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Superstructure-Based Synthesis and Optimization of Oil Palm Eco-Industrial Town: Case Study in Iskandar Malaysia

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As one of world's edible oil main producers, Malaysia has planted more than 5.23 Mha of palm oil plantations and established more 400 palm oil mills. However, current oil palm industry practices produce million tons of biomass waste through harvesting and mill's processing. Towards to promote sustainability, oil palm industry must find a balance between economic and environmental needs. In this article, an oil palm eco-industrial town (EIT) is proposed to utilize oil palm biomass in totality through seven oil palm-based industries included crude-palm oil industry, bio-fertilizer industry, bio-gas industry, bio-fuel industry, livestock pellet industry, medium density fibre industry, and paper and pulp industry. The oil palm EIT promotes energy and material sharing among the industries to reduce energy and waste generation. The oil palm EIT could benefits both in economic (by producing multi products) and in environmental (by minimizing of biomass waste). A multi objectives linear programming (MILP) model is formulated to maximize economic performance and job opportunity; while, minimizing wastes generation in oil palm EIT. The proposed model considers the operational constraints such as biomass availability, material composition, environmental effect, and production yield of the individual industry. The reliability of the model is assessed based on case study in Iskandar Malaysia (IM). The model shall assist the decision maker to identify the sub- industries in the EIT in order to promote sustainability in oil palm industry.

1. Introduction

Oil palm is one of the most important crops in Malaysia in the aspect of economy, environmental and social benefits. Supported by tropical climate, oil palm plantation in Malaysia has reached 5 Mha in 2013 or about 15 % of land area in the country (MPOB, 2013). In 2012, oil palm generates largest amount of biomass in the country which estimated about 83 Mt. In fact, there were more than 400 palm oil mills established to process fresh fruit bunches (FFB) into crude palm oil (CPO) and crude palm kernel (CPK). Huge amount of oil palm biomass generated from palm oil mill as by-products. Among the available biomass available after processed fresh fruit bunch (FFB) and unharvest biomass at plantation included oil palm fronds, oil palm trunk, empty fruit bunch, oil palm shell and oil palm fiber. Sustainable pathway of resource can improve economic and environmental performance of industry (Lim et al., 2014).
Oil palm industry has potential to create oil palm eco-industrial town (EIT) by utilizing availability of oil palm biomass and employing eco-industrial cluster concept. Oil palm eco-industrial town (EIT) could contribute to the economy, environment and play vital role as green economic development for local community. Among the potential industries that can be incorporated in the EIT are bio-fertilizer industry, bio-gas industry, oil palm plantation, crude palm oil mill, and a community. Beside of bringing positive impact of economic value, these industry activities will also benefits the local community by providing job opportunities and developing contiguous area. Therefore, this paper targets to identify the most optimal oil palm biomass utilization approach that can decide the profitable products that will give maximum profit and job opportunities, while give less impacts to the environment. The optimization is done via multi objectives linear programming (LP) model. The model is then implemented at Kluang as a case study, an area located at the southern part of peninsular Malaysia.

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2. Literature Review

In last decades, eco-industrial cluster (EIC) concept has been studied to improve current economic and environmental of oil palm industry. As part of industry ecology field, industry symbiosis commonly employ in EIC to promote materials and energy shared among the industries. EIC model is more environmental friendly with efficient use of energy and material compared to the conventional industrial model. Kasivisvanathan et al., 2012) presents a novel application of the concept of systematic optimisation approach to retrofit a palm oil mill into a sustainable palm oil-based integrated bio-refinery. The efficiency and sustainability of biomass-based production can be maximised by producing biofuels along with other valuable co-products in a "biorefinery (Shabbir et al., 2012). However, there is less study on benefit of oil palm EIC concept to the community. In fact, oil palm biomass can be utilized as source of electricity to the local community (Ho et al., 2013). Therefore, an eco-industrial town (EIT) that emphasized in economy, environment and community is proposed. There are five potential industries identified to be evolved in this EIT including bio-fertilizer industry, bio-gas industry, oil palm plantation, crude palm oil mill, and a community. These industries were selected based on resource linkages between the oil palm based industries. Mixed-Integer Linear Programming (MILP) can be used to synthesis supply-network within the industries selected (Kiraly et al., 2013). It is possible to share utilities and materials among the industries due to the evolved industries are using same based material which is oil palm biomasses. In fact, in current practices, oil palm plantation, crude palm oil mill, and community are linked through material and utilities. For example, FFB produced from the oil palm plantation is used as raw material for crude palm oil mill. Then, the crude palm oil mill will produce electricity to community (surrounding area) and empty fruit bunches (by-product) as organic fertilizer for oil palm plantation. Similar approach will be applied to all industries in the oil palm EIT to ensure the material/utility demand and wastes generated will significantly reduce.

3. Superstructure generation

Figure 1 shows the superstructure of oil palm EIT that illustrates the types input materials/utility (set i), types of industries (set m), and types output products (set k). There are two types of subsets under the set i, which is subset u(i) to represent the utility and subset b(i) to represent biomass(main material) material. The output for each industry in the EIT can be classified under subset p(k)-product, subset q(k)-by-product, subset r(k)-by-utility, and subset y(k)- waste. Product is the profitable material that produced by industry. Waste is the unused material that will give impact the environment. On the other hand, by-utility and by-product are produced material/utility that can be used for other industries within the oil palm EIT.

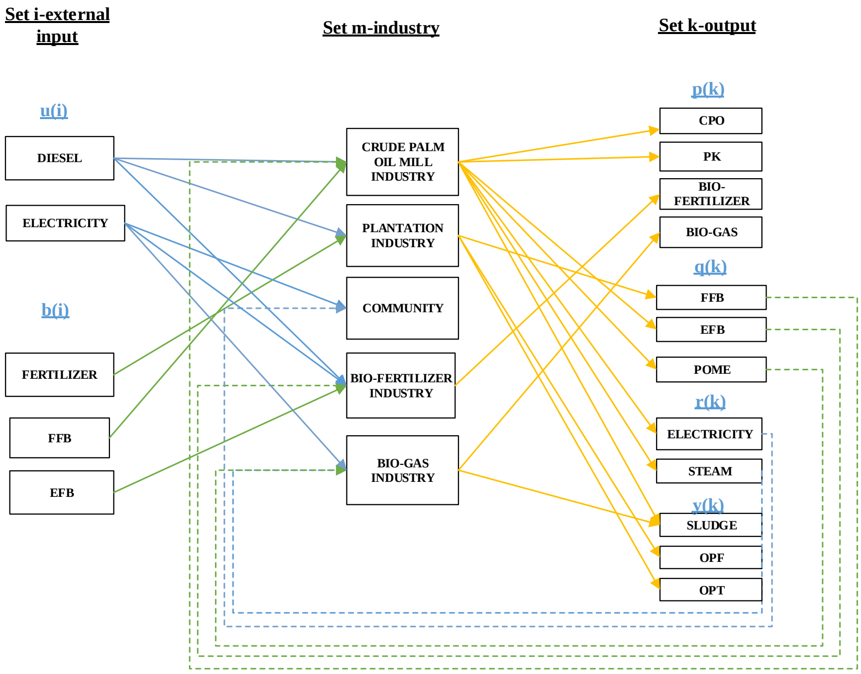

Figure 1: Superstructure of oil palm EIT

4. Model formulation and data collection

4.1 Model Formulation

The section describes the model developed for this study. Eq(1) to Eq(2) are formulated to ensure the external biomass and external utility are sufficient to support industries in the EIT. While Eq(3) and Eq(4) bound the external biomass and utility are send to respective industries.

$$\mathrm{AVBIO}_b \geq \sum\nolimits_m \mathrm{EXBIO}_{(b,m)} \ \forall\ b \tag{1}$$

$$\mathrm{AVUTILITY}_u \geq \sum\nolimits_m \mathrm{EXUTILITY}_{(u,m)} \ \forall\ u \tag{2}$$

$$\mathrm{EXBIO}_{(b,m)} = \mathrm{EXBIO}_{(b,m)} \times \mathrm{Tab1}_{(b,m)} \ \forall\ b \ \forall\ m \tag{3}$$

$$\mathrm{EXUTILITY}_{(u,m)} = \mathrm{EXUTILITY}_{(u,m)} \times \mathrm{Tab1a}_{(u,m)} \ \forall\ u \ \forall\ m \tag{4}$$

The cumulative biomass and cumulative utility for each industry may come from external and internal as shown in Eq(5) and Eq(6). The external biomass/utility is the resource that imported from outside EIT, while, the internal biomass/utility is the resource that produced within the industries in the EIT. The output of industry can be the classified as product, by- products, by-utility and waste. The amount of industry output is depend on the CBIO_m as formulated in Eq(7) to Eq(10).

$$\mathrm{CBIO}_m = \sum_b \mathrm{EXBIO}_{(b,m)} + \sum_q \mathrm{INBIO}_{(q,m)} \ \forall\ m \tag{5}$$

$$\mathrm{CUTILITY}_m = \sum_u \mathrm{EXUTILITY}_{(u,m)} + \sum_r \mathrm{INUTILITY}_{(r,m)} \ \forall\ m \tag{6}$$

$$\mathrm{CBIO}_m \times \mathrm{Tab3}_{(m,p)} = \mathrm{DPRO}_{(m,p)} \ \forall\ m \ \forall\ p \tag{7}$$

$$\mathrm{CBIO}_m \times \mathrm{Tab3a}_{(m,q)} = \mathrm{DBYPRO}_{(m,q)} \ \forall\ m \ \forall\ q \tag{8}$$

$$\mathrm{CBIO}_m \times \mathrm{Tab3b}_{(m,r)} = \mathrm{DBYUTILITY}_{(m,r)} \ \forall\ m \ \forall\ r \tag{9}$$

$$\mathrm{CBIO}_m \times \mathrm{Tab3c}_{(m,y)} = \mathrm{DWASTE}_{(m,y)} \ \forall\ m \ \forall\ y \tag{10}$$

The Eq(11) to Eq(16) are made to differentiate the types of output between product, by-product, by-utility and waste. The by-product and by-utility will be send to the other industries as formulate in Eq(17) and Eq(18).

$$\mathrm{AVPRO}_p = \sum\nolimits_m \mathrm{DPRO}_{(m,p)} \ \forall\ \mathrm{subpro} \tag{11}$$

$$\mathrm{AVBYPRO}_q = \sum\nolimits_m \mathrm{DBYPRO}_{(m,q)} \ \forall\ q \tag{12}$$

$$\mathrm{AVBYUTILITY}_r = \sum\nolimits_m \mathrm{DBYUTILITY}_{(m,r)} \ \forall\ r \tag{13}$$

$$\mathrm{AVWASTE}_y = \sum\nolimits_m \mathrm{DWASTE}_{(m,y)} \ \forall\ y \tag{14}$$

$$\mathrm{AVBYPRO}_q \geq \sum\nolimits_m \mathrm{INBIO}_{(q,m)} \ \forall\ q \tag{15}$$

$$\mathrm{AVBYUTILITY_r} \geq \sum\nolimits_{m} \mathrm{INUTILITY_{(r,m)}}\ \forall\ r \tag{16}$$

$$\mathrm{INBIO_{(q,m)}} = \mathrm{INBIO_{(q,m)}} \times \mathrm{Tab2_{(q,m)}}\ \forall\ q\ \forall\ m \tag{17}$$

$$\mathrm{INUTILITY_{(r,m)}} = \mathrm{INUTILITY_{(r,m)}} \times \mathrm{Tab2a_{(r,m)}}\ \forall\ r\ \forall\ m \tag{18}$$

The economic, environment, and job opportunities index are shown in Eq(19) to Eq(21). The profit consist of annual operating cost consist of the industry variable O&M cost, and industry fixed O&M cost. The variable O&M cost and biomass material cost are calculated over a year of operation. The investment cost on the other hand consists of capital costs of industry power plant.

$$\mathrm{ENV_n} = \sum\nolimits_{y} \mathrm{AVWASTE_y} \times \mathrm{ENVIND_{(y,n)}}\ \forall\ n \tag{19}$$

$$\mathrm{JOB2} = \sum\nolimits_{p} \mathrm{AVPRO_p} \times \mathrm{JOB_{(p,s)}} \tag{20}$$

$$\begin{aligned}\mathrm{PROFIT} = \sum\nolimits_{p} \mathrm{AVPRO_p} \times \mathrm{PRICE_{(p)}} &- \sum\nolimits_{m} \mathrm{CBIO_m} \times \mathrm{VARCOST_{(m)}} \\ &- \sum\nolimits_{m} \mathrm{CBIO_m} \times \mathrm{FIXEDCOST_{(m)}} - \sum\nolimits_{m} \mathrm{CBIO_m} \\ &\times \mathrm{INVESTCOST_{(m)}}\end{aligned} \tag{21}$$

Objective function

The objective function of this model is to maximise the λ which consists of economic, environment, and job opportunities index, as shown in Eq(22) to Eq(24). The λ is continuous variable that ranges between 0 and 1, as formulated in Eq(25).

$$\frac{\mathrm{PROFIT} - \mathrm{PROFIT_L}}{\mathrm{PROFIT_U} - \mathrm{PROFIT_L}} \geq \lambda \tag{22}$$

$$\frac{\mathrm{ENV_{SU}} - \mathrm{ENV_s}}{\mathrm{ENV_{SU}} - \mathrm{ENV_{SL}}} \geq \lambda \tag{23}$$

$$\frac{\mathrm{JOB2} - \mathrm{JOB_L}}{\mathrm{JOB_U} - \mathrm{JOB_L}} \geq \lambda \tag{24}$$

$$0 \leq \lambda \leq 1 \tag{25}$$

4.2 Case study and data collection

The model is developed to produce multi products from oil palm based while generate minimise waste to the environment. In this case study, a typical palm oil mill (60 t/h with 8,000 h/y) is assumed neighbouring with five oil palm based industries and a community to allow utilities and materials sharing within the EIT. The information to illustrate the case study and material economic value are shown in Table 1 and Table 2.

Table 1: Material/utility allocation diagram

Input material/ utility	Amount	Industry	Output material	Amount	Source
*FFB	1 t	Crude palm oil mill	CPO	0.2 t	(Yoshizaki et al., 2013)
Diesel	0.12 L		CPK	0.06 t	(Chavalparit and Rulkens, 2006)
Electricity	14.5 kWh		POME	0.65 t	
			EFB	0.23 t	
*Fertilizer	1 t	Oil palm plantation	FFB	58.12 t	(Patthanaissaranukool et al., 2013)
Diesel	17.44 L		OPF	2.91 t	
*EFB	1 t	Bio-fertilizer	Bio-fertilizer	0.4 t	(Schuchardt and Stichnothe, 2008)
POME	2.3 t				
Diesel	0.30 L				
*POME	1 t	Bio-gas	Methane	14.77 m^3	(Schuchardt and Stichnothe, 2008)
Electricity	0.12 kW		Sludge	0.05 t	

*main material

Table 2: Estimated market price

Products	Price	Unit	Source
CPO	735.01	USD/t	(MPOB, 2014)
CPK	437.5	USD/t	(MPOB, 2014)
Bio-fertilizer	139.5	USD/t	(MPOB, 2014)
Bio-gas	0.255	USD/m^3	-

5. Results and discussion

5.1 Results

The MILP model described in Section 4.1 was coded in GAMS and with the objective to maximise the λ, the model is solved via CPLEX 12.3.0.0 0 solver which applies the branch and cut algorithm. The results reveal that the optimal energy system for utilizing EFB energy is by using crude palm oil mill. Based on the objective function, the λ of the system was revealed as 0.656. The results are summarised in Table 3.

Table 3: Optimal Results

Variable	Value
λ	0.656
Profit	8.23 M USD
CO_2 emission	5,948 t CO_2 eq.
Job opportunity	456

5.2 Discussion

The model mainly produce huge amount of CPO and CPK compared other products due to the lower cost of crude palm oil mill. Another reason leading to this outcome is abundant availability of FFB from oil palm plantation. Moreover, the crude palm oil mill able to produce large quantities of marketable products with lower cost. Although the bio-fertilizer industry has lowest production compared to the crude palm oil mill and bio-gas industry, the current price of bio-fertilizer is not profitable.

6. Conclusions

In conclusion, the developed and optimized model can decide the profitable products that will give maximum profit and job opportunities, while give less impacts to the environment. Oil palm biomass indeed has potential to generate multi bio-products and bio-energy and benefit to community. The results show that crude palm oil industry and bio-fertilizer are the most efficient way to utilise abundant oil palm biomass into profitable products. EIT has potential to assist the town planner and decision maker to identify the sub-industries in the EIT for sustainable oil palm based industries.

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