Debottlenecking of the Integrated Biomass Network with Sustainability Index in Malaysia

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ABSTRACT

The world has grown large interest towards the biomass industry but there are many challenges that forbid the commercialization of biomass conversion technologies. The underutilized biomass in Malaysia proves that optimisation of individual processes is no longer sufficient to introduce advancement or breakthrough in the biomass industry. This research paper aims to firstly identify several bottlenecks or challenges that have been hampering the development of the biomass utilization at any stage of the biomass network, and secondly to debottleneck using sustainability index and P-graph. The integration of sustainability index into the biomass network for debottlenecking is a novel approach in this research paper. This research will help in the development of the nation's biomass utilization and industry by using debottlenecking approaches to expand the biomass industry and unlock the potential of underutilized biomass.

Keywords: Biomass Network, Oil Palm Biomass, Sustainability Index

1.0 INTRODUCTION

Sustainability and biomass utilization have been a major concern over the entire globe as the world's demand for food, energy and water are increasing at such a tremendous rate. Even with advancement in technology, sustainability cannot be achieved without proper resource management.

This research project will discuss on the debottlenecking of the integrated biomass network with sustainability index. A sustainability index is generated by combining all the quantifiable factors using mathematical and statistical approaches. After collecting data and statistics related to the supply chain, the sustainability index is used to seek for several optimum solutions towards a cost effective, environmentally friendly and safe biomass network.

This research is motivated by the Malaysian Biomass Industry Action Plan 2020 (MBIAP 2020), which aims to promote biomass utilization for value-added products and to adopt Sustainable Production practices in Malaysia. The potential of the biomass industry in Malaysia is split into four sub-industries, which are bio-energy, bio-chemicals, bio-fertilizers and bio-composites [1].

There are many journals using different approach to assess or evaluate the biomass network due to the difference in biomass (composition), availability and topography for different countries, which lead to different constrains. Therefore, this paper will develop a methodology to integrate the biomass network with sustainability index.

Although this research will only focus on certain states in Malaysia, it is possible to implement the proposed approach to debottleneck the biomass network in the entire Peninsular Malaysia or even whole Malaysia. Since Indonesia and Malaysia accounts for 85% of global palm oil production, the proper utilization of oil palm biomass using the debottlenecking approach will have a huge impact on the economics of the country and significantly reduce carbon emission.

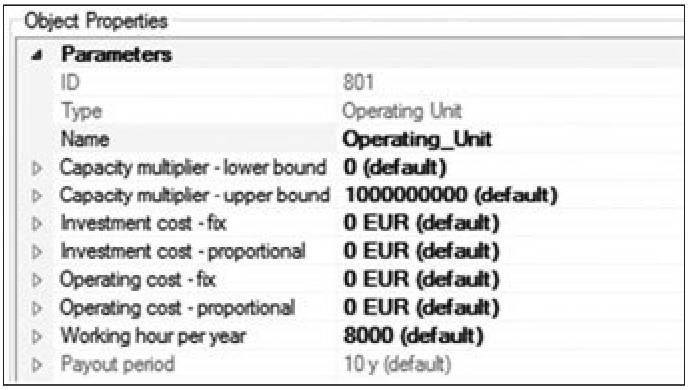
2.0 METHODOLOGY

P-graph (process graph) framework is used for the biomass supply chain formulation and it is further discussed in the Section 2.1. The index model which uses mathematical approach to calculate Biomass Network Sustainability Index (BNSI) is discussed in Section 2.2. After the formulation of BNSI, it is then integrated with supply chain by using P-graph approach. The output of the P-graph solution is analysed in order to identify opportunities of debottleneck or optimization. In this research paper, any improvement on the biomass network using existing infrastructure is considered optimization and only breakthrough on the biomass network such as building new facilities or reorganizing harvesting and storage systems are considered debottlenecking.

2.1 P-graph Framework

The P-graph technique is a tool that creates and optimizes networks that meet the particular design requirements. Over the past few years, it has started to be employed in the area of biomass supply network synthesis. The network synthesis problem is defined by the desired product, available raw biomass and intermediate operating units. These inputs into the P-graph generate a structural model and mathematical model in the background. Although P-graph can use several algorithms to generate solutions, only accelerated branch-and-bound (ABB) algorithm is used in this research paper to satisfy the objective of determining all the feasible and optimal solution structures [2].

After constructing a superstructure in P-graph that includes several pre-treatment technologies, transportation modes and distances, conversion technologies and warehouse placement, it is then analysed and evaluated based on desired criteria such as profitability, which can then be optimized or debottlenecked using ABB algorithm. This process is highly iterative because when a certain challenge is solved by debottleneck, other pathway that was initially infeasible might become more feasible and sustainable than the originally best solution.



Object Properties

Parameters

ID	801
Type	Operating Unit
Name	**Operating_Unit**
Capacity multiplier - lower bound	**0 (default)**
Capacity multiplier - upper bound	**1000000000 (default)**
Investment cost - fix	**0 EUR (default)**
Investment cost - proportional	**0 EUR (default)**
Operating cost - fix	**0 EUR (default)**
Operating cost - proportional	**0 EUR (default)**
Working hour per year	**8000 (default)**
Payout period	10 y (default)

Figure 1: Object properties that require user input for each operating units

P graph is a very powerful tool in performing optimization and debottleneck for a superstructure because it has 'Capacity multiplier', 'Investment cost' and 'Operating cost' that is defined by the user as shown in Figure 1, which allows for a more complex structure. For example, when a centralized hub is suggested, the solution will either choose to send the feedstock to a centralized hub for pre-treatment or directly to the processing plant for on-site pre-treatment. Since different pathways have different cost due to different capacity, P-graph allows the user to utilize several operating units to represent different scenarios and therefore can simulate the cost function more accurately to a real-life scenario.

2.2 Biomass Network Sustainability Index Model

This section explains the generation of the sustainability index, starting from defining the important indicators that will be used to represent the various stakeholders concerns and issues in the biomass network along with their respective weightages. The development of a single dimensionless index to represent each of the three sustainability dimensions at every stage of the biomass network and finally the aggregation of these Sustainability Index (SI) to form the Biomass Network Sustainability Index (BNSI). The development of the BNSI is adapted from the generic hierarchy of a composite sustainability index with the aid of guidelines recommended in the OECD Handbook on Constructing Composite Indicators, which is further explained in Section 2.2.1 to 2.2.3.

2.2.1 Collection of Quantitative Data

The three sustainability dimensions (Social, Environmental and Economic) are defined by indicators such as process temperature, process pressure, CO_2 emission and revenue. An indicator indicates a variable that can be counted or measured; an index on the other hand, is often known as a scaled composite variable.

The quantitative data is collected in order to calculate the values for the indicators. This will serve as the data for the indicators in the development of the Sustainability Index at every stage of the biomass network. Since there are no attainable records of data for direct assessment, most of the data has to be calculated manually based on reasonable assumptions and available information from the current existing biomass industries in the region studied.

2.2.2 Normalisation of Indicator Values

In order to develop an index, normalization of the calculated data is needed. Normalisation will allow the index to be aggregated since the individual indicators are on the same scale as normalised indices. Hence, an additive model can be used to aggregate the indicators based on the individual weightage. In other words, the individual indicators will contribute to the index in proportion to the weights. Table 1 below is an example of each individual indicator (such as process temperature) that will contribute to the index (such as social/safety) based on different categorization of values. The normalisation and weightage given is mostly based on the case study and is very subjective to different opinions.

Table 1: The evaluation of social, environmental and economic index based on process parameters

SOCIAL / SAFETY		ENVIRONMENTAL	ECONOMIC	INDEX
Process Temperature (ºC)	Process Pressure (bar)	CO_2 emission (kg CO_2 / t biomass)	Revenue (RM / t biomass)	Score
25 – 70	1 – 5	< 20	< 50	0
71 – 150	6 – 25	21 – 50	51 - 1200	1
151 – 300	26 – 50	51 – 100	1201 - 1700	2
301 – 600	51 – 200	101 – 150	1701 - 2500	3
> 600	201 – 1000	> 150	> 2500	4

2.2.3 Aggregation of index to Form Sustainability Index at Every Stage of Biomass Network

The index is calculated for all three dimensions by multiplying the normalised indicator with the determined weightage for each respective dimension. The sum of the index will yield the Sustainability Index (SI) for every stage of the biomass network as shown in Equation (1).

$$SI = \sum_i \text{Weightage}_i \, \text{Index}_i \qquad \text{Equation (1)}$$

The Biomass Network Sustainability Index (BNSI) is the sum of all the Sustainability Index (SI) at every stage of the biomass network shown in Equation (2).

$$BNSI = SI_{harvest} + SI_{transport} + SI_{pretreat} + SI_{conversion} + SI_{warehouse} \qquad \text{Equation (2)}$$

3.0 RESULTS AND DISCUSSION

The biomass involved in this research project includes empty fruit bunch (EFB) and oil palm frond (OPF). Both biomasses can be combusted directly to produce steam, which in turn produce electricity by passing the high or medium pressure steam through a steam turbine connected to a generator. Other conversion technologies include thermochemical conversion and biological conversion such as pyrolysis and fermentation.

In order to illustrate the application of sustainability index on technology selection using P-graph, EFB and OPF are selected to go through some of the technologies as shown in Table 2 while the price of feedstock and products are reported as average values of the market as shown in Table 3.

After defining the conversion and cost of different process technologies, it is important to study the availability of the biomass. In order to ensure that the data of the base case will be as reliable as possible, the biomass availability is obtained from Department of Agriculture (DOA) and Malaysian Palm Oil Board (MPOB) shown in Table 4.

Table 2: Conversion of different technology using different biomass

BIOMASS	TECHNOLOGY	CONVERSION	REFERENCES
EFB	Combustion	1192 kWh / t EFB	-
	Pyrolysis	0.42 t biochar / t EFB	[3]
	Fermentation	0.13 t bioethanol / t EFB	[4]
OPF	Combustion	1036 kWh / t OPF	-
	Pyrolysis	0.51 t biochar / t OPF	[5]
	Fermentation	0.32 t bioethanol / t OPF	[6]

Table 3: Price of feedstock and products

	PRICE (RM/UNIT)
FEEDSTOCK	
EFB	245 / t
OPF	300 / t
PRODUCTS	
Electricity	0.31 / kWh
Bioethanol	2662 / t
Biochar	4730 / t

One of the difficulties of the biomass industry is to evaluate which process technology is the most suitable process for a certain biomass. This research paper will utilize P-graph to justify the desired product based on the availability of biomass locally or globally through the evaluation of its sustainability.

Using all the data obtained from Table 1, 2 and 3, a base case which is the conventional approach of accessing the economics of the technology is constructed in P-graph as shown in Figure 2.

Table 4: Availability of EFB and OPF in different district of Selangor and Perak

	EFB AVAILABILITY (T/YR)	OPF AVAILABILITY (T/YR)
Selangor		
Gombak	0	16334
Hulu Langat	0	28497
Hulu Selangor	102362	259485
Klang	102362	55238
Kuala Langat	170604	415045
Kuala Selangor	102362	424337
Petaling	34121	12051
Sabak Bernam	0	160578
Sepang	68242	136573
Perak		
Batang Padang	218394	676924
Hilir Perak	509585	1256787
Hulu Perak	0	46420
Kerian	109197	304633
Kinta	36399	185975
Kuala Kangsar	109197	262469
Larut Matang	291191	233863
Manjung	109197	645163
Perak Tengah	181995	526583
Selama	72798	119858

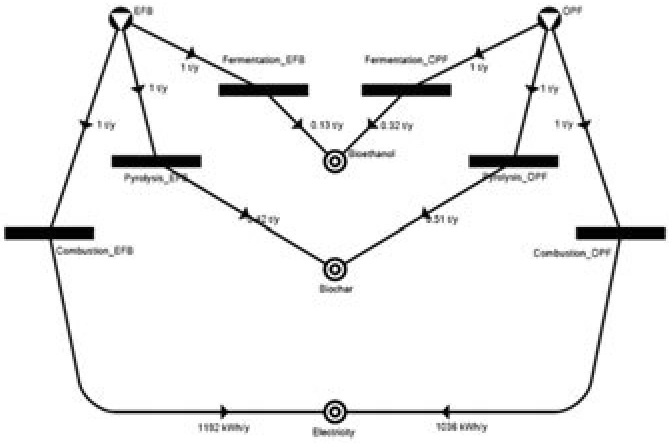


Figure 2: P-graph of technology selection from EFB and OPF

Figure 2 illustrates the structure for P-graph to select the most economical technology pathway. Assuming the biomass availability in Hulu Selangor in this particular P-graph, the generated solution suggests that biochar production is the most profitable pathway but this result is insufficient to ensure the sustainability of the technology. Therefore, a modified P-graph structure as shown in Figure 3 is constructed.

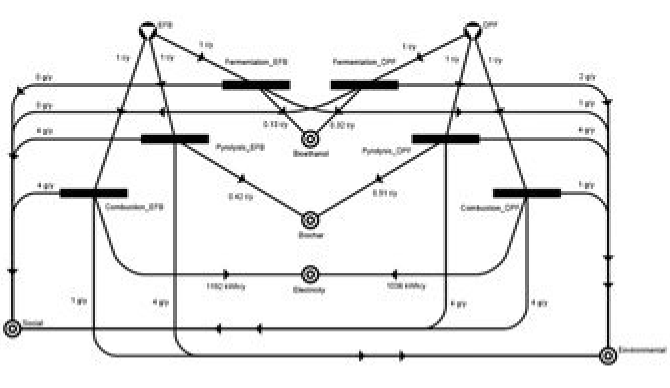


Figure 3: P-graph completed with Sustainability Index

Since P-graph will only select the pathway that yields the greatest profit (economics), the sustainability indicated by social, environmental and economic aspects has to be represented in terms of cost in order to ensure that every pathway is a possible solution and that all aspects are being properly assessed. The environmental aspect is included in the P-graph either by accommodating a cost for the technology of CO_2 reduction, which is the marginal abatement cost or by paying carbon tax as defined by 2015 Carbon Dioxide Price Forecast. The carbon tax is assumed to be RM 110 per tonne of CO_2, which corresponds to $ 25 per tonne of CO_2 quoted by [7] while the carbon abatement cost is assumed to be RM 288 per tonne of CO_2 quoted by [8]. On the other hand, social aspect emphasizing on process and worker safety is also considered and being represented by the cost of penalty and indemnification.

After generating results from P-graph using the structure in Figure 3, biochar is still the preferred pathway but now it is appropriate to consider this technology selection to be sustainable because not only it is the most profitable pathway, it also emits acceptable amount of CO_2 and the process condition is moderate. The SI generated is 5, which is 20% lower than all the other technologies. The SI is formulated in such a way that the lower the score, the better the pathway selection. An approach to debottleneck at the technology stage is to limit the production of biochar and look into the drawbacks of other processes which give a higher SI value. For a scenario of promoting bioethanol production as biofuel, it is noticed that fermentation of EFB has a lower conversion, which means its sustainability can be enhanced if conversion can be increased. Alternatively, debottleneck approach is to convert OPF into bioethanol while converting EFB to biochar to achieve SI of 5.8, which is only 16% higher than the best solution but be able to fulfil the local demand.

One of the major challenges in the biomass industry as indicated in the National Biomass Strategy 2020 is the inconsistent supply of biomass feedstock. In order to look into this challenge with greater depth, a smaller area instead of the whole of Selangor and Perak is required to narrow down the focus. Hence, area segregation is performed to form smaller clusters of land of approximately the same area size, which simplifies the case study and shortens the computational time. Clusters of smaller area, which in this paper is segregated based on district level, allows the assumption of negligible transportation cost within the same area clusters unless specified otherwise, for example when the availability is relatively high compared to other clusters, which require much more transportation frequency or when the transportation distance is close to the maximum range of the entire cluster.

As reported by literature, approximately 20%-40% of the production cost goes to supply and 90% of it is related to logistics [9]. Logistics can amount to more than 50% of the overall cost within the biomass network if logistics for distribution is also accounted [10]. Acknowledging the high cost of transportation, logistics and technology must be studied simultaneously because they are interrelated. As the research work continues, if there is a huge burden on truck transportation cost, bulk transport by train can act as an alternative [11].

It can be seen from Table 4 that certain districts have OPF supply but not EFB supply. This indicates that not all districts have palm oil mills and hence, transportation across cluster boundary will inevitably occur, leading to significant amount of fuel cost and also carbon emission. Therefore, a different P-graph structure is required for transportation.

Considerations such as difference in topography, terrain, road infrastructure and transportation lead time before conversion process are important when road transport is the sole option. In order to preserve the quality of biomass, an early pre-treatment might be required, which opens up the opportunity of having centralized processing hub. This will create another issue of having a fluctuating transportation cost with each decision made as it is mainly affected by travelling distance and load.

Results from Figure 4 suggests that combined pre-treatment will be a more sustainable solution since the total cost per mass of biomass pre-treated is lower for larger capacity. The debottleneck approach to ensure a more sustainable pre-treatment process is to allocate a centralized hub in Gombak. Analysis of the generated results indicates that the centralization of processing hub will favour the location with higher biomass availability to avoid huge amount of biomass transported at long distance.

Through the improvement of the biomass supply chain within a small cluster, a broader coverage will then be analysed to search for a better solution at a macroscale, which will potentially act as the debottleneck strategy by having a centralized processing hub or conversion plant in every 5 cluster.

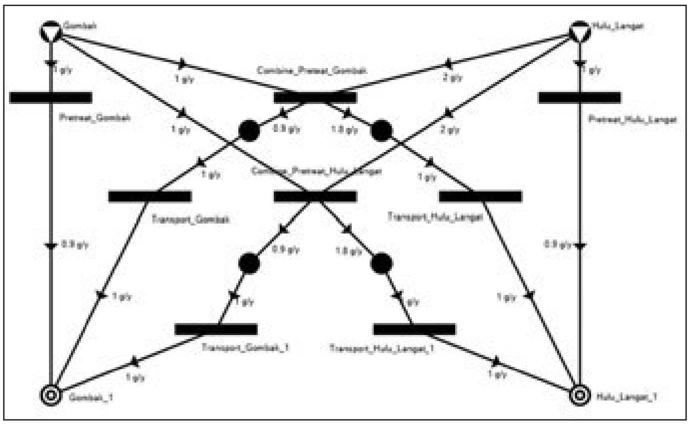


Figure 4: Transportation consideration in P-graph for centralization of processing hub

4.0 CONCLUSION

In overall, this research project addresses some of the challenges faced in the biomass industry and proposes a novel approach to integrate the sustainability index with the P-graph to tackle the problems and ultimately to perform debottleneck within the biomass supply chain. It is of utmost importance that the objective and target of debottleneck is clearly defined and that there is prior knowledge of the biomass network in order to ensure that the P-graph is constructed accordingly for effective, accurate and reliable computational results. This research paper has shown that the novel approach to debottleneck the biomass network at the transportation and conversion stage is successful. Therefore, future work will focus more on debottleneck solutions at any other stage of the biomass network. ■

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