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Optimal Location and Allocation for the Development of Oil Palm Eco-Industrial Town: Case Study in State of Johor

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In 2015, there were about 160 Mt of oil palm biomass produced by the oil palm industry nationwide. In this article, oil palm based eco-industrial town (EIT) is proposed to improve the profitability of oil palm industry while optimally utilise the availability of oil palm biomass and network infrastructure. The oil palm EIT is the integration of nine palm oil based industry and a community at the same location to promote energy and material sharing via industry symbiosis. The energy usage and waste generation are expected to reduce within the collaborated industries in the EIT. Due to the geographical location of existing palm oil mills in State of Johor, a crucial decision is required to choose a cost effective operating system and location for the development of oil palm EIT. A mixed integer linear programming (MILP) model is formulated to maximise economic performances, while selecting a cost effective operational system, either to employ centralised or decentralised system. Geographical information system (GIS) tool ArcGIS 10 was used to identify the location of existing crude palm oil mills, potential locations of oil palm EIT, and transportation network including roads and railways. Network analysis was performed to rank and calculate the most efficient network to transport oil biomass from oil palm plantation (surrounding existing palm oil mills) to the potential EIT locations via roads and railways. Generated results from network analysis were formulate as MILP model and optimised using General Algebraic Modelling System (GAMS). The optimisation results show that decentralised oil palm EIT system was the most profitable system with USD 241.54 M/y profit. The optimised model also suggested that the most efficient way to utilise abundant oil palm biomass are via crude palm oil mill, paper mill, livestock production, medium density fibre board mill, bio-diesel and bio-gas mill. The model shall assist the decision maker to identify system, location and the sub-industries in the EIT in order to promote sustainability in oil palm industry and bring benefits to the industry and community.

1. Introduction

Malaysian oil palm industry has generated about 160 Mt of oil palm biomass annually (MPOB, 2015). These biomasses are included fresh fruit bunches (FFB), empty fruit bunches (EFB), oil palm frond (OPF), oil palm trunk (OPT), and palm oil mill effluent (POME). Improper management of oil palm biomasses lead to the resources loss, carbon dioxide emission, and environmental pollutions. In order to improve profitability and environment performance of oil palm industry, conceptual of oil palm eco-industrial town (EIT) is proposed. Integration of nine oil palm-based industries and a community at one location allows collaboration in raw materials, utilities, wastes, and energy usage.

A sustainable and integrated bio-refinery concept for a palm oil mill was proposed by Ali et al. (2014). The concept targeted a zero emission system, which could produce higher value-added products from oil palm biomass such as bio-fertiliser, bio-char, biofuels, and biomaterials (Ng et al., 2014) presented a symbiotic bioenergy park that can fairly distribute cost and benefits among the collaborative industries. Most of these methodologies are exclusively designed to improve the crude palm oil mill as individual at one location and not consider centralising available biomass from others resources location. There are about 65 crude palm oil mills and 739,583 ha of oil palm plantations scattered in Johor, Malaysia. Upgrading the all existing crude palm oil mill into the oil palm EIT might be too costly since the oil palm EIT integrates nine oil palm based industry. Centralised resource could be more productive and cost efficient for development of oil palm EIT. Lim et al.

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(2013) developed a framework for the optimal design and planning of the product portfolio and processing route of an integrated, resource-efficient (IRE) rice mill complex. The objective function is to maximise the profitability of the rice mill by using the developed multi-period mathematical model. There is less of study on resource allocation for development of oil palm EIT.

The main objective of this study is to develop a mathematical model that can select the optimal operating system for development of oil palm EIT, whether to choose centralised or decentralised system. In this study, a mixed integer linear programming (MILP) model is formulated to maximise economic performances, while choosing the most optimal operating system and location for the development of the oil palm EIT. GIS tool (ArcGIS 10) was used to plot the location of existing crude palm oil mills, potential locations of oil palm EIT, and transportation network including roads and railways. Network analysis was performed to rank and calculate the most efficient network to transport oil biomass from the existing palm oil mills to the potential EIT locations via roads and railways. Generated results from network analysis were then used in the developed MILP model and coded into General Algebraic Modelling System (GAMS) as an optimisation tool. GAMS version 23.5 was used to solve optimisation problems in this research due to the GAMS specially designed for modelling of linear, nonlinear and mixed-integer optimisation problems. Over the years, GAMS had been widely used to solve optimisation problem throughout the world and is proven useful for handling large and complex problems which may require many revisions to establish an accurate model.

2. Materials and method

2.1 Case study

Kluang district of Johor was selected as case study due to the number of crude palm oil mills and vast oil palm plantation areas. Five conventional crude palm oil mills and two potential locations for development of oil palm EIT are taken as case study. The existing five mills are assumed to create decentralised system, while the two potential locations are assumed to create centralised system for the oil palm EIT. Plantation for each crude palm oil mill is assumed to be located within 5 km of radius. Each of oil palm EIT is assumed to have a palm oil mill, a community, a livestock production of cows, bio-fertiliser mill, bio-gas mill, bio-diesel mill, bio-pellet mill, medium-density fibre (mdf) board mill, and paper mill. All plants in the EIT are assumed to operate 20 h daily for 310 d annually.

2.2 Superstructure Development

Figure 1 presents the simplified superstructure of the oil palm EIT, as described in the case study. The model comprises of five main sets, which are *set a*- types of input, *set y*-types of system, *set n*- types of industry output, set s- market, and set p for treatment facility. There are two types of external input resources to the industry or community, which are the main material *i* and utility *f*. Based on the main material that is processed by the industry or community, each industry in EIT can produce various products i.e. main product m, utility u, and by-product *l*. Main products and utilities generated by EIT can be used among the industries in EIT or sale to the market, s. The generated by-product can either be utilised by industries in the EIT or send the treatment facility.

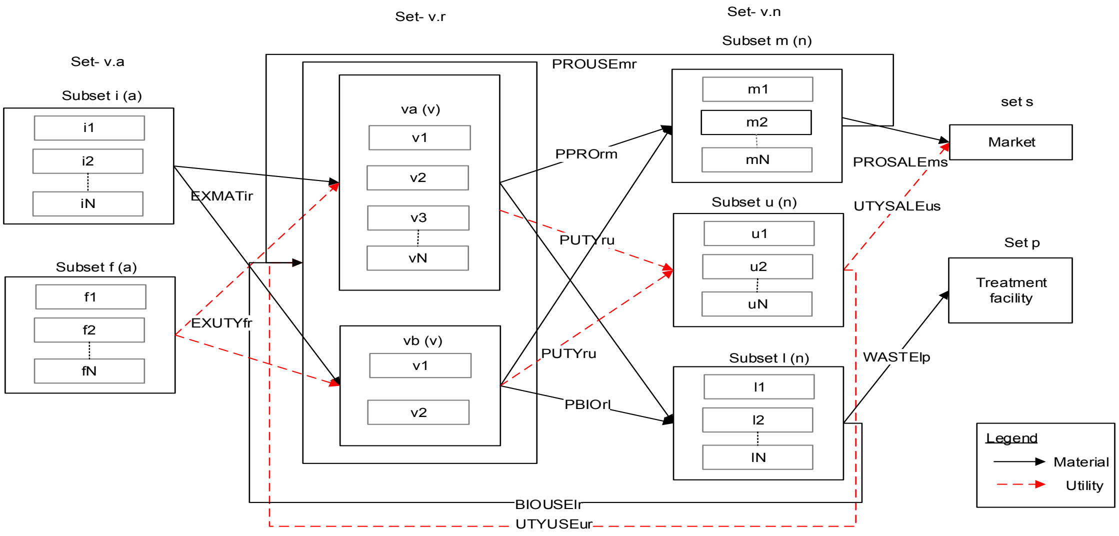

Figure 1: Simplified superstructure diagram of oil palm EIT

2.3 Model Formulation

In this section, definition of key terms in this study are first made, followed by defining the sets, variable and parameters, prior to the formulation of objective function and constraints (see Table 1).

Table 1: List of indices, parameters and variables

List of indices	
a	Index for external resource
v	Index for location
$va(v)$	Location for decentralised system
$vb(v)$	Location for centralised system
n	Index for industry output
s	Index for market
p	Index for treatment facility
List of parameters	
$RES_{a,vs}$	Amount of available external resource (t/y)
$CPCOST_{v,r}$	Amount of capital cost of industry y (USD/y)
$CNVSyv_{vrvsn}$	Conversion factor of industry y to produce internal resource n
$DSTNCi_{avvsr}$	Travel distance of external resource i to industry y (km)
List of continuous variables	
EITPROFIT	Total revenue of oil palm EIT (USD/y)
SALES	Revenue of sales (USD/y)
UTYCOST	Expenses for utility (USD/y)
CAPCOST	Expenses for capital cost (USD/y)
MATCOST	Expenses for feed cost (USD/y)
TRANSCOST	Expenses for transportation (USD/y)
TREATCOST	Expenses for waste treatment (USD/y)
$RMAT_{vr}$	Amount of main material at industry y (unit/y)
$PPRO_{v,r,vs,m}$	Amount of product *n* produced from industry y (unit/y)
$PBIOy_{v,r,vs,l}$	Amount of biomass *n* produced from industry (unit/y)
$WASTE_{vs,l,p}$	Amount of biomass *n* sent to treatment facility p (unit/y)
$PUTY_{v,r,vs,u}$	Amount of utility *n* produced from industry y (unit/y)
List of binary variables	
YA	Selection for decentralised system
YB	Selection for centralised system
XVB_{vb}	Selection for centralised location

2.3.1 Objective function

The objective function of this model is to maximise the total revenue of the oil palm EIT, which represent by the variable *EITPROFIT*. Variable *EITPROFIT* consists of *SALES*, *MATCOST*, *CAPCOST*, *UTYCOST*, *TRANSCOST*, and *TREATCOST* variables as shown in Eq(1) to Eq(7).

$$PROFITS = SALES - MATCOST - CAPCOST - UTYCOST - TRANSCOST - TREATCOST \tag{1}$$

$$SALES = \sum_{v,r,vs,m} PPRO_{v,r,vs,m} \times INPR_m + \sum_{v,r,vs,u} PUTY_{v,r,vs,u} \times INPR_u \tag{2}$$

$$MATCOST = \sum_{i,vs,v,r} EXMAT_{i,vs,v,r} \times EXPR_i + \sum_{vs,m,v,r} PROUSE_{vs,m,v,r} \times INPR_m + \sum_{vs.l.vr} BIOUSE_{vs,l,v,r} \times INPR_l \tag{3}$$

$$CAPCOST = \sum_{va,r} CPCOST_{va,r} \times YA + \sum_{vb,r} CPCOST_{vb,r} \times XVB \tag{4}$$

$$UTYCOST = \sum_{f,y} EXUT_{i,y} \times EXCOST_f + \sum_{n,y} UTUSE_{n,y} \times INCOST_y \tag{5}$$

$$TRANSCOST = \sum_{a,vs} EXMAT_{a,vs,v,r} \times R \times DISTANCE_{a,vs,v,r} \tag{6}$$

$$TREATCOST = \sum_{vs,l,,p} WASTE_{vs,l,,p} \times TRCOST_l \tag{7}$$

2.3.2 Constrains

The maximisation of the objective function of *EITPROFIT* is subjected to the following constraints: Eq(8) is formulated to ensure the oil palm EIT has enough supply of raw materials and utilities from external resources. The raw material at industry in EIT may come from external and internal resources as shown in Eq(9). Eq(10) indicated the products, utilities, and by-products produced by the industries and community in EIT. The summation of products, utilities and by-products from all industries and community in EIT are expressed in Eq(11). Products and utilities generated by EIT can be used by the industries or sale to market as bound by Eq(12). Eq(13) to Eq(18) is formulated to select of operating system and location for development of oil palm EIT.

$$RES_{i,vs} \geq \sum_{v,r} EXMAT_{i,vs,v,r} \; \forall \; i \; \forall \; vs \tag{8}$$

$$RMAT_{v,r} = \sum_{i,vs} EXMAT_{i,vs,v,r} + \sum_{vs,m} PROUSE_{vs,m,v,r} + \sum_{vs,l} BIOUSE_{vs,l,v,r} \; \forall \; r \; \forall \; r \tag{9}$$

$$RMAT_{v,r} \times CNVS_{v,r,vs,m,} = PPRO_{v,r,vs,m} \; \forall \; v \forall \; r \; \forall \; vs \; \forall \; n \tag{10}$$

$$\sum_{v,r} PPRO_{v,r,vs,m} = PRO_{vs,m} \; \forall \; vs \; \forall \; vm \tag{11}$$

$$PRO_{vs,m} = \sum_{v,r} PROUSE_{vs,m,v,r} + \sum_{s} PROSALE_{vs,m,s} \; \forall \; vs \; \forall \; m \tag{12}$$

$$RMAT_{va,r} \leq \sum_{i,vs} RES_{i,vs} \times YA \quad \forall \; va \; \forall \; r \tag{13}$$

$$RMAT_{vb,r} \leq \sum_{i,vs} RES_{i,vs} \times YB \; \forall \; vb \; \forall \; r \tag{14}$$

$$YA + YB \leq 1 \tag{15}$$

$$RMAT_{vb,r} \leq CPPCOST_{vb,r} \times XVB_{vb} \; \forall \; vb \; \forall \; r \tag{16}$$

$$RMAT_{rd} \leq \sum_{i} RES_{i} \times YB \quad \forall \; rd \tag{17}$$

$$\sum_{vb} XVB_{vb} \leq 1 \tag{18}$$

2.4 Data Input

Table 2 illustrated the material and utility ratio (for 1 t basis of main material) at respective industry in the oil palm EIT. For example, if 1 t of fresh fruit bunches feed in at crude palm oil mill, the mill required about 0.0006 t of diesel and 1.26 t of water as material or utility input; and produces about 0.2 t of crude palm oil (key-product), 0.06 t of palm kernel, 0.23 t of empty fruit bunches, 0.65 t of pome and 17 kWh of electricity as material or utility output. Table 3 showed the information on existing palm oil mills at Kluang district. Transportation cost was taken from real field cost data which was USD 0.6 / km-t.

2.5 GIS data

The ArcMAp 10 was used as GIS tool to plot location of existing crude palm oil mills, potential location for centralised system, and transportation link of roads and railways in the State of Johor. There were 65 crude palm oil mills and 23 potential locations were considered. Figure 2 showed the plotted GIS map for location of crude palm oil mills, potential centralised system location for EIT development and transportation link via roads and railways. Network analysis tool was used to calculate the most cost effective link between resource and the potential centralised system location. Table 4 summarised the distances via roads that produced from network analysis tool.

Table 2: Material and utility ratio for industry in the oil palm EIT

Input Material	Amount	Industry	Output Material	Amount	Source
FFB[a]	1 t	Crude palm oil	CPO[b]	0.23 t	(Patthanaissaranukool et al., 2013)
Diesel	0.0006 t	mill	PK	0.06 t	
Electricity	14.5 kWh		POME	0.65 t	
Water	1.26 t		EFB	0.23 t	
			Bioelectricity	17 kWh	
EFB[a] /OPT[a]	1 t	Bio-fertiliser	Bio-fertiliser[b]	0.4 t	(Yoshizaki et al. 2013)
Diesel	0.0015 t	mill			
Water	1 t				
OPF[a]	1 t	Paper mill	Paper[b]	0.5 t	(Singh et al. 2013)
Electricity	17 kWh				
POME[a]Dung[a]	1 t	Bio-gas mill	Bio-electricity[b]	39.6 kWh	(Yoshizaki et al. 2013)
Electricity	9 kWh		Sludge	0.06 t	

[a]main material
[b]key product

Table 3: Existing palm oil mills and potential centralised EIT in Kluang District, Johor

Operating system	Palm oil mill	Plant size (t/h)	Annual capacity (t/y)	Annual capital and maintenances cost (USD/y)	Plantation area (ha)
Decentralised system	KKS Bukit Lawiang	40	248,000	388,542	6,260.87
	KKS Belitong	54	334,800	465,198	8,452.17
	KKS Ulu Remis	60	372,000	495,556	9,347.83
	KKS Southern Malay	40	248,000	388,542	6,260.87
	KKS Air Hitam	40	248,000	388,542	6,260.86
Centralised system	EIT A (Ayer Hitam)	200	1,240,000	1,020,516	-
	EIT B (Kbr Cina)	200	1,240,000	1,020,516	-

Table 4: Distances (km) between oil palm biomass resources to the oil palm EIT

Location	KKS Bukit Lawiang	KKS Belitong	KKSUlu Remis	KKS Southern Malay	KKS Air Itam	EIT A (Ayer Hitam)	EIT B (KbrCina)
Bukit Lawiang	5	8	47.59	33.45	48.43	32.77	13.78
Belitong	8	5	50.65	36.94	45.52	39.45	19.40
Ulu Remis	47.59	50.65	5	16.13	36.89	32.34	34
Southern Malay	33.45	36.94	16.13	5	20.89	16.74	20.06
Air Hitam	48.43	45.52	36.89	20.89	5	13.26	32.85

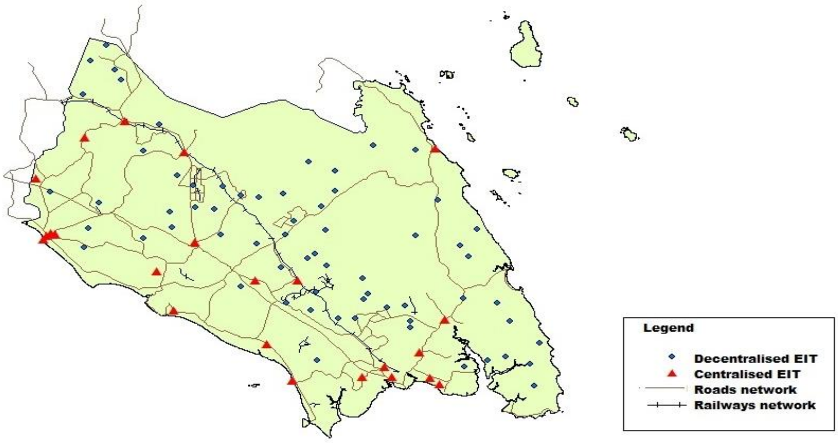

Figure 2: GIS map of crude palm oil mills location, centralised location and transportation link in State of Johor

3. Results and Discussion

The MILP model described in Section 2.3 was coded in GAMS with the objective to maximise the total annual oil EIT profit. The result indicates that the optimal system for developing oil palm EIT is by using decentralised system. Based on the objective function, the annual oil palm EIT profit of the system was revealed as USD 241.54 M (see Table 5). The highest expense was material cost with USD 147.63 M. Followed by capital and maintenances cost with USD 8.22 M, transportation cost with USD 7.90 M, and utility cost with USD 3.84 M. The oil palm EIT can reduce the cost of external utilities by utilising bio-diesel produced by the internal industries in the EIT. The lowest cost was the expense for treatment cost with USD 0.17 M. This is due to the most of the produced oil palm biomasses were used by the industries in EIT. The model has selected the decentralised system is mainly due by the high transportation cost required by the centralised system. The optimised model also suggested that the most efficient way to utilise abundant oil palm biomass are via crude palm oil mill, paper mill, livestock production, medium density fibre board mill, and bio-gas mill.

Table 5: Optimal result of oil pam EIT

Description	Variable	Value (M USD/y)
Total revenue of oil palm EIT	*EITPROFIT*	241.54
Revenue of sales	SALES	409.29
Expenses for material cost	*MATCOST*	147.63
Expenses for capital maintenances cost	*CAPCOST*	8.22
Expenses for utility	*UTYCOST*	3.84
Expenses for transportation cost	*TRANSCOST*	7.90
Expenses for treatment cost	*TREATCOST*	0.17
Selection of decentralised system	*YA*	1
Selection of centralised system	*YB*	0

4. Conclusion

In this study, the model to maximise the economic performances of oil palm EIT by considering the logistic and availability of oil palm biomass, centralised and decentralised operational system and integrated biomass pathway for production of value added products has been successfully developed. It was found that the abundant supplies of palm oil biomass offer a wide range of investment prospects in the palm oil downstream sectors i.e. multi bio-products and bio-energy and fighting poverty through community development. The model is useful to assist the town planner and decision maker to select operational system, location, and sub- industries for development of the oil palm EIT.

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