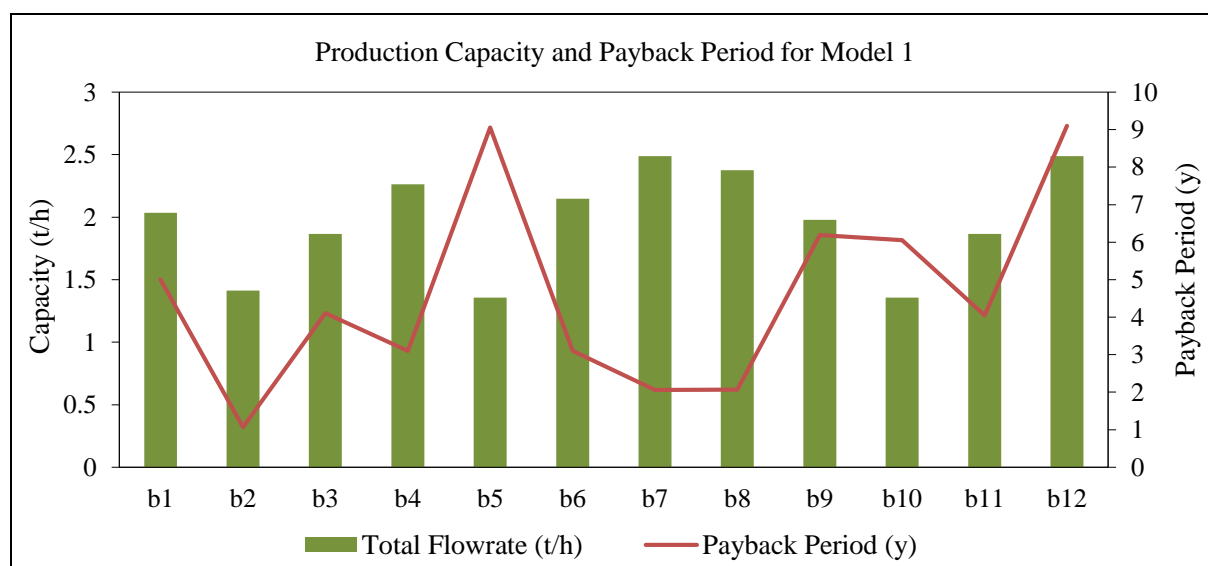
Material	Cost (MYR/t)	Product	Price (MYR/t)	Operating Cost (MYR/t)	Capital Cost (MYR)
EFB	16.10	PLT	402.59	88.57	905,823
		DLF	805.18	74.48	2,173,975

## 5. Result and discussion

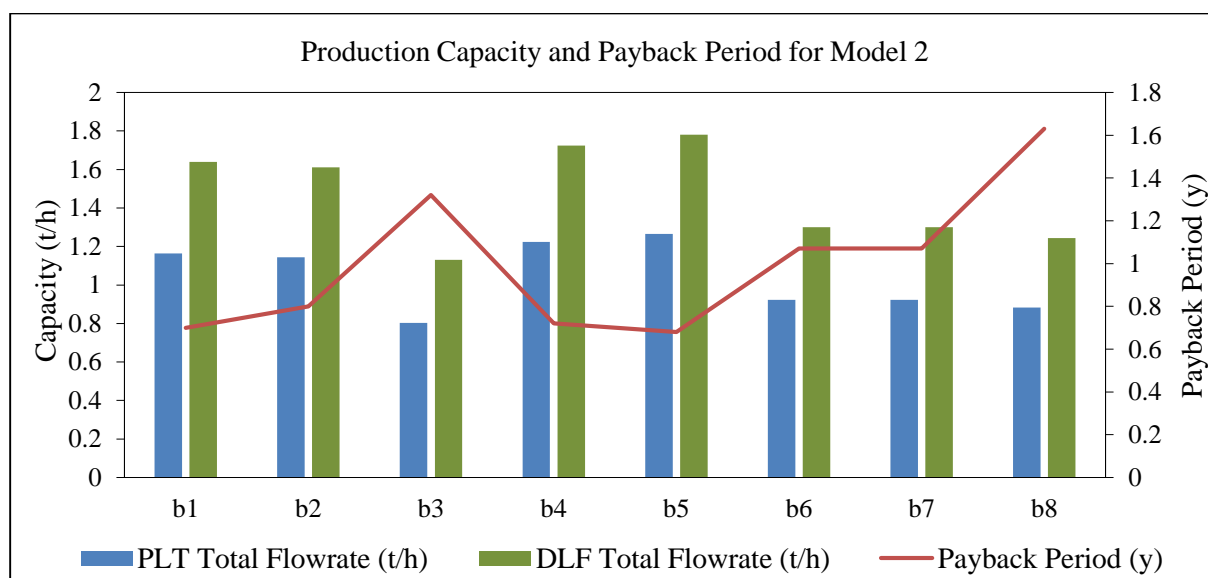
The model results are summarized in Table 6. Figure 2 to Figure 4 detailed the capacity and performance of the three models.

**Table 6.** Average processing capacity of biomass facility for each model.

		Model 1	Model 2	Model 3
Processing capacity of biomass facilities	DLF flowrate (t/h)	1.36 - 2.48	1.13 - 1.78	0.34 - 1.36
	PLT flowrate (t/h)	-	0.80 - 1.26	-
Number of processing facility hub <i>b</i>		12	8	39
Estimated payback period (y)		1.07 - 9.10	0.68 - 1.63	1.01 - 4.68

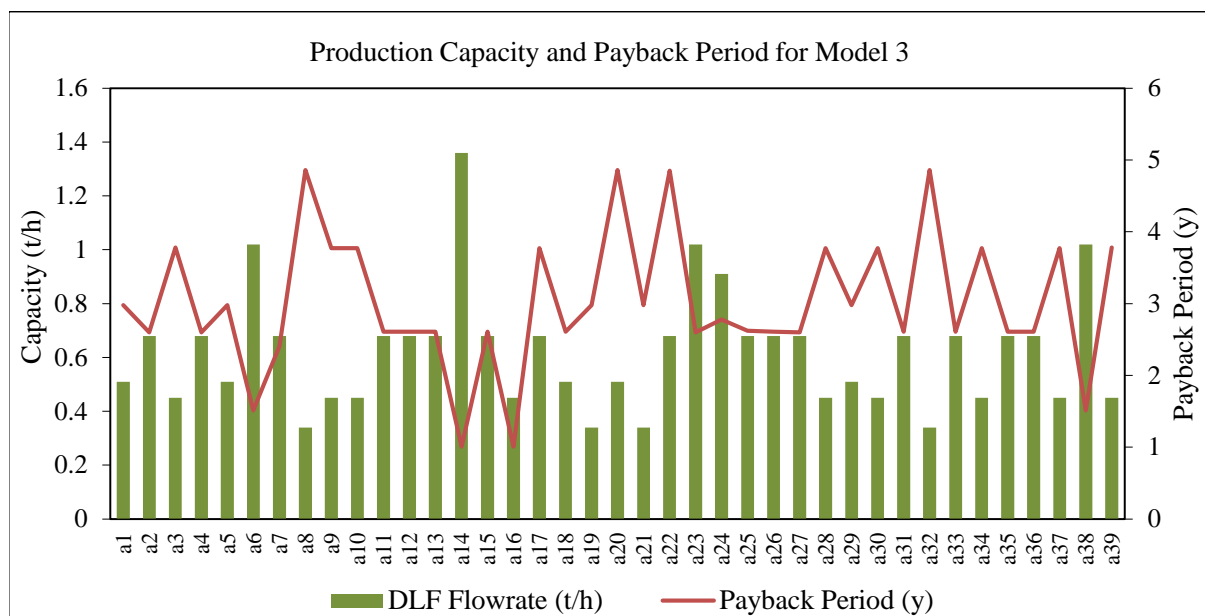


**Figure 2.** Result of case study 1.



**Figure 3.** Result of case study 2.





**Figure 4.** Result from case study 3.

## 6. Model limitation

In this work, assumptions are made in developing the models: (i) The locations of the facilities are represented in two-dimensional form and the straight-line distance between the facilities are calculated. This may result in inaccuracy in estimating the logistic cost which brings great impact to the performance of Model 1 and Model 2. The limitation can be improved by considering three-dimensional coordinates in estimating distances or taking the real distance between the facilities based on existing roadway availability; (ii) The capital costs of the processing equipment are taking the average value of equipment cost of all capacity. It shall be noted that lower capacity equipment generally incurs higher cost per unit capacity and higher capacity equipment generally incurs lower cost per unit capacity; (iii) Only 39 out of 76 of the POMs in Sarawak, Malaysia are considered in this work due to the unavailability of POM information. If all POMs are taken into consideration, a different scenario to develop the biomass industry may be obtained; (iv) The prices products are assumed to be the same from previous publication. It shall be noted that product prices for exportation generally fluctuates depending on stock supply and customer demand. Besides, the drastic currency fluctuation of the country affects the potential of the models. Sensitivity analysis can be carried out to account for this uncertainty; (v) The models assumed a constant supply of EFB from POMs. This is less realistic as FFB supply, and therefore EFB supply, fluctuates over the year due to local weathers. Proper production scheduling and stocking may be taken into consideration to tackle this scenario.

Nevertheless, the main objective of this work is to provide a framework which introduces a potential strategy of centralising and decentralising the palm biomass processing facility for the development of regional palm biomass industry.

## 7. Conclusions and future works

This research investigates the feasibility of the centralized or decentralized palm biomass processing facilities in Sarawak, Malaysia. Three scenarios are developed in this work, which are centralized palm biomass processing facilities with single product, centralized palm biomass processing facilities with multiple products and decentralized palm biomass processing facilities. Cost analysis is carried out to evaluate the economic performance of these three scenarios. It is observed that centralized palm biomass processing facilities with multiple products scenario has the highest potential to be developed.



This work can be extended to resolve the model limitations. The models can be further expanded to include all the biomass available in a POM such as PKS, OPF, OPT and et cetera. Business tendency can be introduced for this development of palm biomass processing facility supply network. An industrial symbiotic strategy can be introduced and promoted to optimize the usage and recovery of resources among the processing facilities. Besides, further research can be done study the effect of integrating carbon footprint towards the performance of centralized processing facilities. Besides, the potential of each biomass processing facilities can be evaluated to provide a rating for a systematic development of the industry.

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## Nomenclature

$a$	Set index of palm oil mill source points
AR	Annual revenue (MYR/y)
$b$	Set index of palm biomass processing facilities
$c$	Set index of sink $c$
Cc	Total capital cost (MYR)
Cd	Total transportation cost (MYR)
Cm	Maintenance cost in every three years (MYR/ 3y)
Cop	Total operational cost (MYR)
Cr	Total raw material cost (MYR/t)
COM <sub><math>i</math></sub>	Composition of component $i$
CPO	Crude palm oil
CT	Total cost (MYR)
DLF	Dried long fiber
EFB	Empty fruit bunch
F0 <sub><math>a</math></sub>	Flowrate of palm biomass in palm oil mill $a$ (t/h)
F1 <sub><math>a</math></sub>	Flowrate of component $i$ in palm oil mill $a$ (t/h)
F2 <sub><math>a</math></sub>	Recyclables flowrate in palm oil mill $a$ (t/h)
F3 <sub><math>a,b</math></sub>	Leftover palm biomass's flowrate in palm oil mill $a$ to processing hub $b$ (t/h)
F4 <sub><math>b,s</math></sub>	Flowrate of palm biomass in processing hub $b$ sent to technologies $s$ for conversion (t/h)
F5 <sub><math>b,s,k</math></sub>	Product flowrate in processing hub $b$ produced from technology $s$ into palm biomass product $k$ (t/h)

$F_{6_{b,c}}$	Flowrate of products from processing hub $b$ to sink $c$ (t/h)
FFB	Palm fresh fruit bunch
$i$	Set index of type of palm biomass
$k$	Set index of palm biomass product
lat	Latitude (°)
$LB_s$	Lower boundary of the operating capacity of technology $s$ , 25% of the maximum operating capacity (t/h)
lon	Longitude (°)
OPF	Oil palm fronds
Pb	Payback period of processing hub $b$ (y)
PKS	Palm kernel shell
PLT	Pellet
POM	Palm oil mill
POME	Palm oil mill effluent
$PR_s$	Conversion rate of technology $s$
$r$	Radius of earth (km)
REC	fraction of palm biomass retained for POM's self-consumption
$s$	Set index for palm biomass processing technology
$t_d$	Total operational days for the processing hub
$t_h$	Total operational hours for the processing hub
$UB_s$	Upper boundary of the operating capacity of the technology $s$ (t/h)
WLF	Wet long fiber
WSF	Wet short fiber