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Novel Approach for Integrated Biomass Supply Chain

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In Malaysia, palm-based biodiesel is one of the renewable energy that has been commonly produced and used to produce energy. To increase the energy security, the development of another renewable energy source is very critical. This paper proposes a multiple biomass corridor concept for systematic design of waste-to-energy supply network. Paddy, sugar cane and pineapple biomass are incorporated in the strategy together with palm biomass to form a supply chain in order to meet the increasing energy demand. These are the main agricultural plantations after palm oil in Malaysia. These biomass sources have good potential to meet the developing local biodiesel market in Malaysia as well as the growing renewable energy share globally. In the supply chain, these wastes are converted to value-added product or energy. Therefore, this zero-waste approach will result in a fall in carbon emission. A Mathematical Programming model is then developed to synthesise the multiple biomass corridor. Based on the optimised result, the distribution and logistics network as well as the potential centralized processing hubs are determined. In addition, the optimum processing technologies path/network of the processing hub is determined. To elucidate the proposed framework, a real case study that geographically based on a state in the Peninsular of Malaysia is performed.

1. Introduction

Fossil fuels such as coal, oil and natural gas are main energy sources for heat, electricity and transportation. They are still dominant in the energy market, accounting 86 % of the total energy consumption (BP, 2015a). As the population is growing, the world is coming to face a terrific energy crisis due to the activities of human kinds. To meet the ever increasing energy demand, the discovery of primitive, cheap and clean energy is very critical. To improve energy security, Malaysia is working towards fuel diversification to reduce its dependency on fossil fuels. Therefore, Malaysia has implemented New Energy Policy to encourage the implementation of renewable energy projects in the Tenth Malaysia Plan in 2010. With the emphasis being placed on the use of renewable energy and increasing energy efficiency, the 'new energy' has been gaining influence in current energy development as potential alternative to fossil fuels. As shown in Energy Outlook 2035 (BP, 2015b), substitution of fossil fuel with renewable energies in 2035 is expected to account for around 8 % of total world primary energy. Among all renewable energy sources, bioenergy is the oldest source of energy known to mankind and it is the largest source of renewable energy, which accounts to roughly 6.3 % of world total primary energy supply (IEA, 2011). Bioenergy is the energy derived from biomass. Biomass is biological material, especially plant matter which can be used as fuel for heat and power generation, as well as converted into liquid and gas biofuels with low greenhouse gases emission (Bringezu, et al., 2009). It can also be used as a feedstock to produce biochemical (such as bio-acid and bio-ethanol), construction material, animal feed as well as fertiliser. Innovation Agency Malaysia predicts bioenergy could provide 410 MW of electricity, reduce carbon emission by 12 % and generate a gross national income of 30 billion MYR (AIM, 2013).

As agricultural sector is the backbone of Malaysia's economy, Malaysia is bestowed with significant amount of biomass resources. A minimum of 168 Mt/y of biomass waste is generated in Malaysia. The agricultural and forestry sectors produce a large amount of residues that have no other commercial values than potential energy generation. The existence of these wastes and residues has created some disposal problems to the country. The Department of Environment has discouraged burning the material due to

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pollution and possible forest burning problems. The best solution to this problem is to extract energy from these materials through different processes and technologies. Since Malaysia accounts for 39 % of the world palm oil production, palm oil waste is commonly used as the feedstock for biorefinery. Two palm oil biomass supply chain were proposed previously for this problem: two-stage optimisation model (Ng, et al., 2012) and functional clustering model (Ng and Lam, 2013).

However, there are a lot more unutilized agricultural wastes which can be good sources of energy. Some of the potential feedstock includes pineapple, sugar cane, rice straw and husk should be considered and integrated into the biomass supply chain network for heat and power generation through biorefinery processes. The availability of these alternative energy sources is able to increase the energy security of the country (Klemeš and Lam, 2009). Furthermore, utilisation of the wastes offers the prospective to reduce the environmental impact (i.e. reduction in greenhouse gasses) of energy supply (Sun, et al., 2014). In order to fully utilise the potential of such wastes in the energy plan, a multiple biomass corridor concept is proposed. This concept plans from the initial stage of biomass harvesting, transportation and processing up to the final delivery stage of value-added product as shown in Figure 1. This may act as a guideline to the future development of the Malaysia biomass industry.

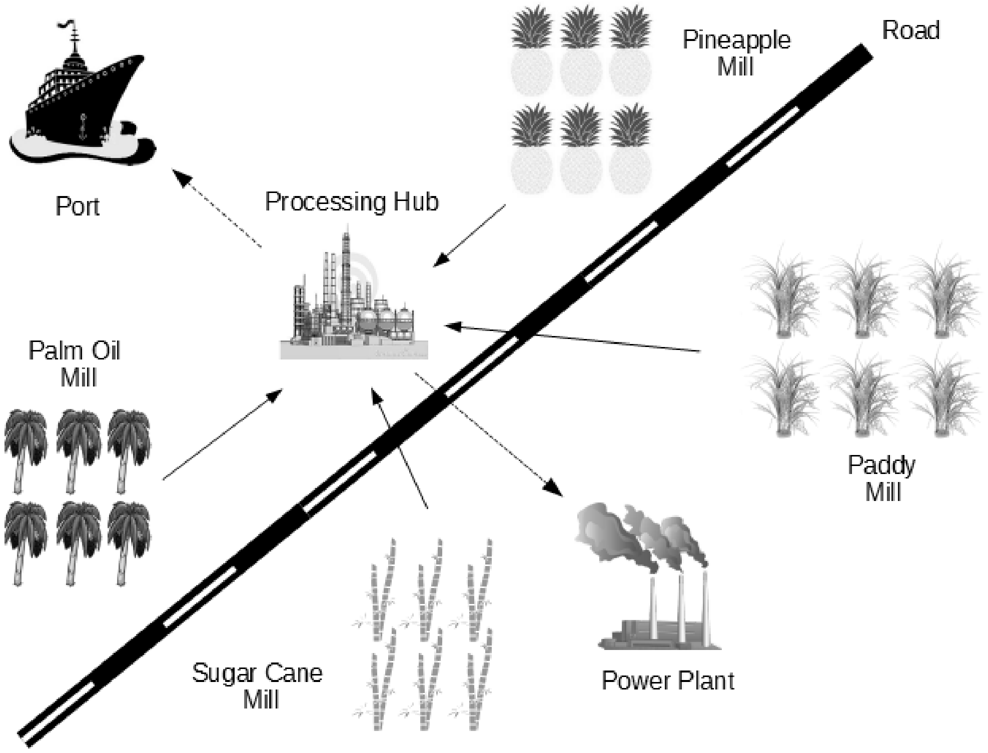

Figure 1: Multiple biomass corridor

2. Problem statement

The problem to be addressed in this work is formally stated as follows: a set of biomass from source a ∈ A is to be allocated a set of integrated processing hub b ∈ B and the final product is to be sent to a set of ports or power plants c ∈ C.. In the processing hub, biomass type i ∈ I is converted to intermediate k ∈ K through technology j ∈ J and finally converted to product m ∈ M via technology l ∈ L.. Besides, energy (i.e. electricity and steam) e ∈ E can be produced from biomass type i and intermediate k via technology j and l to sustain the process or to be exported. The superstructure is illustrated in Figure 2.

The economic potential of the supply chain is measure based on gross profit which is the difference between the logistic cost and the revenue from the processing hubs. The logistic cost of the supply chain is calculated according to the amount of material transported across its sources a, processing hubs b and ports/power plants c, distance travelled and the handling cost with the respective handling cost. On the other hand, the revenue of the processing hub is determined by cost of biomass i, operating cost and capital cost of technologies j and l, profit from product m as well as the energy consumption/generation e. The model is optimised to achieve maximum economic potential (i.e. maximum gross profit).

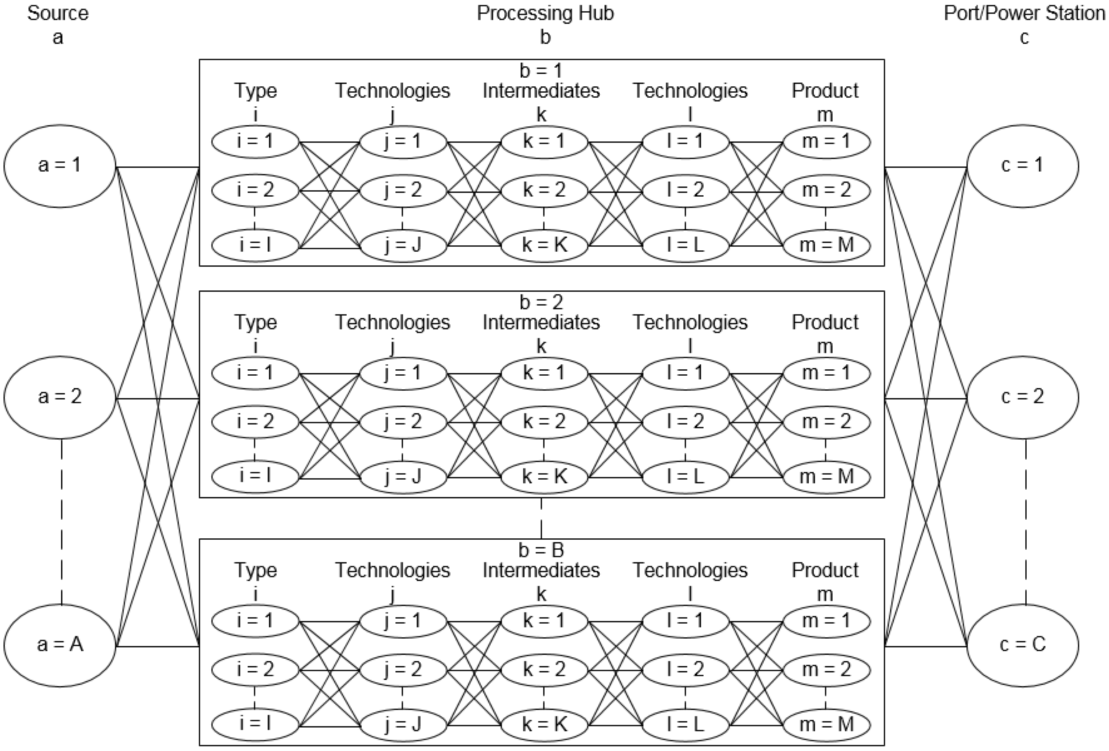

Figure 2: Superstructure of the model

3. Methodology

The methodology proposed describes the formulation of a model to design optimum supply network of biomass from multiple sources to processing hubs, an optimum integrated processing hub, and optimum delivery network of product from processing hubs to ports and power stations (i.e. optimum biomass corridor). In the supply chain network, the biomass is first transported from source a to hub b to be processed to value-added products. The total biomass delivered from source a to hub b is constrained by the biomass available at a.

$$F_a \geq \sum_{b \in B} F_{a,b} \tag{1}$$

where F_a is the amount availability of biomass at source a; $F_{a,b}$ is amount the biomass flow from source a to hub b. The selection of potential processing hubs can be defined as follows and the total number of selected hubs is pre-determined.

$$\sum_{b \in B} \sum_{a \in A} F_{a,b} = \sum_{b \in B} \sum_{a \in A} (\beta_b F_{a,b}) \tag{2}$$

$$\sum_{b \in B} \beta_b = n_b \tag{3}$$

where β_b denotes the selection of hub b; n_b denotes the number of hub required. All the processing hubs are assumed to be identical (i.e. integrated with all the technologies available). The total biomass from source a to hub b will be equal to the available biomass feedstock in hub b. In processing hub b, the available biomass feedstock is equal to the total biomass of type i.

$$\sum_{a \in A} F_{a,b} = F_{b,in} \tag{4}$$

$$F_{b,in} = \sum_{i \in I} F_i^b \tag{5}$$

Where $F_{b,in}$ represents the available biomass in hub b, $F_i^b$is the amount of biomass type i. Biomass type i is then transferred to technology j to be converted to intermediate k.

$$F_i^b = \sum_{j \in J} F_{i,j}^b \tag{6}$$

$$F_k^b = \sum_{j \in J} \sum_{i \in I} \left(F_{i,j}^b Y_{j,k} \right) \tag{7}$$

where $F_{i,j}^b$is the amount of biomass i transferred to technology j; F_k^b is the amount of intermediate k; $Y_{j,k}$ is the yield of technology j converting biomass i to intermediate k. The intermediate k is then sent to technology l to be further processed into final product m.

$$F_k^b = \sum_{l \in L} F_{k,l}^b \tag{8}$$

$$F_m^b = \sum_{l \in L} \sum_{k \in K} \left(F_{k,l}^b Y_{l,m} \right) \tag{9}$$

where $F_{k,l}^b$ denotes the amount of intermediate k sent to technology l; F_m^b is the amount of product m; $Y_{l,m}$ is the yield of technology l converting intermediate k to product m. Energy is generated from both biomass i and intermediate k via technology j and l to sustain the plant operation. Excess or shortage of energy can be exported and imported respectively.

$$E_{GEN}^b = \sum_{j \in J} \sum_{i \in I} \left(F_i^b Y_{j,e} \right) + \sum_{l \in L} \sum_{k \in K} \left(F_k^b Y_{l,e} \right) \tag{10}$$

$$E_{CON}^b = \sum_{j \in J} \sum_{k \in K} \left(F_k^b E_j \right) + \sum_{l \in I} \sum_{m \in M} \left(F_m^b E_l \right) \tag{11}$$

$$E_{CON}^b = E_{GEN}^b + E_{IM}^b - E_{EX}^b \tag{12}$$

where E_{CON}^b, E_{GEN}^b, E_{IM}^b, E_{EX}^b is the amount of energy consumed, generated, import and export respectively in hub b; $Y_{j,e}$ and $Y_{l,e}$ is the yield for energy generation from biomass i and intermediate k respectively; E_j and E_l is the electricity consumed per unit of product of technologies j and l. The total product produced in hub b is equal to the product output of hub b. At the last stage, the product output of hub b is to be respective ports and power stations.

$$\sum_{m \in M} F_m^b = F_{b,out} \tag{13}$$

$$F_{b,out} = \sum_{c \in C} F_{b,c} \tag{14}$$

Where $F_{b,out}$ denotes the product output of hub b and $F_{b,c}$ represents the amount of product transported from processing hub b to port/power station c. The objective function of the model is to maximise the gross profit generated. The gross profit GP is calculated as follows:

$$\begin{aligned} GP = {} & \sum_{m \in M} F_m\, SC_m - \sum_{i \in I} F_i\, BC_i + \sum_{e \in E} E_{EX}\, SC_E - \sum_{e \in E} E_{IM}\, BC_E - \sum_{k \in K} \sum_{j \in J} \left(F_k CC_j \right) - \sum_{m \in M} \sum_{l \in L} \left(F_m CC_l \right) \\ & - \sum_{k \in K} \sum_{j \in J} \left(F_k OC_j \right) - \sum_{m \in M} \sum_{l \in L} \left(F_m OC_l \right) - \sum_{a \in A} \sum_{b \in B} \left(F_{a,b} \left(TC \times D_{a,b} + HC \right) \right) \\ & - \sum_{b \in B} \sum_{c \in C} \left(F_{b,c} \left(TC \times D_{b,c} + HC \right) \right) \end{aligned} \tag{15}$$

$$OBJ = MAX\ GP \tag{16}$$

where TC denotes transportation cost; $D_{a,b}$ represents the distance travelled; HC is the handling cost; SC and BC denotes the selling price and buying cost respectively; CC and OC represents capital cost and operating cost respectively.

4. Case study

To illustrate the proposed framework, a case study that geographically based on Peninsular Malaysia is presented. In this case study, a multiple biomass corridor is to be synthesised in the state of Johor, Malaysia. Twenty five palm oil, pineapple, sugar cane and paddy plantations are included in this case study. The biomass is first transported to a single centralised hub that is to be chosen from 5 potential locations. In the centralised hub, these resources are to be processed by 16 different technologies into intermediates then products. It is assumed that the “super” hub contains all the technologies available and it acts as warehouse storage for both the raw materials and products. The final products are assumed to be either consumed by local power plant or to be exported. The distance travel is obtained from Google Map. There are total of 4 power plants and 2 ports available in the state. A mixed-integer linear programming (MILP) model is generated and optimized using Microsoft Excel with add-in What’sBest 13.0.0.1 (Lindo, 2014).

An optimised processing hub structure is generated as shown in Figure 3. Out of 16 technologies, there are only 11 technologies being chosen to process the respective biomass and intermediates. This is because the value of the products converted from these technologies gives higher revenue as compared the other 6 technologies. Although the hub can generate electricity by itself, electricity is imported to support its operation. This can be explained by the cheap electricity price in Malaysia. To verify this situation, the electricity cost in the model is adjusted to a higher value. As a result, the hub tends to generate just enough electricity to meet its own usage. This optimum processing facility can generate a total annual GP of $149 \cdot 10^6$ \$/y.

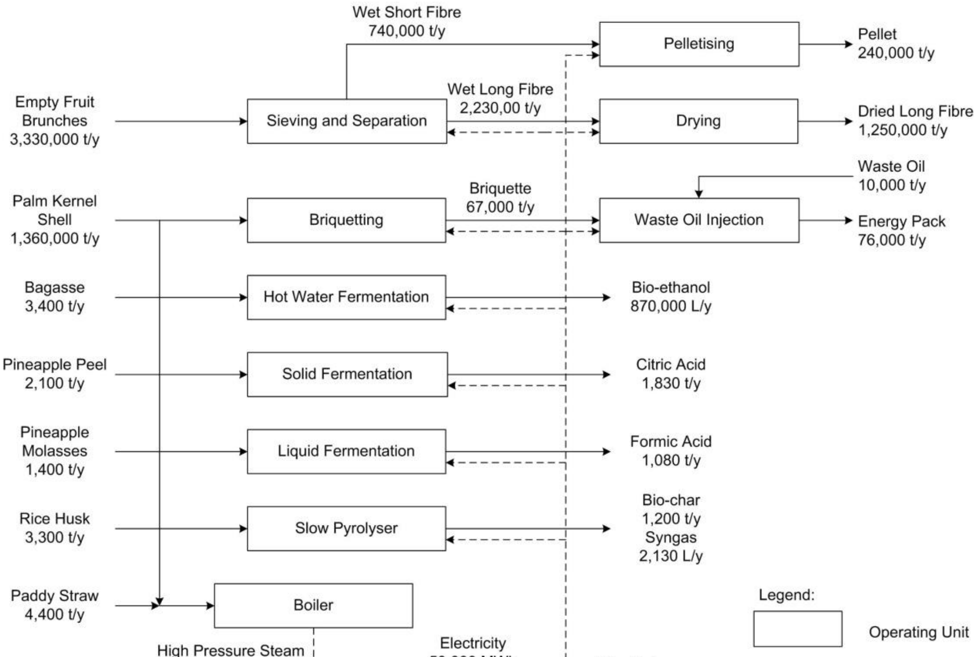

Figure 3: Optimised processing hub structure

The optimum supply and delivery network of this case study formed is shown in Figure 4. Simpang Renggam is chosen as the location from the 5 possible locations to set up the centralised processing hub because of its strategic geographical location. Majority of the plantations with high density of biomass locate near to the hub chosen. The final product will then be sent to the power plant and port in Johor Bahru as it takes the shortest distance to travel to these locations. With this network, the logistic cost is optimised to $64 \cdot 10^6$ \$/y. The maximum economic potential of the network will be $85 \cdot 10^6$ \$/y.

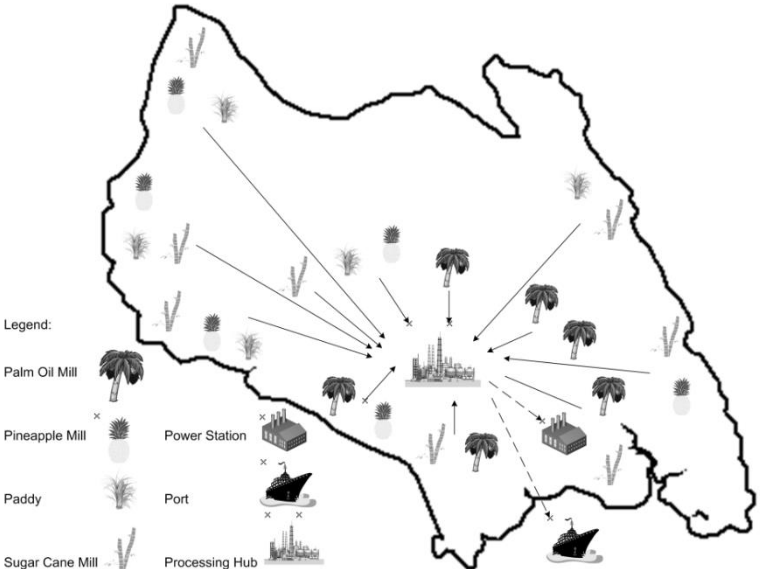

Figure 4: Optimised supply and delivery network

5. Conclusion

This paper presented a multiple biomass corridor concept which utilises waste to generate energy and value-added product. Through this strategy, fuel is diversified and the country's dependence on fossil fuels is expected to reduce. Besides, reutilisation of waste will lead to a drop in carbon emission. A MILP model is applied to synthesise an optimum multiple biomass corridor. This approach is successfully illustrated on a case study on Peninsular Malaysia. The optimum processing structure is determined and an optimum supply chain structure is generated with a net profit of 85 M$/y.

Future research work can be carried out to investigate the relationship between number of hubs and the optimality of the supply chain. The capacity, reliability and uncertainty of the processing hub and transportation can be incorporated into the model. Apart from that, scheduling of the transportation will be a good field of research. A biomass supply chain index can be designed to measure the performance of a supply chain based on different aspects.

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