CHEMICAL ENGINEERING TRANSACTIONS

VOL. 45, 2015

A publication of
AIDIC
The Italian Association
of Chemical Engineering
www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Jiří Jaromír Klemeš, Sharifah Rafidah Wan Alwi, Jun Yow Yong, Xia Liu

ISBN 978-88-95608-36-5; **ISSN** 2283-9216

DOI: 10.3303/CET1545310

Functionality of Element Targeting Approach in Dynamic Biomass Resources Supply Chain System

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In the development of sustainable system, biomass is one of the best options of renewable resources. However, there are many issues in biomass supply chain management. Element Targeting Approach is a novel approach introduced in Demand-Resources Value Targeting (DRVT) and Biomass Element Life Cycle Analysis (BELCA) to improve existing biomass supply chain. It enables consideration of underutilised biomass in biomass supply chain optimization model. The approach integrates biomass resources and process technology via biomass element characteristics to allow more flexibility in biomass feedstock selection without compromising process operation. However, fluctuation of biomass availability such as seasonal biomass remains as one the main problem in biomass supply chain management. In this work, functionality of element targeting to handle fluctuation of biomass availability is conducted. Several case studies to simulate dynamic scenario in biomass resources are constructed. DRVT model with element targeting approach is used to evaluate the problems and alternative biomass supply chain is proposed to optimise each scenario by maximising overall profit. Promising result is presented and biomass selection for each process technology in the case study is compared. The approach allows the model to tackle dynamic situation in biomass resources and this can be used as management tools to propose optimum supply chain network for dynamic problems in biomass industry.

1. Introduction

Emphasis on world sustainability leads development in alternative renewable resources such as biomass. However, supply chain management in biomass industry yet to be well established and feasible due to high transportation cost and complex biomass property. Aside from that, dynamic in supply chain management such as fluctuation of biomass availability further exacerbates the limitation in biomass industry, especially in the case of dealing with seasonal biomass. Element targeting is introduced by Lim and Lam (2014a) in Demand-Resources Value Targeting (DRVT) approach to integrate biomass supply chain via biomass element characteristic. The approach is further improved with consideration of process bio-waste as potential biomass feedstock in Biomass Element Life Cycle Analysis (BELCA) by Lim and Lam (2014b). Biomass element characteristic considered include, and not limit to, physical and chemical properties such as moisture, ash, fixed carbon, volatiles, heat value, carbon, hydrogen, sulphur, oxygen, nitrogen, and biomass size. Several studies concluded that the yield of process is governed by feedstock element characteristic. For example, yield of bio-oil and char is based on the cellulose, hemicellulose and lignin content in pyrolysis (Rabacai et al., 2014). Azargohar et al. (2014) conducted work on evaluation of biomass potential application as activation carbon based on hydrogen, carbon and oxygen ratio, and ash content of the biomass. More ash content in biomass feedstock produces more char in pyrolysis (Choi et al., 2014). Thus, element acceptance range is introduced as a platform for biomass selection for each process technology. The process is assumed to be consistent if element characteristic of biomass feedstock is within the range. Consequently, element targeting allows biomass feedstock selection based on element acceptance range of respective biomass process technology instead of biomass species. The

Please cite this article as: Lim C.H., Lam H.L., 2015, Functionality of element targeting approach in dynamic biomass resources supply chain system, Chemical Engineering Transactions, 45, 1855-1860 DOI:10.3303/CET1545310

approach enables consideration of all biomasses within the system including underutilised biomass, and proposes optimum biomass distribution to process plants to maximise overall profit.

In this work, sensitivity analysis is conducted to evaluate functionality of element targeting approach in dynamic biomass supply chain system. One of the main problems in biomass supply chain management is dealing with the fluctuation of biomass availability due to low production, quality issue, natural causes or seasonal biomass. Conventionally, in order to maintain production rate, several back-up suppliers of same species of biomass are dedicated to tackle these problems. These suppliers are most likely to be unfavourable choice due to longer distance of transportation, lower quality or higher purchase cost. Thus, overall purchase cost will be more expensive. With element targeting, more biomass species are considered as potential feedstock for each technology. This allows integration of underutilised biomass as potential alternative biomass feedstock, and significantly increases the overall profit of biomass industry as shown in Lim and Lam (2014a). The same approach is also applicable tackle the dynamic situation of biomass industry as the option of biomass replacement is no longer limited to the same biomass species. Element targeting approach acts as a management tool to determine potential alternative biomass species available within the system as replacement of effected biomass. A theoretical case study demonstrates several cases in biomass selection in dynamic supply chain system via DRVT approach proposed by Lim and Lam (2014a).

2. Methodology

In order to reflect the fluctuation of biomass availability in biomass industry, total amount of biomass available in resources is altered. This creates biomass shortage for respective process technology. DRVT approach is used to optimise the biomass supply chain network, and biomass selection for each process technology and overall profit are evaluated. DRVT model is formulated such that optimum biomass distribution network is obtained in each dynamic scenarios.

3. Demonstration case study

Regional biomass industry taken from Lim and Lam (2014a) as shown in Figure 1 is used in this case study. R1, R2, R3, and R4 are biomass resource collection point; Plant 1, Plant 2, Plant 3, and Plant 4 are process plant in the region with respective process technology of T1, T2, T3, and T4; D1, D2, D3, and Export are the demand point of the region. Table 1 summarised standard average biomass availability, market demand, raw biomass cost and net product profit. Table 2 presents element characteristic of each biomass that considered in the study including cellulose (Cel), hemicellulose (Hcel), lignin (Lig), extractive (Ext), ash (Ash), and moisture (MC). Consideration of more element characteristics enhances accuracy of case study.

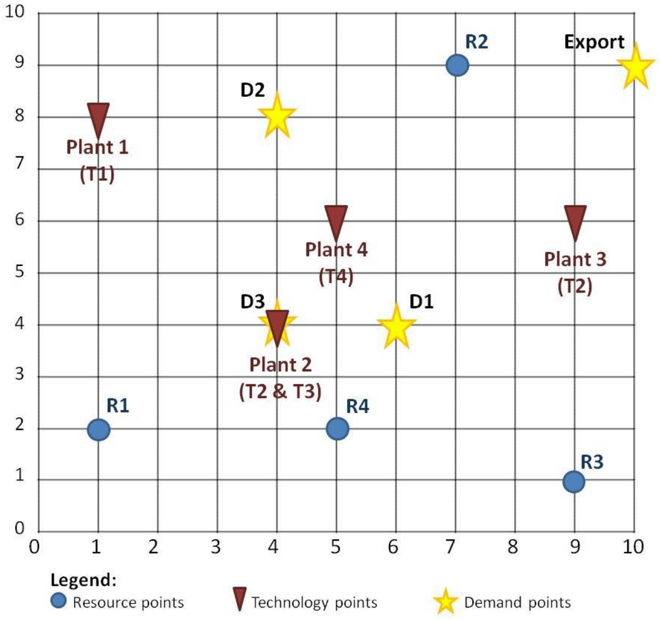

Figure 1: Mapping for regional biomass industry

Table 1: Information on biomass at resource locations and product at demand points

Location	Biomass/Product	Availability/Market Demand	Cost/Profit (RM/unit)
R1	Palm shell (PS)	2,500 t	120
	Oil palm fronds (OPF)	1,500 t	110
	Palm oil empty fruit bunch (EFB)	2,000 t	105
	Palm kernel trunk (PKT)	800 t	65
R2	Palm shell (PS)	1,750 t	120
	Oil palm fronds (OPF)	2,300 t	110
	Palm oil empty fruit bunch (EFB)	2,100 t	105
	Palm mesocarp fibre (PMF)	750 t	75
R3	Soft wood (SW)	1,500 t	50
R4	Hard wood (HW)	1,750 t	85
D1	Bio-oil	1,000 t	300
	Bio-ethanol	850 t	450
D2	Syngas	600 N/m^3	325
D3	Syngas	350 N/m^3	325
	Power	700 MJ	260
Export	Bio-oil	Unlimited	300
	Syngas	Unlimited	325
	Bio-ethanol	Unlimited	450

Table 2: Element characteristic of biomass

	Element characteristic (wt %)						
Biomass	Cel	Hcel	Lig	Ext	Ash	MC	Reference
Palm shell (PS)	27.7	21.6	44.0	2.0*	2.1	11.0	Abnisa et al. (2011)
Oil palm fronds (OPF)	30.4	40.4	21.7	2.7	1.3	16.0	Yong et al. (2007)
Palm oil empty fruit bunch (EFB)	37.3	14.6	31.7	1.3	6.7	10.0	Sudiyani et al. (2013)
Palm kernel trunk (PKT)	34.5	31.8	25.7	2.7	4.3	13.0	Yong et al. (2007)
Palm mesocarp fibre (PMF)	33.9	26.1	27.7	6.9	3.5	13.1	Yong et al. (2007)
Soft wood (SW)	37.5	27.5	28.5	2.5*	3.5*	14.0*	McKendry (2002)
Hard wood (HW)	47.5	27.5	22.5	2.5*	3.5*	14.0*	McKendry (2002)

*assumption for case study illustration

Table 3 shows the original feedstock and conversion yield of each process technology. In this case study, each element characteristics are assumed to be equally important. Thus, the element acceptance range of each technology is assumed to be ±5 wt% of the element characteristic of original biomass feedstock. Based on the given information, DRVT approach is used to optimise biomass selection and supply chain network to maximise overall profit. Several cases of dynamic biomass supply chain system as shown in Table 4 are constructed and the functionality of element targeting in DRVT is analysed.

Table 3: Original feedstock and conversion yield of process technology

Technology	Process	Feedstock	Conversion yield	Reference
T1	Bio-oil production via pyrolysis	Palm shell	46.1 wt% of feedstock	Abnisa et al. (2011)
T2	Syngas production via gasification	Oil palm fronds	1.94 Nm^3 per kg of feedstock	Guangul et al. (2012)
T3	Power generation plant	Oil palm fronds	10.30 MJ per kg of feedstock	Guangul et al. (2012)
T4	Production of bio-ethanol via fermentation	Palm oil empty fruit bunch	24.16 wt% of feedstock	Sudiyani et al. (2013)

Table 4: Biomass resources fluctuation for case study

Case Study	Description of biomass resources fluctuation
A	All biomass availability fulfilled standard average requirement
B	R1 generate 50 % less than standard average amount for each biomass
C	R2 generate 50 % less than standard average amount for each biomass
D	Both R1 and R2 generate 50 % less than standard average amount for each biomass

4. Results and discussions

All cases of fluctuation in biomass availability to reflect dynamic condition in biomass supply chain management is optimised via DRVT approach. The model provides optimum biomass selection and distribution network to maximise overall profit of the regional system. As the main focus of the study is to evaluate functionality of element targeting in DRVT approach to handle dynamic condition at biomass resources point, other parameters such as location data, plant capacity, market demand, and transportation cost are set to be constant. Thus, amount of product generated at each process plant are constant in all 4 case study. Distribution network between process plant and market demand remained constant as well due to consistent total transportation cost. Due to the fluctuation of biomass availability, overall raw material cost of biomass and transportation cost between resources points and process plants are subjected to changes. Element targeting approach enables the model to determine optimum biomass selection based on the element acceptance range of each technology and element characteristics of each biomass species. Biomass with lower raw material cost and transportation cost (nearer to process plant) are more favourable to maximise overall profit.

Table 5 shows the distribution for biomass from resources points to each process plants for all Case A, Case B, Case C, and Case D. The overall profits of each case are reported to be 808 k RM, 602 k RM, 341 k RM, and 110 k RM. Overall profit of Case D is the lowest among all cases due to the least biomass availability in the system and limits the option in biomass selection for each technology.

Table 5: Biomass distribution from resources point to process plant

	Biomass (t)	**Case A**					**Case B**				
		Plant 1, T1	Plant 2, T2	Plant 2, T3	Plant 3, T2	Plant 4, T4	Plant 1, T1	Plant 2, T2	Plant 2, T3	Plant 3, T2	Plant 4, T4
R1	PS	1,367.81	-	-	-	-	1,250.00	-	-	-	-
	OPF	-	204.99	28.45	1,266.56	-	-	204.99	28.45	516.56	-
	EFB	554.15	-	-	-	-	554.15	-	-	-	-
	PKT	-	284.70	39.51	475.78	-	-	284.70	39.51	75.78	-
R2	PS	-	-	-	-	-	117.81	-	-	-	-
	OPF	-	-	-	2,300.00	-	-	-	-	2,300.00	-
	EFB	-	-	-	-	2100.00	-	-	-	-	2,100.00
	PMF	247.23	-	-	-	502.77	247.23	-	-	-	502.77
R3	SW	-	-	-	1,500.00	-	-	-	-	1,500.00	-
R4	HW	-	-	-	540.51	915.45	-	-	-	248.10	915.45

	Biomass (t)	**Case C**					**Case D**				
		Plant 1, T1	Plant 2, T2	Plant 2, T3	Plant 3, T2	Plant 4, T4	Plant 1, T1	Plant 2, T2	Plant 2, T3	Plant 3, T2	Plant 4, T4
R1	PS	1,487.95	-	-	-	-	1,250.00	-	-	-	-
	OPF	-	204.99	28.45	1,266.56	-	-	204.99	28.45	516.56	-
	EFB	270.13	-	-	-	308.45	189.72	-	-	-	810.28
	PKT	411.11	284.70	39.51	64.67	-	75.78	284.70	39.51	-	-
R2	PS	-	-	-	-	1,651.67	231.58	-	-	-	643.43
	OPF	-	-	-	1,150.00	-	-	-	-	1,150.00	-
	EFB	-	-	-	-	1,050.00	-	-	-	-	1,050.00
	PMF	-	-	-	-	375.00	375.00	-	-	-	-
R3	SW	-	-	-	1,500.00	-	-	-	-	1054.79	-
R4	HW	-	-	-	-	133.09	47.12	-	-	-	1,014.50

The model optimised alternative biomass supply chain network to handle each case study. For example, R1 provides 88.6 % of biomass feedstock for Technology 1 at Plant 1 in Case A. Due to unforeseen circumstances where R1 generates 50 % less biomass as described in Case B, an alternative solution is proposed to utilise same biomass species of PS from R2 as substitution. It is interesting to note that the overall biomass species ratio is remained constant as shown in Figure 2. This is due to availability of PS in R2 is sufficient to operate as a backup resources. In comparison with Case C and D, biomass feedstock species ratio for T1 at Plant 1 is altered. PKT from R1 is used as a portion of feedstock in Plant 1 due to limitation of resources in R2 in Case C. As both resources from R1 and R2 are affected in Case D, Plant 1 utilised multiple biomass species from multiple resources to provide sufficient raw material that fulfilled element acceptance range of the technology. The result shows that integration of biomass via element characteristic enabled flexibility in biomass selection to ensure consistence production rate to fulfilled market demand. The model guarantees biomass feedstock is within element acceptance range of respective technology to ensure consistency in process operation. Similar result is obtained when comparing biomass feedstock ratio of Technology 4 in Plant 4 in Case D with respect to other cases. Due to the limitation of biomass from R1 and R2, HW is utilised as alternative biomass feedstock.

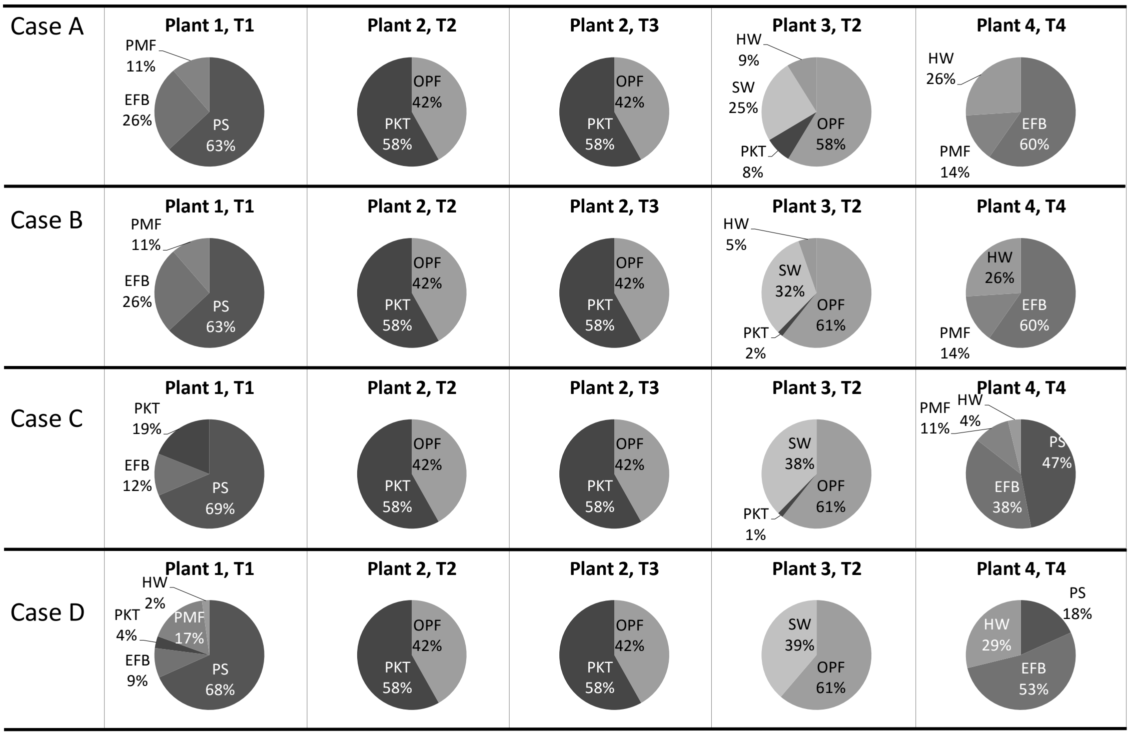

Figure 2: Optimum biomass feedstock selection for each process plants in different dynamic supply chain condition

Based on the result presented, it shows that element targeting in DRVT approach act as a platform to evaluate the status of biomass availability and proposes optimum supply chain network to achieve the objective function. This provides opportunity for management to determine the best solution in the critical event of fluctuation in biomass availability. The method can be implemented on fluctuation on market demand, fluctuation on element acceptance range of process technology due to process modification, changes of biomass collection point, introduction of new biomass species or resources, and fluctuation of biomass quality in terms of different value of element characteristics. More element characteristics of biomass will be considered in future work to ensure consistency in process operation.

5. Conclusions

Element targeting approach is implemented in DRVT supply chain model to integrate biomass resources to process technology via biomass element characteristics. Functionality of the model to handle critical problems in fluctuation in biomass availability is studied. Several case studies are constructed to create the scenario of shortage of biomass resources. From the result, DRVT model proposed alternative biomass supply chain network for each cases and maximise overall profit of the system. Alternative biomass is selected in the event of biomass limitation. All mixtures of biomass feedstock are according to element acceptance range of respective process technology to ensure process consistency. In conclusion, element targeting improves biomass supply chain flexibility in terms of biomass feedstock selection without affecting the operation of process technology. This creates a huge improvement in the limitation of biomass industry due to the constraint of biomass availability. Biomass distribution and selection can be assessed based on seasonal supply chain issue and propose best solution in terms of supply chain management.

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