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Debottlenecking Biomass Supply Chain Resources Deficiency via Element Targeting Approach

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Biomass has been one of the focus in research and development of renewable resources for energy, chemicals and downstream products. Despite many success of biomass conversion technologies such as pyrolysis, gasification, fermentation, and combustion, implementation of such technologies in industrial scale is often very challenging. The major limitations within the system include unique properties of each biomass species, unique regional nature of biomass system, complex supply chain and logistic distribution. Nonetheless, the demand for renewable energy and its products are favourable, increasing the need for more sustainable and green processes. However, most of the current biomass technology being implemented is only designed in relatively small scale due to limitation of local biomass resources. Availability of biomass resources has been one of the main constraint for mass production of biomass product. Element targeting approach was used in previous Biomass Element Life Cycle Analysis (BELCA) model to allow consideration of underutilised biomass based on element characteristics as alternative resources for existing conversion technologies to minimise supply chain distribution and material cost. Nevertheless, the approach only considers all of biomass species available and identified in the local region. This results in the total amount of biomass acquired within the regional area to be the bottleneck for mass production in fulfilling the increasing demand. The common rectification is to import similar biomass species from outer region to increase the resources for technology feed. In this research, a new biomass supply chain modelling approach is proposed to debottleneck the system via element targeting approach. The main advantage of the model is the investigation of the bottleneck biomass resources element characteristic properties instead of the limiting biomass species. Based on the regional biomass element characteristic deficiency, optimum biomass species or combination of biomasses can be identified for importation from outer region according to availability, logistic and cost. The proposed debottlenecking approach for biomass supply chain system enable an in-depth understanding of the resources deficiency based on the properties instead of biomass species, which allow higher flexibility in biomass importation and selectivity. This can be utilised as decision-making-tool to determine the best biomass species or combination to be imported into the regional system.

1. Introduction

With the initiation of the United Nations Sustainable Development Goals, research focus on sustainable study is at the critical stage for the transformation towards a sustainable world. To this date, fossil fuel still remains as the main source of energy and chemical despite its effect on the environment and its unsustainable nature (Yilmaz and Atmanli, 2017). Nonetheless, many great inventions have been proposed by researchers to generate energy and chemicals from alternative resources using greener approaches. For example, utilisation of biomass is one of the most promising alternative resource for fossil fuel. Biomass are sustainable resources obtained from plantation waste and widely available in every region. Utilising biomass for energy and chemical production embraces the concept of Waste-to-Wealth (Ng et al., 2012), and at the same time avoids the

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argument of competition with food sources (Kucher and Linnér, 2017). With the high interest in biomass development, many conversion technologies to utilise biomass have been proposed by numerous researchers. For example, algal biomass harvested from fresh water river is used to generate biodiesel and bioethanol (Kumar et at., 2018). Corn-cob biomass is used to create highly active catalyst for Huisgen reaction to achieve a more environmental friendly and cost-effective process (Mandal et al., 2017). Cahyono et al. (2017) investigated the effect of binder concentration on briquettes properties using the binder agent derived from durian. Biomass is also used to produce hydrogen at relatively low carbon dioxide emission in supercritical water gasification process (Correa and Kruse, 2018). Various factors that influence the process are discussed in this work, including the impact of biomass composition, choice of catalyst, water impact, reactor material, and operating conditions. Various types of biomass have been tested in co-firing system with coal to increase the process efficiency and reduce pollution. Xue et al. (2018) conducted a case study on avocado pit biomass co-firing with coal process efficiency via torrefaction and carbonization. A simulation of organosolv pretreatment method via lignocellulosic biomass for alternative bioethanol production process is investigated for cost saving (Silva et al., 2017). Although various biomass conversion technologies have successfully been developed in laboratory and pilot plant scale, implementation in industrial scale is still facing multiple challenges, especially in the supply chain network management due to high logistics and transportation cost.

To ensure feasibility of large scale implementation of biomass, various researches have been conducted to minimise the overall cost in biomass supply chain. With the surge of sustainable development, biomass supply chain optimisation is further explored by looking into environmental aspects. For example, Lam et al. (2010) constructed a biomass supply chain model to minimise carbon footprint in regional system. The approach divides regional system into clusters to simplify complexity and problem size. Čuček et al. (2014) evaluated biomass supply chain based on the nitrogen and climate impact. How and Lam (2017) proposed a supply chain optimisation model to maximise the overall profit and minimise environmental impact of the system. Formal and informal success factors perceived by biomass supply chain stakeholders were considered in a study of woody biomass energy system in Japan in order to achieve long-term success (Ahl et al., 2018). Hu et al. (2017) incorporated cyberGIS approach into biomass supply chain optimization model to tackle uncertainty and sensitivity analysis. In previous work, Element Targeting approach was introduced to consider alternative biomass species into the existing system via selection of biomass feedstock based on biomass properties (Lim and Lam, 2016). The proposed approach enables integration of underutilised biomass into the process to minimise waste and reduce the means of importation of raw material into the regional system.

Nonetheless, with the increasing population and developing industrial activities, demand for higher volume of material for energy and chemicals production are unavoidable (Masnadi et al., 2015). With the limited amount of biomass generated at dedicated regional system, raw material constraint will be the eventual process bottleneck. This research is aimed at tackling the potential of system bottleneck at resource limitation via element targeting approach. The main advantage of element targeting is to enable better understanding of the biomass resources deficiency in terms of biomass element characteristic. The biomass element characteristics deficiency profile will act as a platform to determine the biomass or biomass mixture to be imported in the regional system. Hence, this approach provides a new biomass selection method via element characteristic deficiency profile rather than specific biomass species.

2. Method

As proposed by Lim and Lam (2014), the technology feedstock selection should be bound by biomass elements instead of biomass types. In the event of limitation of biomass resources (i.e., process bottleneck) due to increasing demand, decision making for optimum biomass to be imported into the regional system should not be bound by biomass properties. Instead, proposing a biomass element deficiency of the system is more appropriate such that optimum resources, single biomass or mixture of biomass, will be selected for importation depending on the season, quantity, import logistic, and cost. In this work, a P-graph model is constructed to optimise the biomass utilisation with the consideration of biomass element targeting. Figure 1 shows an example of P-graph model formulation. To illustrate, biomass A and biomass B serve as the potential feedstock for a given technology. Their biomass characteristics (e.g., moisture content, heat value, etc.) are defined in the M-type vertices (i.e., named as “Element”). Note that the weight fraction of each element is inserted as the “conversion ratio” in each arc. Then, red O-type vertices (or so-called “element checkers”) are inserted to define the element acceptance tolerance of the given technology (note that the upper and lower acceptance limit is input as “capacity constraint” in the O-type vertex). In other words, only biomass which contains acceptable range of element profile is considered “suitable” for the given technology.

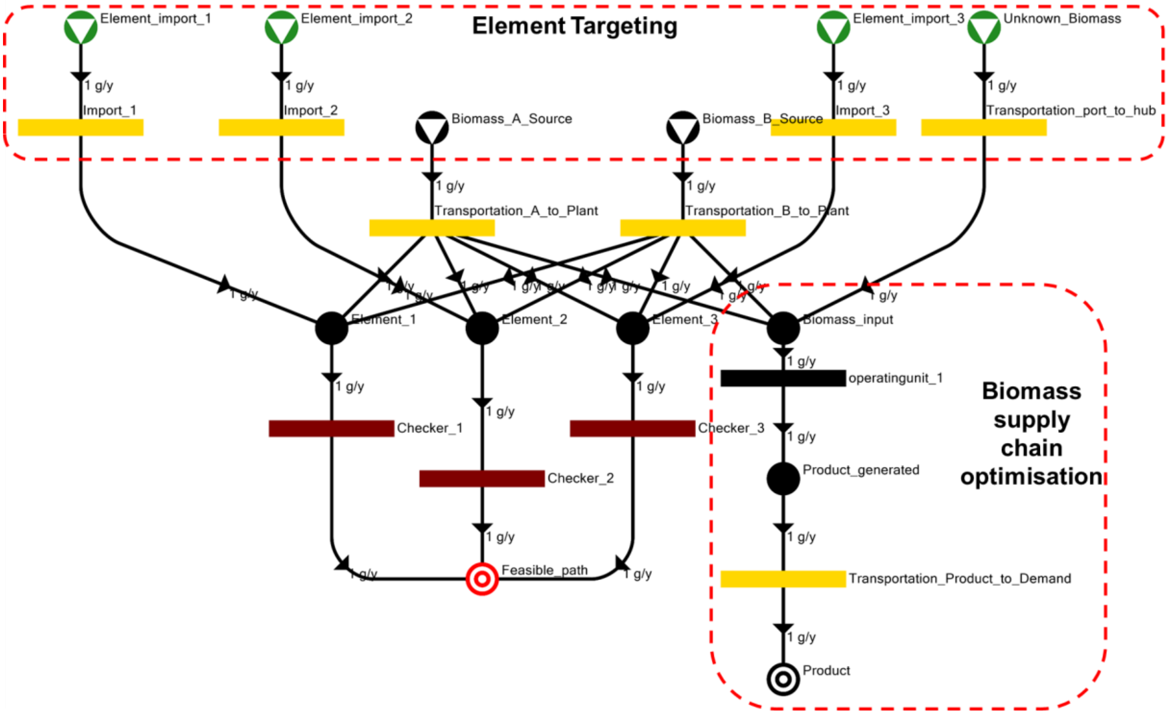

Figure 1: P-Graph optimisation model to debottleneck biomass element characteristics deficiency

On the other hand, the biomass conversion pathway is considered in the model as well. It is worth to mention that the market demand is defined in the M-type vertex which is named as “Product”. However, additional biomass may have to be imported from other places to meet the market demand (due to insufficient local biomass availability). Keeping this in mind, an element targeting section is added to the model to identify the acceptance tolerance range of the imported biomass. Note that the “unknown biomass” indicates the imported biomass, while other green M-type vertices refer to the amount of element contained in the imported biomass. The upper and lower limits of each element can be determined by adjusting the price of the imported element and price of the red M-type vertex. Fundamentally, P-graph model aims to optimise the profit. Therefore, the upper limit is obtained when the price red M-type vertex is inserted; while the lower limit is obtained when the cost of imported element is inserted.

3. Case study demonstration

Figure 2 shows a regional biomass refinery system for demonstration case study. The region consists of two biomass resources (labelled as “X” with their unique element characteristics), 200 t/y of pinewood and 1,500 t/y of hazelnut shell. Single processing hub with gasification technology is available in the region. Pinewood is the original biomass used in the technology. Based on the typical fluctuation of pinewood element characteristic, element acceptance range of the gasification process is determined as shown in Figure 2. The typical market demand for syngas is estimated to be in the range of 2 to 4 Mm^3/y. The case study will demonstrate the method to identify the regional system biomass element deficiency in the event of increasing market demand. The result can be used to determine the amount and type of biomass to be imported at the port.

Transportation cost is simplified to single mode with RM 0.78 /km.t (Lam et al., 2013), both pinewood and hazelnut shell collection prices are assumed to be at RM 10 /t, syngas production cost and selling price are RM 340.5 /m^3 and RM 2 /m^3 respectively (Zuldian et al., 2017), and importation of biomass from port is assumed to be 50 RM/t. Table 1 shows five scenarios of different syngas demand proposed to showcase the advantages of element targeting and to determine the biomass element deficiency of the system. P-graph model is used to determine the element characteristics deficiency at port for each scenario.

Table 1: Case study scenarios

Scenario	Y1	Y2	Y3	Y4	Y5
Syngas demand (Mm^3/y)	2	2.5	3	3.5	4

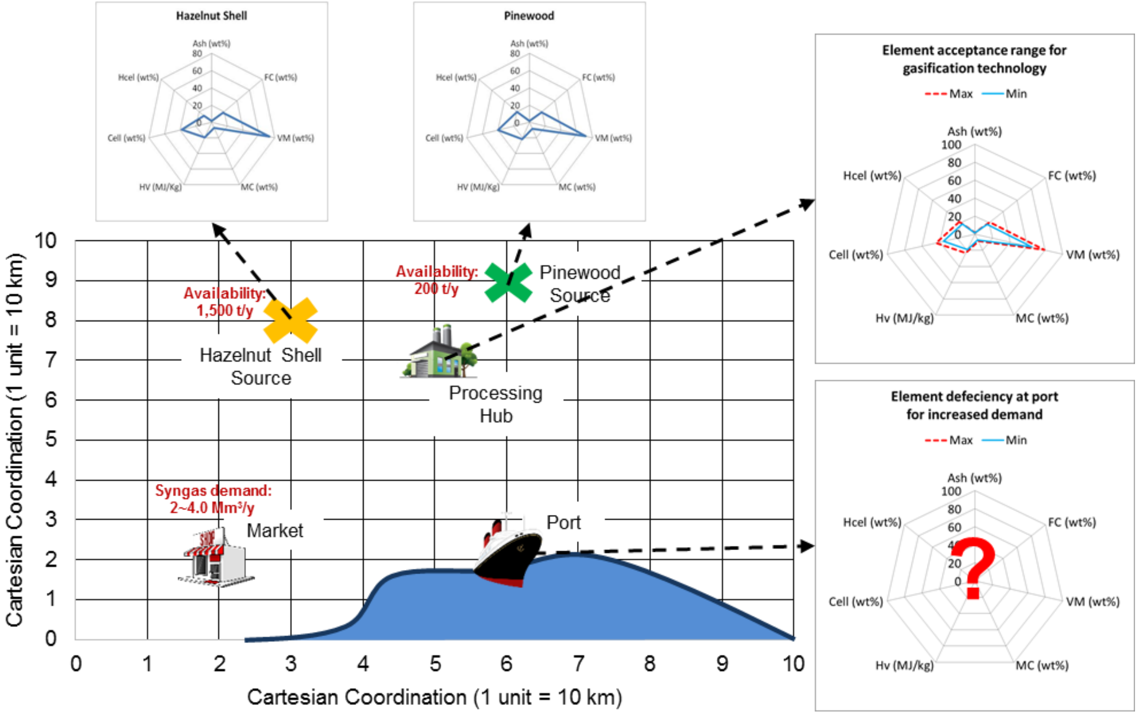

Figure 2: Regional biomass industry mapping in Cartesian coordinate system

4. Result and discussions

Figure 3 shows an example of optimum biomass supply chain network solution obtained from P-graph for scenario Y1 and Y3. Table 2 summarizes the usage of pinewood and hazelnut shell (for all scenarios) at both resource points, as well as the amount of additional biomass to be imported into the region via port in order to fulfil the increasing demand. Based on the result, it is observed that at low demand, only pinewood is utilised in the system. This is a very typical conventional practise where only a dedicated biomass species is considered in the supply chain network. Integrating the concept of element targeting, the model enables consideration of alternative biomass species and determination of the best feedstock options as long as the element characteristics for the mixture is within the element acceptance range of the technology. The advantage of element characteristic can be seen in scenario Y2 where the model chooses hazelnut shell as part of the feedstock to cope with the increased demand. In this case, pinewood alone is not sufficient to fulfil plant feedstock requirement, thus the system requires to use alternative resources such as hazelnut shell to increase the syngas production. However, in scenario Y3, Y4 and Y5, the demand of syngas has significantly increased. This creates a scenario where the limitation of the regional biomass resources is the supply chain bottleneck. Thus, it is essential to import additional material from external region in order to sustain the local regional demand of syngas.

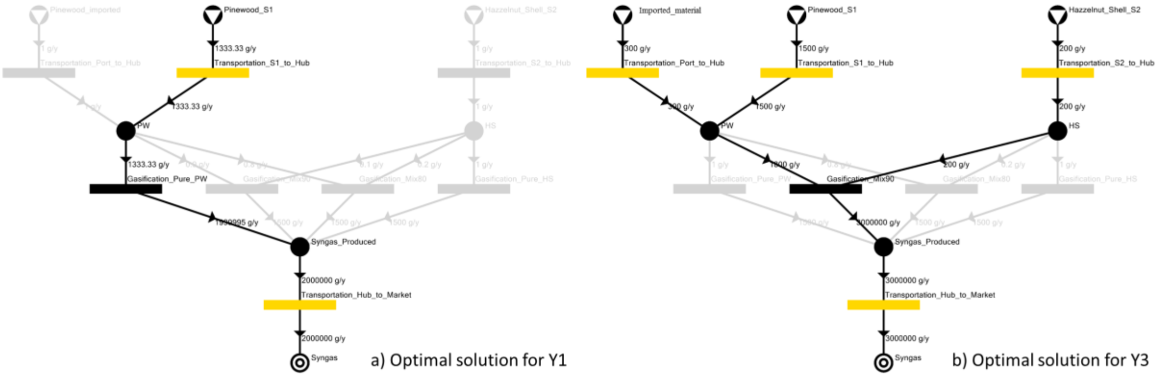

Figure 3: Example of optimum solution for biomass supply chain network in scenario Y1 and Y3

Table 2: Utilisation of regional biomass and requirement of external resources

Scenario	Y1	Y2	Y3	Y4	Y5
Utilised pinewood (t)	1,333.3	1,500.0	1,500.0	1,500.0	1,500.0
Utilised hazelnut shell (t)		166.7	200.0	200.0	200.0
Requirement of external resource (t)			300.0	633.3	966.7

Upon implementing the proposed P-graph optimisation model, result shows that 300.0 t, 633.3 t, and 966.7 t of additional biomass is required to be imported for scenario Y3, Y4, and Y5 respectively. As the idea of element targeting is to integrate biomass selection based on element characteristics instead of biomass species, these deficiencies of biomass should not be bound by biomass species such as pinewood or hazelnut. Figure 4 summarizes the regional biomass element characteristics deficiency determined at port for each scenario. Any biomass or biomass mixture to be imported at port should fulfil the proposed element acceptance range such that the process hub can accept the material without interfering the process efficiency. This information can be used by the port distributor to decide the optimum biomass species to be imported at respective periods of time, thus significantly increasing the flexibility in biomass selection and importation. Depending on the season and availability of various external biomass resources, the process of decision making to determine type of biomass to be imported based on the proposed regional biomass element characteristics deficiency can be more flexible and optimum as compared to traditional method that strictly restricts to specific biomass species (such as pinewood for this case).

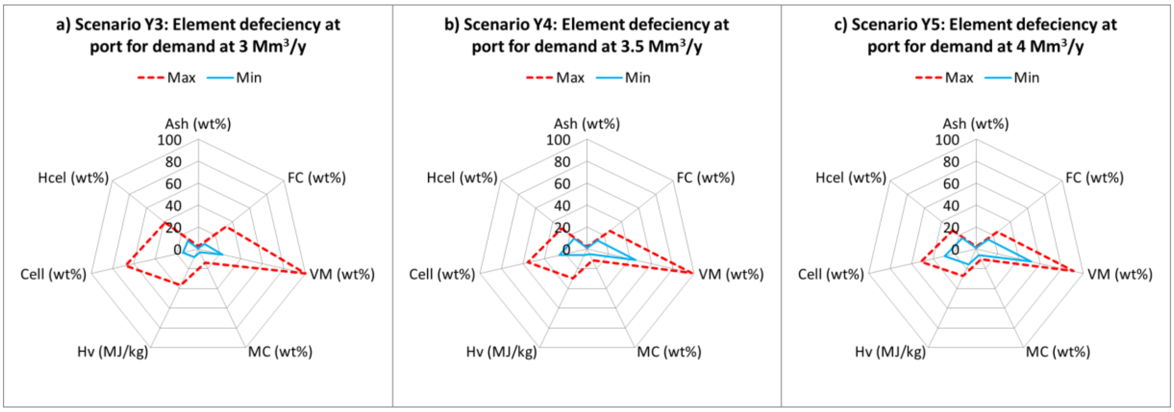

Figure 4: Regional biomass element characteristics deficiency due to increased demand

When comparing the scenarios, flexibility of element acceptance range at the port reduces when the demand increases, and the overall radar chart shape is closer to the pinewood element characteristics radar chart as shown in Figure 5. This is due to in scenario Y3, the amount of additional external biomass used is relatively low compared to the local biomass. Thus, the biomass mixture element characteristics are governed by the local biomass, which mainly consisted of pinewood, the original feedstock for the process hub. Even if the imported biomass has significant differences in element characteristic, the eventual impact on the element characteristics of the biomass mixture is relatively small. Therefore, the element deficiency at port for scenario Y3 has a relatively huge range of acceptance. In contrast, scenario Y4 and Y5 require higher amount of biomass from external region. Consequently, the external biomass element characteristics will be the deciding factor for the eventual biomass mixture properties. Thus, it has to be constrained more towards the element acceptance range of the technology, which in this case is based on pinewood element characteristics. This is to ensure minimum feedstock fluctuation at process feed and safeguard consistent process output and performance. In other words, as long as the imported biomass or biomass mixture at port fulfilled the proposed element characteristics profile as suggested in Figure 3, the existing process hub will be able to accept the material as alternative resource without major impact to the process to support the increased syngas demand.

5. Conclusions

In this work, debottlenecking of biomass supply chain resources deficiency has been conducted via integration of element targeting approach. Increasing demand in a local regional system often leads to ultimate process bottleneck of insufficient biomass resources. Supply chain integration via biomass element characteristics instead of biomass species enable consideration of alternative types of biomass into the model without major process fluctuation. A P-graph approach is proposed in this work to determine the regional biomass element characteristics deficiency when the demand of biomass increased over the local supply. This approach generates a detail platform that can be used by the distributors to determine the best biomass or biomass mixture to be imported as long as the element characteristics fulfilled the element deficiency. Such information improves flexibility of biomass selection and importation depending on various factors such as seasonal availability, logistic for import, import duty, external biomass cost, and etc. A demonstration case study shows that the biomass element characteristic deficiency profile depends on the additional amount of biomass to be imported into the regional. High biomass selection flexibility for importation is observed when the local regional system requires less biomass from external region. Nevertheless, this model can be further improved with more detail consideration in logistic, such as transportation mode, seasonality of biomass, and traffic condition. Real life case study also can be model in future work with more variety of biomass species and process plant.

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