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Biomass Corridor Synthesis for Malaysia Green Energy Supply Chain

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The urban cities of Malaysia are enclosed by greenery, mainly oil palm plantation which it covers 4.98 Mha of the land area of the country. Due to the huge volume of oil palm availability, palm biomass appears to be one of the key concerns to the country. Space and technologies are needed to allocate the resulting palm biomass, which its volume is directly proportional to the amount of palm fresh fruit bunches (FFB) being processed. Due to the characteristics of biomass being low density, porous and low calorific value, the biomass may be integrated with other source of useful material, say waste industrial oil, to boost up its efficiency for incineration while symbiotically tackling the waste oil disposal difficulty. The Malaysian government has set a target on the biomass generated renewable energy. However, the realisation of the energy target is challenging. The crop aging and promotion of replanting policy by the government may reduce the availability of biomass, which threatens the accomplishment of the energy target. The adapted biomass with higher energy value may be able to tackle the mentioned threat, enhancing the energy security of the country. In this work, a biomass energy supply plan is proposed and a simplified supply network design is presented.

1. Introduction

Palm biomass exerts high green potential in Malaysia (Ng et al., 2012). Yearly, more than 90 Mt of oil palm biomass is produced in Malaysia. Palm briquette is the compacted palm fibres which can act as an indigenous, affordable and clean source of energy that can be used for system heating or power generation. According to Purohit (2006), uniform combustion can be achieved for palm briquette incineration and the combustion rate of palm briquette is comparable to that of coal. Based on the statistics from Road Transport Department (JPJ) in 2011, more than 200 ML/y of lubricant oil is utilised and disposed in Malaysia (JPJ, 2011). The waste oil collected may end up to be recycled as low grade engine oil. Nevertheless, the oil will eventually end up to be incinerated. It shall be noted that waste motor oil contains heating value which heat energy can be recovered upon incineration.
As the world is coming to face a shortage of fossil fuels, substitution of fossil fuel with an indigenous, affordable and cleaner source of energy should be brought in to meet the ever-increasing energy demands leading to energy conservation. Malaysian government has introduced two plans to promote renewable energy sources, which are Small Renewable Energy Program (SREP) and Renewable Energy Policy. SREP promotes the wider integration of renewable energy, especially, in the power generation system. Renewable Energy Policy promotes the utilisation of local renewable energy resources, leading to sustainable socio-economic development and improving the country's energy

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security. As a measure to boost the development of renewable energy power generation industry, the price of the energy or the Feed-in Tariff (FiT) has been proposed to quote from 9 cents USD per kWh onwards for biomass-produced energy (KeTTHA, 2011). The FiT rate is governmentally incentived so as to improve the profitability of the renewable energy generators.

In this work, the substitution of coal with biomass (palm briquette) for co-firing energy production is possible. However, the modification on the power generation facilities is needed to adapt the dissimilar burning properties of the fuels. Apart from that, biomass corridor is proposed. Biomass corridor is a conceptual zone which circles the facilities from the initial stage of biomass harvesting to the final delivery stage of product supply. The processing facilities in the biomass corridor are unbounded. From the biomass supply point, the biomass can be delivered and processed to low value-added products or high value-added products. However, one of the main obstacles in realising the existence of biomass corridor is the site planning of the processing facilities. The existing biomass processing facilities are distributed and they can hardly be relocated. In Malaysia, the biomass industry is at its first stage to be developed. The concept of biomass corridor may act as a systematic management scheme or facilities positioning guideline to the Malaysian biomass industry at its first formation. The situation in Malaysia is unique as compared to other countries. In most of the countries, the location of biomass feedstock is far from the city, yet, the Malaysian city is surrounded by greenery, mostly oil palm plantations. This situation and the biomass corridor concept are illustrated in Figure 1. This leads to the relatively short transportation path of biomass to the urban city. This situation allows the realisation of the proposed energy strategy.

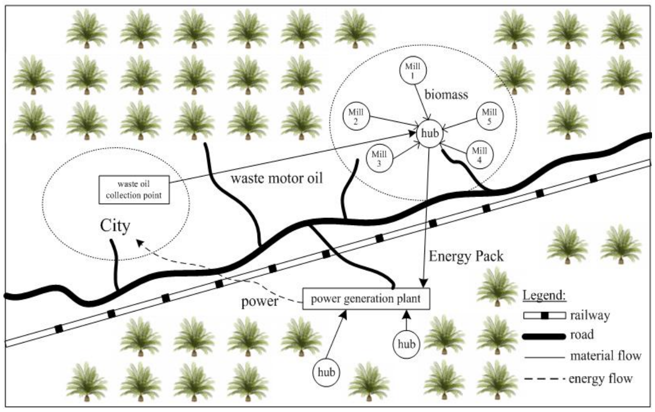

Figure 1: The concept of biomass processing hub and material/energy flow of proposed energy strategy

2. Problem statement

The problem to be addressed in this work is formally stated as follows: given a set of palm biomass from a set of processing hubs *b* is to be allocated to a set of power stations *c* or ports *d* for exportation. The objective of this work is to determine the optimum allocation of biomass products production and the amount of possible renewable energy generation to substitute coal power with optimum supply network design. A two stages model is proposed, macro-stage for supply network design and micro-stage for process design.

The supply chain model is defined as the followings: In layer 1 (L1), industrial waste from various source points $a \in A$ with flowrate W^{SR} are transported to a set of processing hub points $b \in B$ at layer 2 (L2). In L2, biomass $i \in I$ is/are sent to technologies $j \in J$ to produce intermediate(s) $k \in K$ at the conversion rate of $X^{I}_{j,k}$. The intermediate(s) *k* with flowrate of $W^{II}_{k,j'}$ is/are then upgraded to product(s) $k' \in K''$ at the conversion rate of $X^{II}_{j',k'}$ via technologies $j' \in J'$. The total production rate of intermediates *k* and products *k'* is given as W^{INT}_{k} and $W^{PR}_{k'}$ respectively. Other than producing intermediates *k* and products *k'*, energy (i.e., steam and electricity) can be generated from technologies *j* and *j'* via material

and energy recovery. The energy produced $e \in E$ per unit source *i* or intermediate *k* via technologies *j* or *j'* is specified as $Y^{I}_{j,e}$ and $Y^{II}_{j',e}$, respectively. The total production rate of energy is denoted as E^{Gen}_{e}. The total energy consumption rate E^{Con}_{e} is calculated according to the energy consumed via technologies *j* and *j'* per unit main product produced, which is specified as $E^{I}_{i,j}$ and $E^{II}_{k,j'}$ respectively. The amounts of total energy imported and exported are given as E^{Imp}_{e} and E^{Exp}_{e} respectively. The outflow of products $k' \in K'$ from processing hub $b \in B$ is then sent to power generation facilities $c \in C$ in Layer 3 (L3) and ports $d \in D$ in Layer 4 (L4).
The gross profit (*GP*) of the synthesised integrated processing hub is determined by the cost of biomass sources *i* (C^{SR}_{i}), the processing cost and the annual capital cost per unit main product produced via technologies *j* (C^{Proc}_{j} and C^{Cap}_{j}) and *j'* ($C^{Proc}_{j'}$ and $C^{Cap}_{j'}$) respectively as well as the revenue obtained from each final product *k'* ($C^{PR}_{k'}$). In addition, technologies *j* and *j'* also generate energy as mentioned earlier. Energy import cost (C^{Imp}_{e}) will be taken into consideration if the energy generated is insufficient or the export cost (C^{Exp}_{e}) will be taken into consideration if the energy generated exceeds the total energy consumption. However, the energy consumption within the sustainable integrated processing hub has to be self-sustaining prior to the consideration of energy exportation as proposed by Tay et al. (2011). The logistic cost, $COST^{tr}$ of the supply chain is calculated based on the distance travelled and total mass transported across the layers. The conversion of energy pack to electricity in power plant is calculated by steam generators theory.

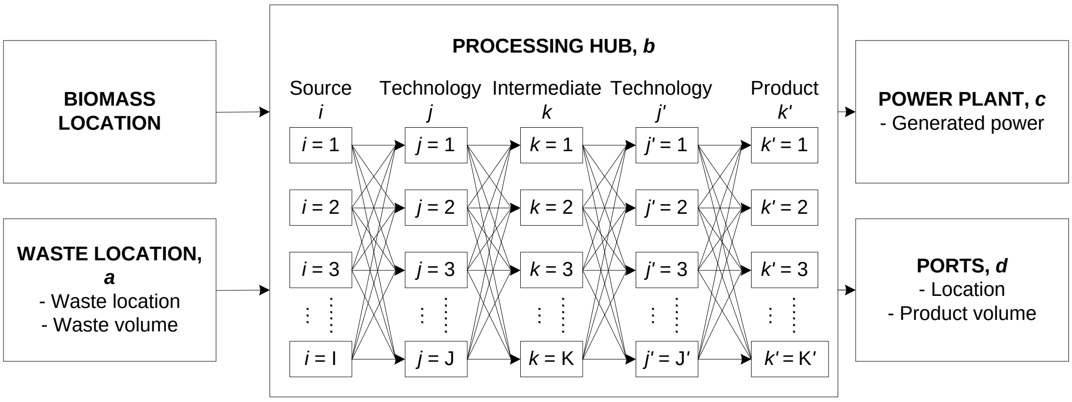

Figure 2: Generic superstructure of the two stages model

3. Model formulation

3.1 Micro-layer (process selection)

For the biomass conversion from biomass *i* to product *j*, varying $i = 1...N_I$ and $j = 1...N_J$, the following objective function is defined for the micro-layer:

$$NPV = Max \sum_{t}^{t_{max}} \frac{GP}{(1+R)^{t}} \tag{1}$$

where tmax is the operating lifespan and R is the expected rate of return. This simplified net present value (NPV) equation estimates the economic performance of an integrated processing hub's profit or loss over its operational lifespan, assuming that the main factor of economic performance is based on gross profit (GP). GP is determined by revenue obtained from final product k' ($C^{PR}_{k'}$) and energy export cost (C^{Exp}_{e}) subtract the energy import cost (C^{Imp}_{e}), cost of biomass sources i (C^{SR}_{i}), the processing cost (C^{Proc}_{j} and $C^{Proc}_{j'}$) and the annual capital cost per unit main product produced (C^{Cap}_{j} and $C^{Cap}_{j'}$). *GP* is therefore given as:

$$GP = \sum_{k' \in K'} W_{k'}^{\text{PR}} C_{k'}^{\text{PR}} + \sum_{e \in E} E_e^{\text{Exp}} C_e^{\text{Exp}} - \sum_{e \in E} E_e^{\text{Imp}} C_e^{\text{Imp}} - \sum_{i \in I} W_i^{\text{SR}} C_i^{\text{SR}}$$
$$- \sum_{k \in K} \sum_{j \in J} W_k^{\text{INT}} C_j^{\text{Proc}} - \sum_{k' \in K'} \sum_{j' \in J'} W_{k'}^{\text{PR}} C_{j'}^{\text{Proc}} - \sum_{k \in K} \sum_{j \in J} W_k^{\text{INT}} C_j^{\text{Cap}} - \sum_{k' \in K'} \sum_{j' \in J'} W_{k'}^{\text{PR}} C_{j'}^{\text{Cap}} \qquad (2)$$

Biomass i are converted to intermediates k via technologies j at the production rate of W_k^{INT}, with the conversion of $X_{j,k}^{\text{I}}$. The production rate of intermediate k is given as:

$$W_k^{\text{INT}} = \sum_{i \in I} \sum_{j \in J} \left(W_{i,j}^{\text{I}} \; X_{j,k}^{\text{I}} \right) \qquad \forall k \in K \qquad (3)$$

The intermediates k can be distributed to potential technologies j' for further processing to produce final product k'. The splitting constraint of intermediates k is written as:

$$W_k^{\text{INT}} = \sum_{j' \in J'} W_{k,j'}^{\text{II}} \qquad \forall k \in K \qquad (4)$$

The total production rate of final product k' ($W_{k'}^{\text{PR}}$) can be determined by converting intermediates k at the conversion rate of $X_{j',k'}^{\text{II}}$ via the technologies j'.

$$W_{b,k'}^{\text{L2}} = \sum_{k \in K} \sum_{j' \in J'} \left(W_{k,j'}^{\text{II}} \; X_{j',k'}^{\text{II}} \right) \qquad \forall k' \in K' \qquad (5)$$

Biomass sources i and intermediates k are allowed to by-pass technologies j or j', where no technology is required to produce intermediates k or desired final products k' without any conversion. The energy generated from technologies j and j' is determined through energy conversion of $Y_{j,e}^{\text{I}}$ and $Y_{j',e}^{\text{II}}$. The total production rate of energy e streams E_e^{Gen} is given as:

$$E_e^{\text{Gen}} = \sum_{j \in J} \sum_{i \in I} \left(W_{i,j}^{\text{I}} \; Y_{j,e}^{\text{I}} \right) + \sum_{j' \in J'} \sum_{e \in E} \left(W_{e,j'}^{\text{II}} \; Y_{j',e}^{\text{II}} \right) \qquad \forall e \in E \qquad (6)$$

The total energy consumption E_e^{Con} is determined based on the energy consumed in technologies j and j'. The total energy consumption is determined as:

$$E_e^{\text{Con}} = \sum_{j \in J} \sum_{i \in I} \left(W_k^{\text{INT}} E_{e,i,j}^{\text{I}} \right) + \sum_{j' \in J'} \sum_{k \in K} \left(W_{k'}^{\text{PR}} \; E_{e,k,j'}^{\text{II}} \right) \qquad \forall e \in E \qquad (7)$$

The excess energy E_e^{Exp} can be sold and exported to any third party plants if the total energy generation exceeds the total energy consumption ($E_e^{\text{Gen}} > E_e^{\text{Con}}$). Note that external energy importation E_e^{Imp} is needed for the synthesized integrated processing hub if the total energy generated is insufficient for the total consumption ($E_e^{\text{Gen}} < E_e^{\text{Con}}$). Therefore, the energy correlation can be written as:

$$E_e^{\text{Con}} = E_e^{\text{Gen}} + E_e^{\text{Imp}} - E_e^{\text{Exp}} \qquad \forall e \in E \qquad (8)$$

3.2 Macro-stage (supply network selection)

The material flow of industrial waste supplied to the centralised hub, $\sum_{a \in A} W_{a,b}^{L1,L2}$ (t/h) is defined as the following to match the hub requirement:

$$\sum_{a \in A} W_{a,b}^{L1,L2} \geq \sum_{k' \in KB'} W_{b,k'}^{L2} \times n^{ind} \qquad \forall b \in B \qquad (9)$$

where n^{ind} is the ratio factor for industrial waste requirement by weight of briquette produced. The energy pack produced $k' \in KB'$ from processing hub b is sent to power generation plant C at Layer 3 (L3) for electricity generation. This is defined as:

$$\sum_{k' \in KB'} W_{b,k'}^{L2} = \sum_{c \in C} W_{b,c}^{L2,L3} \qquad \forall k' \in KB' \qquad (10)$$

The energy pack is used to generate power. The energy conversion factor, $X_{k'}$, is the factor that indicates the amount of power to be produced per unit weight of fuel. The energy conversion factor is defined as:

$$X_{k'} = \frac{HV_{k'} \times \eta}{3600} \qquad \forall k' \in KB' \qquad (11)$$

where $HV_{k'}$ (kJ/t) is the heating value of product k', η is the efficiency of power generation facility. The energy conversion factor, $X_{k'}$, is used to calculate the amount of power generated based on steam generators theory. The amount of power generated, E_c (kW), per power generation plant c is given by:

$$E_c = \sum_{b \in B} W_{b,k',c}^{L2,L3} \times X_{k'} \qquad \forall k' \in KB' \qquad (12)$$

The other end products produced $KP' \in$ DLF ∪ pellet ∪ PKS, from the hubs are sent to ports at Layer 4 (L4). This is defined as:

$$\sum_{k' \in KP'} W_{b,k'}^{L2} = \sum_{d \in D} W_{b,d}^{L2,L4} \qquad \forall k' \in KP' \qquad (13)$$

In the supply chain model, the transportation cost is dependent on the distance travelled, *DT* (km), the amount of biomass supply, *W* (t/y), transportation cost, *q* ($/t/km/y) and the handling cost, *HL* ($/t). The transportation cost acts as the objective function which is to be minimised. The total annual transportation cost, $COST^{tr}$ ($/y) is defined as:

$$COST^{tr} = \sum_{a \in A} \sum_{b \in B} \left[W_{a,b}^{L1,L2} \times \left(q \times DT_{a,b}^{L1,L2} + HL \right) \right] + \sum_{b \in B} \sum_{c \in C} \left[W_{b,c}^{L2,L3} \times \left(q \times DT_{b,c}^{L2,L3} + HL \right) \right] + \sum_{b \in B} \sum_{d \in D} \left[W_{b,d}^{L2,L4} \times \left(q \times DT_{b,d}^{L2,L4} + HL \right) \right] \qquad (14)$$

4. Illustrative case study

A simplified case study is presented to illustrate the application of the model. In the macro-stage (supply network), 4 layers are proposed in the network: supply, processing, demand and power generation which are interconnected by material transfer across the layers. The optimal product selection in a processing hub is first synthesised based on the currently available facilities capacity in the micro structure. The output of the products is then fed into the macro-structure for optimal supply network design. Besides, the industrial waste motor oil is collected from the selected major cities and transported to selected hubs for energy pack production in processing hub. The power distribution and energy point demand is not considered in this case as the electricity supply of Peninsular Malaysia is well connected with National Grid System. In the supply network, the supply chain design for the procurement of palm biomass from various supply sources in west Peninsula Malaysia to power plant for electricity generation is studied. In the case study, 4 coal power generation plants, 12 optimised hub locations and 3 ports along the 772 km North-South Expressway (NSE) is used.

In the micro-stage, 2 main biomass sources i, empty fruit bunches (EFB) and palm kernel shell (PKS) are converted to intermediates k (wet long fibre (WLF) or short fibre (SF)) or final products (pellet, dried long fibre (DLF), briquette) via technologies j or j' within an integrated processing hub. Throughout the sieving process, SF is produced. The SF can be further processed to valuable products through pelletizing or briquetting process, thus, it can be taken as another source. In addition, sources i can also be converted to high pressure steam through boilers and sent to turbine for the production of electricity and medium pressure steam. As PKS can be sold as final product, therefore, PKS can by-pass all technology level via “blank” technology.

The optimisation of micro stage model is solved by maximising *NPV* using the optimisation software LINGO. Based on the optimised result, the maximum *NPV* is targeted as USD 108.51 million over its

operational 15 y with gross profit of USD 17.31 million per year. It is noted that all pellet, DLF and briquette production pathways are selected in this scenario. A total of 108.62 t/h of fresh EFB and 28.21 t/h of fresh PKS are utilised to produce DLF and energy pack at the production rate of 8 t/h and 42 t/h, respectively. Meanwhile, 5.86 t/h of wet short fibre is collected from the DLF production. Part of the fresh EFB and PKS are sent to boiler and turbine to generate 153.85 t/h of steam and 8923.08 kWh of electricity for the self-consumption in the integrated processing hub. There is an excess of 23.08 kWh of electricity which can be exported to external facilities.
Applying the case data on the energy supply chain framework (macro stage model), an optimal material network solution with the objective to minimise the logistic cost is found for the base case. The model is solved with the software GAMS. The equations under 'model formulation' are used to build the Mixed Integer Linear Programming (MILP) model. This energy strategy generates 536 MW of power in total and incurs a transportation cost of USD 32.50 million per year.

5. Conclusion

This work presented an energy plan of power production by substituting coal with palm briquette as fuel. It is expected that the energy supply of Malaysia will turn less dependent on the supply of fossil fuel - coal, which is imported into Malaysia, by substitution certain amount of coal with energy pack made of palm briquette and industrial waste oil. However, the incineration of industrial waste oil releases sulphurous and other hazardous emissions, which requires specific design of furnaces and installation of gaseous waste treatment processes. Further research work may be carried out to investigate the equipment design of this proposed energy generation facility as well as the detailed combustible properties of 'energy pack' (Čuček et al., 2010). Life cycle analysis and some other aspect such as nitrogen footprint (Čuček et al., 2012) of the biomass product can be investigated as well. The technology for briquette production to absorb more oil can be further explored to increase the heating value of 'energy pack'. Apart from that, the supply network by railway system (train) can be investigated for a more economical and environmental friendly mode of transportation.

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