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Synthesis of Regional Energy Supply Chain Based on Palm Oil Biomass

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This paper presents the synthesis of a regional energy supply chain that is based on the palm oil biomass residue of empty fruit bunch (EFB). EFB has always been identified as one of the most abundant energy resources in Malaysia. Hence, the EFB has good potential to meet the targeted share of renewable energy in Malaysia. The regional energy supply chain is synthesised based on a recent-developed mathematical model (Lam et al., 2010a). Modifications are made in order to tailor for the specific application in this work. A case study is presented to elucidate the model.

1. Introduction

Palm oil biomass (POB) residues such as palm empty fruit bunches (EFB), palm fibres and palm shell obtained from the milling process have good potential to meet the targeted share of renewable energy in Malaysia. After some simple pre-treatment processes (e.g. drying and densification), POB with high heating value may be used as the feedstock for combined heat and power (CHP) plant. The generated heat and power may be used by the local plant where CHP is based, while the excess power from the CHP can then be sent to the national grid system.

This paper focuses on EFB since it is the most abundant and widely available POB residue in the mill (the other POB are normally burnt within the mill). In most cases, EFB are transported out from the mill by empty lorries that bring in fresh fruit bunches from the nearby oil palm plantation estates. Hence, the CO_2 emission of these lorries is of concern in the planning of regional energy supply chain that is based on palm oil EFB.

Carbon Footprint (CFP) is commonly used in evaluating the environmental impacts of biomass process and supply chain. CFP is defined as the total amount of CO_2 and other greenhouse gases emitted over the full life cycle of a process or product (POST, 2006). CFP has become an important environmental protection indicator as most industrialised

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countries have committed to reduce their CO_2 emissions by an average of 5.2% in the period 2008–2010 in respect to the level of 1990 (Sayigh, 1999). The CFP of a biomass supply chain is the total CO_2 amount emitted throughout the supply chain life cycle (Perry et al., 2008). The net CFP is mainly caused by the indirect carbon emission generated along the supply chain itself. Transportation activities are the main contributors of CFP in a regional energy supply chain (Forsberg, 2000).
Typical location of biomass sources, the relatively low energy density (energy per unit volume) and the distributed nature of the sources require extensive infrastructure and huge transport capacity for biomass supply. For POB supply chains, road transport is the usual mode for collection and transportation of the fuel. As a result the heavy road transport increases the CFP of the biomass energy supply chain. Hence, this paper presents a mathematical model to minimise the CFP of an EFB energy supply chain. A Malaysian case study is used to illustrate the developed model.

2. Problem Statement

The problem to be addressed in this work can be formally stated as follows: given a set of EFB sources (*supplier*) to be allocated to a set of EFB sinks (*consumer*); the latter make use of the allocated biomass as renewable energy source in generating heat and power. The problem may be described by superstructure representation as shown in Figure 1. The objective of the work is to determine the optimum allocation of biomass in order to minimise the CFP of transportation.

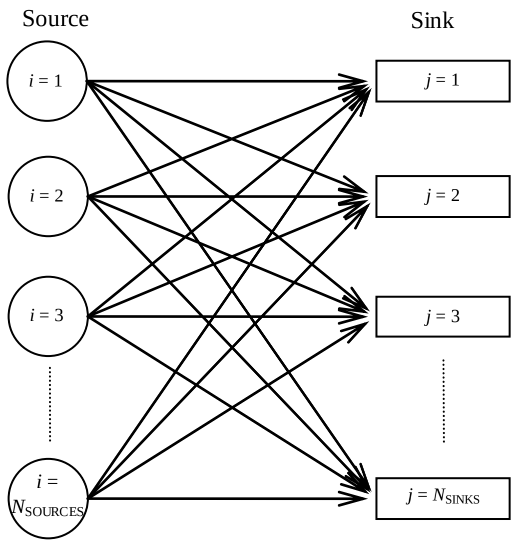

Figure 1: Source-sink representation for EFB allocation problem

3. Model Formulation

For biomass transfer from Source Zones (i) Sink Zones (j), varying $i = 1..N_I$; $j = 1..N_J$, the following objective function is defined:

$$Min(CFP) = \sum_{i=1}^{N_I} \sum_{j=1}^{N_J} CFP_{i,j} \quad (1)$$

$$CFP_{i,j} = FC_{i,j} \times Dist_{i,j} \times \frac{B_{i,j}}{C} \times CEF \quad (2)$$

Carbon Emission Factor (*CEF*) depends on the type of vehicle and the fuels (petrol/ diesel) that being used. The distance for transporting the biomass ($Dist_{i,j}$) is a set of user-specified parameters. For quick estimation, they can be approximated by the straight line distances between the zone centroids. For more realistic studies, road distances retrieved from GIS systems or road maps may be used.

The following constrains are inherent to the problem.

a) The total amount of biomass transported out from an EFB supplier (*i*) to other consumers cannot exceed the available amount AB_i (Eq.3) and flows for transferring biomass to the same zone are forbidden (Eq.4).

$$\sum_j B_{i,j} \leq AB_i \quad \forall i. \quad (3)$$

The total bioenergy (*BE*) delivered to consumer (*j*) should match its desired amount (*TD*) in that zone.

$$\sum_i BE_{i,j} \leq TD_j, \quad \forall j \quad (4)$$

$$BE_{i,j} = HV_i \times B_{i,j}, \forall i, j \quad (5)$$

HV_i is the heating value for the particular biomass from supplier (*i*) and TD_j is the total requirement in consumer (*j*).

The biomass flows in the system must be non-negative:

$$B_{i,j} \geq 0, \quad \forall i, j \quad (6)$$

4. Illustrative Case Study

An illustrative case study is used here to illustrate the application of the proposed model. Data of the case study is based on the actual palm oil mills, refineries and oleochemical plants in the northern part of Borneo Island Malaysia (Figure 2). However, actual names of the companies are not shown for business propriety reason.

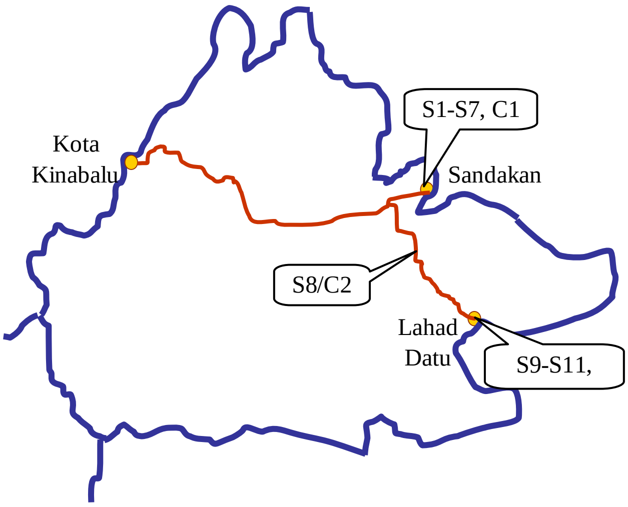

Figure 2: Location of EFB suppliers and consumers

Table 1 shows the suppliers and consumers of the EFB. The former is a group of palm oil mills where EFB is produced. In most cases, these mills are owned by small enterprises without plantation estates that may utilise the EFB (as fertiliser). On the other hand, the EFB consumers are palm oil refinery (C1) and oleochemical plant (C3) that experience energy deficit. It is assumed that combined heat and power (CHP) plants are built in these plants to generate power for plant usage. Besides, a new CHP plant is also planned for an existing mill, i.e. C2. In other words, C2 is essentially the same plant as S8. The geographical location for these plants is shown in Figure 2; while their distance from each other is given in Table 2.

Table 1 Data for EFB Suppliers and Consumers

Suppliers	**EFB capacity (t/y)**	**Consumers**	**Desired power output (MW)**	**EFB requirement (t/y)**
S1	90,000	C1	12	250,000
S2	75,000	C2	10	200,000
S3	80,000	C3	9	190,000
S4	85,000			
S5	82,000			
S6	86,000			
S7	92,000			
S8	78,000			
S9	80,000			
S10	88,000			
S11	84,000			

Table 2: Distance between EFB suppliers and consumers (km)

	C1	C2	C3
S1	11.9	65.7	164
S2	9.9	69.9	168
S3	12.3	66.5	165
S4	12.3	66.5	165
S5	11.9	65.7	164
S6	8.0	77.8	176
S7	8.0	77.8	176
S8	75.6	0	98
S9	172	96.2	1.9
S10	170	94.5	5.5
S11	168	92.5	7.1

Table 3 shows the parameter used for the calculation for the new CHP plant. Solving the objective function in Eq (1) subject to the constraints in Eq (3-7) yield the minimum CO_2 emission at 152,127 kg/y. The optimum allocation scheme is shown in Table 4.

Table 3 Parameter for CHP calculation

Steam requirement for turbine	5.8 kg steam/ kW power
Boiler design capacity	80 t/h steam
Boiler load factor	85%
Energy required to raise 1 kg stream at 50 bar	3195 kJ
Thermal efficiency of boiler	85%
Average calorific value of dry solids	12,000 kJ/kg solid
Moisture in EFB	30%
Annual operation	8,000 hr

Table 4 Allocation of EFB between Suppliers and Consumers (t/y)

	C1	C2	C3	Unutilised
S1		90,000		
S2	72,000			3,000
S3				80,000
S4				85,000
S5		32,000		50,000
S6	86,000			
S7	92,000			
S8		78,000		
S9			80,000	
S10			88,000	
S11			22,000	62,000

5. Conclusions

A mathematical model for the synthesis of a regional energy supply chain that is based on the palm oil biomass residue of EFB has been developed. The model minimises the CO_2 emission from the transportation of EFB. A case study was solved to illustrate the proposed approach.

In the future work the case is going to be extended to (i) synthesis of supply chain to manufacture biogas and liquid biofuel as alternative biomass products (ii) integration of other type of renewable sources into the energy supply chain. A proposed efficient synthesis and optimisation tools is P-graph algorithms (Friedler, 1992; Lam et al., 2010).

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