Cost Analysis and GIS-Modelling for the Production of Biofuel from Lignocellulosic Biomass in Biorefineries in Peninsular Malaysia

Brenna Jia Tian Chen[1,2,3], Chu Lee Ong[1,2]* and Juliette Babin[4]

The global production of aviation fuel, particularly Kerosene Jet A-1, has a market presence of 302.8 billionlitres per year, of which Malaysia consumes up to 3 billion litres per year. The pressure from increasing fuel demand and commitment to reducing CO2 emissions has led to the use of biofuels as possible alternatives. Malaysia possesses a relative abundance of lignocellulosic biomass residues and thus, has much potential in biofuel development. In this work, Geospatial Information System analysis was used to obtain the geo-location biomass supply cost and was then simulated with non-linear cost estimation modeling for biorefinery production. The spatial analysis suggested that paddy and oil palm trunk could offer significant feedstock volumes at reasonable costs while biomass to fuel conversion pathways comparison showed that an "alcohol to jet" route was more feasible among all the alternatives. The simulation results indicated that the production cost of a bioethanol refinery had high variability due to the geographical heterogeneity of the lignocellulosic biomass resources. At the optimal location of paddy residues, utilising rice stalks was substantially cost-efficient compared to other biomass. The lowest range of relative production cost was achieved at RM359.11 – RM726.41/million tonnes per annum at an input capacity of 1.28 – 2.63 million tonnes. Conversely, using oil palm trunks in the same location gave a much more expensive relative production cost of RM472.23 – RM986.63/million tonnes yearly with only 0.40 – 1.03 million tonnes of input capacity. This model was able to suggest location strategies and cost estimations for biorefineries in Peninsular Malaysia. It is hence, useful as a decision and policy making tool for the implementation of biorefineries for aviation uses.

Key words: Sustainable, biomass, biorefinery, Geospatial Information System, information processing, computation analysis, Technology, aviation, economy of scale, biofuel, transport cost, modelling, logistics, location, Southeast Asia, Malaysia

INTRODUCTION

The global production of aviation fuel, particularly Kerosene Jet A-1 has a market presence of 80 billion gallons, or 302.8 billion litres per year. In the United States alone, 83.3 billion litres of aviation fuel per year is refined (Davidson *et al*. 2014). Of this, 12% is used in the military and 88% is used in commercial flights, with North America having the highest rate of consumption of ca. 102 billion litres. Asia and Russia combined has a fuel consumption of ca. 61.2 billion litres (IATA 2011). Malaysia itself consumes up to 3 billion litres of kerosene jet fuel per year, which accounts for only close to 0.01% of the global aviation usage (US DOE 2016). Countries such as Malaysia, with its high biodiversity due to its equatorial climate, boasts a large potential to develop and produce alternative fuels

[1]Center of Excellence on Biomass Valorisation for Aviation (UPM-CIRAD-AMIC), Institute of Tropical Forestry and Forest Product (INTROP) Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[2]Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), Internal Research Unit Biomass, Wood, Energy, Bioproducts (UPR BioWooEB) , F-34398 Montpellier, France.
[3]Aerospace Malaysia Innovation Centre (AMIC), Level 1 MIGHT Building 3517 Jalan Teknokrat 5, 63000 Cyberjaya Selangor, Malaysia.
[4]AgroParis Tech, 16 rue Claude Bernard, F-75231 Paris Cedex 05, France.
*Corresponding author (Chu Lee Ong, e-mail: candice.ocl@gmail.com)

for its transportation industry. Currently, the aviation industry contributes to around 2% or 705 million tonnes (of 36 billion tonnes) of global man-made CO2 emissions. On top of this, it has been forecasted that the aviation industry will double in terms of air traffic in the next 15 years. Aviation associations such as the International Air Transport Association (IATA) has committed to a set of standards as follows:

- Improve fuel efficiency by 1.5% annually,on average, from 2009 to 2020
- Achieve carbon neutral growth (CNG) from 2020
- Reduce net emissions of CO2 by 50% by 2050, from 2005 levels.

These however, create opportunities and speed up the development of “green” fuel (also known as biofuel) as an alternative solutions. Malaysia, with an estimated 168 million tonnes of biomass waste annually, has great potential in biofuel production.

MATERIALS AND METHODS

The study was a combination of two methods. One of the methods used GRASS GIS to perform spatial analysis with data containing land use information acquired by satellite. Massive parallel computing algorithms were performed in a high performance computing station to simultaneously process agronomic, economic and geographic information for 117 million spatial units. Each unit was a quasi-square of approximately 63 metres wide. With statistical programming and a nonlinear modelling cost curve method, the biofuel production data from literature and industrial reports were combined with the geo-location biomass supply costs derived from spatial analysis to simulate the cost estimation modelling for biorefinery plants.

RESULTS AND DISCUSSION

Taking into account the spatial location and residue production density of forests and crops in Peninsular Malaysia, each biomass source has its own optimal location with respective supply cost structures. Two sources of biomass residues offer the cheapest supplies for biorefineries in Peninsular Malaysia using 1-tonne-truck supplying.

- Paddy residues with an annual availability of 3.9 million tonnes and supply costs culminating at RM430.25/tonne at its optimal location - Yan, Kedah.
- Oil palm trunks with an annual availability of 17.8 million tonnes and maximum supply costs culminating at RM571.95/tonne at its optimal location - Jempol, Negeri Sembilan.

Other resources such as forest and rubber primary residues were limited (1.8 & 0.45 million tonnes respectively) with high maximum supply costs. Multicrop-sourcing (primary residues of forest, paddy, rubber and oil palm trunk) had a total availability at 22.2 million tonnes per year with a maximum supply cost of RM639.19/tonne at the optimal location - Temerloh, Pahang. However, the major quantities of multicrop-sourcing were from oil palm trunks (74%) and paddy residues (16%). This suggested that having a single bio-refinery with multicrop-sourcing was not feasible in Peninsular Malaysia. With a multi-plant strategy at its optimal location, each crop source allowed an optimal refinery location with cheaper supply costs. This implied that several biorefinery plants could be considered for Peninsular Malaysia.

While there are several means of biomass conversion and fuel upgrading pathways, only a handful of these are able to handle lignocellulosic or carbohydrate-based feeds. Two pathways that have been gaining traction for such feeds are the “Direct Sugar to Hydrocarbon” and “Alcohol to Jet” routes. The highlighted feedstock from the study, both paddy and oil palm trunks could be fed into either of these process to yield a certifiable drop in kerosene grade fuel.

Preliminary studies on the production costs of biorefineries suggested that an “Alcohol to Jet” route was a feasible option for the process of biofuel production in Malaysia. The cost of producing bio-alcohols such as bioethanol is established in literature and commercial operations. Thus, this study used this pathway as the means to compute the production cost of biorefinery plants.

Results from the spatial analysis were simulated with a cost estimation model to produce biorefinery production costs using a 1-tonne-truck supply cost scenario, and rice stalks and oil palm trunks as biomass feedstock at their optimal locations. The computation showed that the production cost of the biorefineries had high variability corresponding to the mill locations due to the geographical heterogeneity of the lignocellulosic biomass resources.

- At the optimal location of paddy residues, utilising rice stalks were substantially more cost-efficient compared to utilising other biomass. It achieved the lowest range of relative production cost at RM359.11 – RM726.41/million tonnes per annum at an input capacity of 1.28 – 2.63 million tonnes. Conversely, using oil palm trunks in the same location gave a much more expensive relative production cost at RM472.23 – RM986.63/million tonnes yearly with only 0.40 – 1.03 million tonnes of input capacity.
- At the optimal location of oil palm trunks utilising oil palm trunks, a lower cost range of relative production cost at RM370.53 – RM690.93/million tonne annually at an input capacity of 1.13 – 4.82 million tonnes was achieved. Using rice stalks at the same location was significantly inefficient at the relative production cost of RM775.94 – RM1466.18/million tonnes annually with only 0.05 – 0.78 million tonnes of input capacity.

In the case of a biorefinery location at Yan, Kedah; the relatively optimal costs to use rice stalks was between an input capacity of 0.48 to 3.88 million tonnes at costs ranging from RM368.92 – RM999.63/million tonnes and RM603.44 – RM881.26/million tonnes. On the other hand, using oil palm trunks at Yan, the relatively optimal costs ranged between an input capacity of 0.21 to 2.86 million tonnes at costs ranging from RM486.23 – RM1365.61/million tonnes and RM732.19 – RM1045.37/million tonnes. The mill size beyond this capacity was too costly.

The high variability in the production costs stemmed from the location of the mill due to the geographical heterogeneity of the biomass resources. This showed that the location factor was the main determinant of the viability and capacity of biorefinery plants in Peninsular Malaysia.

Table 1. Supply costs of the transport of 100% biomass residues to optimal locations

Biomass residues	Optimal location	1 tonne truck (RM/ton/year)	3 tonne truck (RM/ton/year)	10 tonne truck (RM/ton/year)	26 tonne truck (RM/ton/year)
Logging (Forest)	Gua Musang	575.59	227.24	110.19	85.04
Logging (Rubber)	Raub	319.35	260.55	58.84	45.27
Oil palm trunk (Palm oil)	Jempol	571.95	225.94	109.69	84.67
Rice stalk (Paddy)	Yan	430.25	97.28	50.05	38.89
Multi-biomass	Temerloh	639.19	249.92	118.92	91.57

Table 2. Relative production costs at minimum point in different locations

Biomass and location	Relative Production Cost at Minimum Point			
	Lower Bound (LB)	Upper Bound (UB)	Capacity of LB	Capacity of UB
	RM/Mil ton/year	RM/Mil ton/year	Mil ton/year	Mil ton/year
Paddy@Yan*	359.11	726.41	1.28	2.63
OPT@Yan*	472.23	986.63	0.40	1.03
OPT@Jempol*	370.53	690.93	1.13	4.82
Paddy@Jempol	775.94	1466.18	0.05	0.78

*optimal location

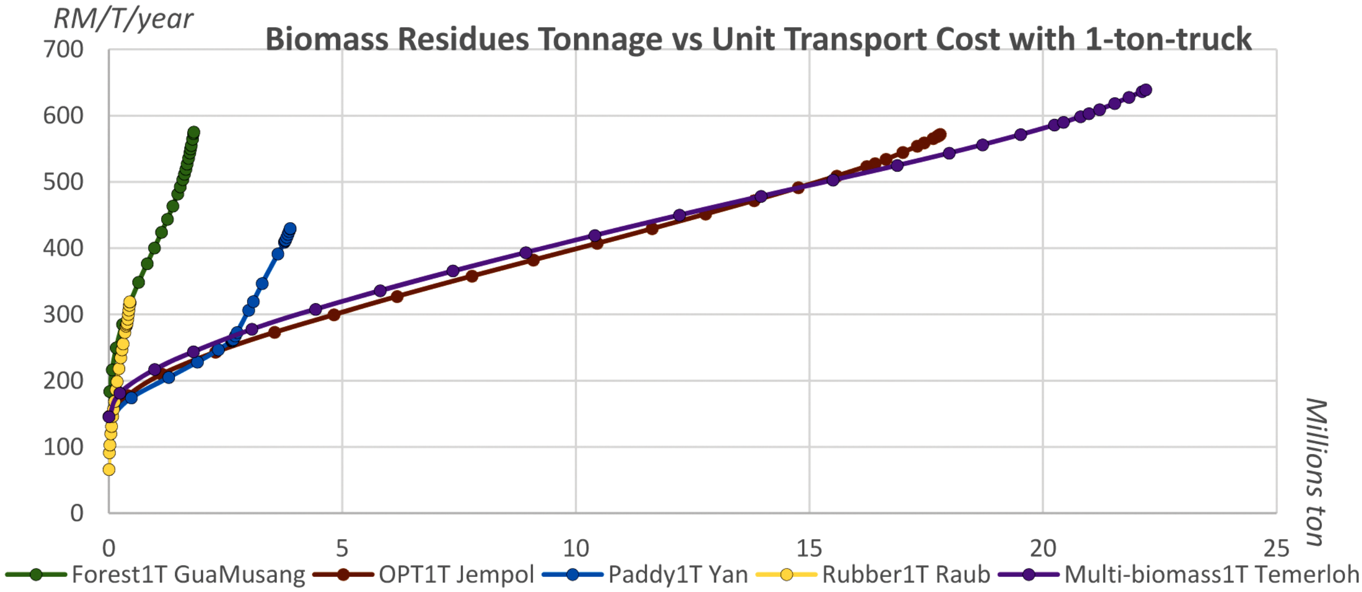
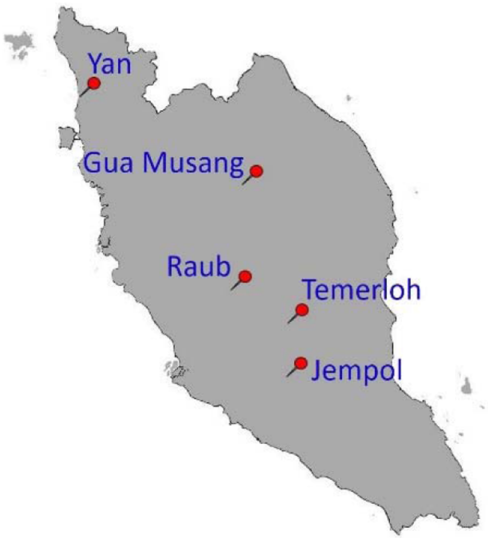
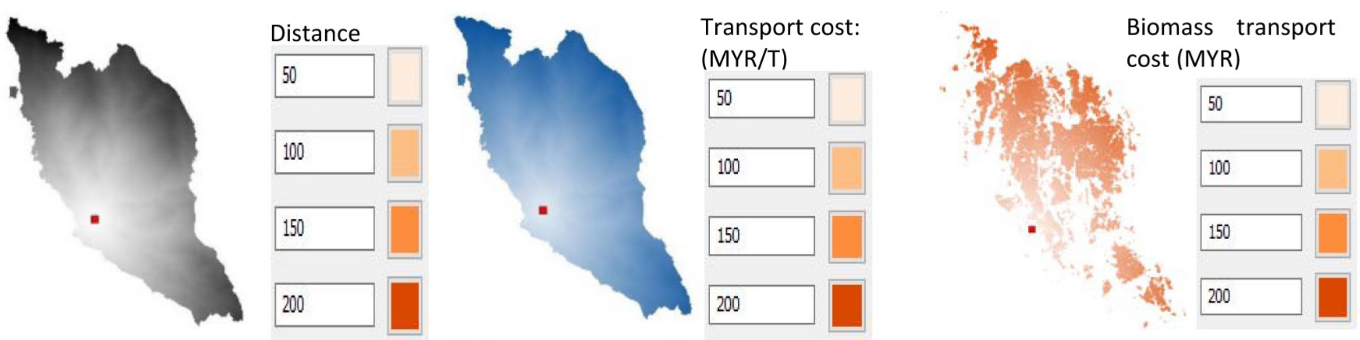


Figure 1. Supply costs and tonnage to each optimal location with a 1-ton-truck



Biomass residues	Optimal location
Logging (Forest)	Gua Musang, Kelantan
Oil palm trunk (Palm oil)	Jempol, Negeri Sembilan
Rice stalk (Paddy)	Yan, Kedah
Logging (Rubber)	Raub, Pahang
Multi-biomass	Temerloh, Pahang

Figure 2. Optimal locations for each biomass & multi-biomass



a) Distance map to Kuala Lumpur

b) Transport cost to Kuala Lumpur using 1-ton-truck

c) Forest residues transport cost to Kuala Lumpur using 1-ton-truck

Figure 3. Examples of travel distance, transport costs and biomass transport costs maps

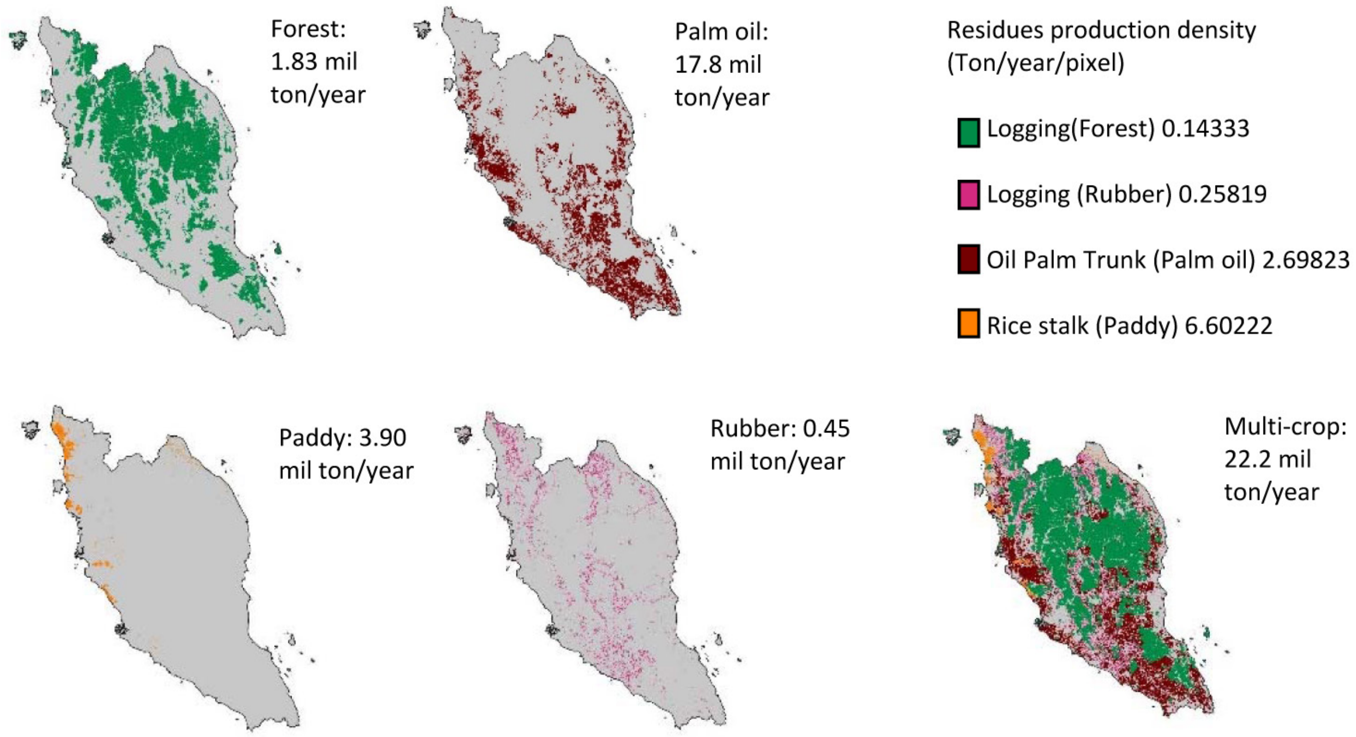


Figure 4. Annual biomass residues production and density

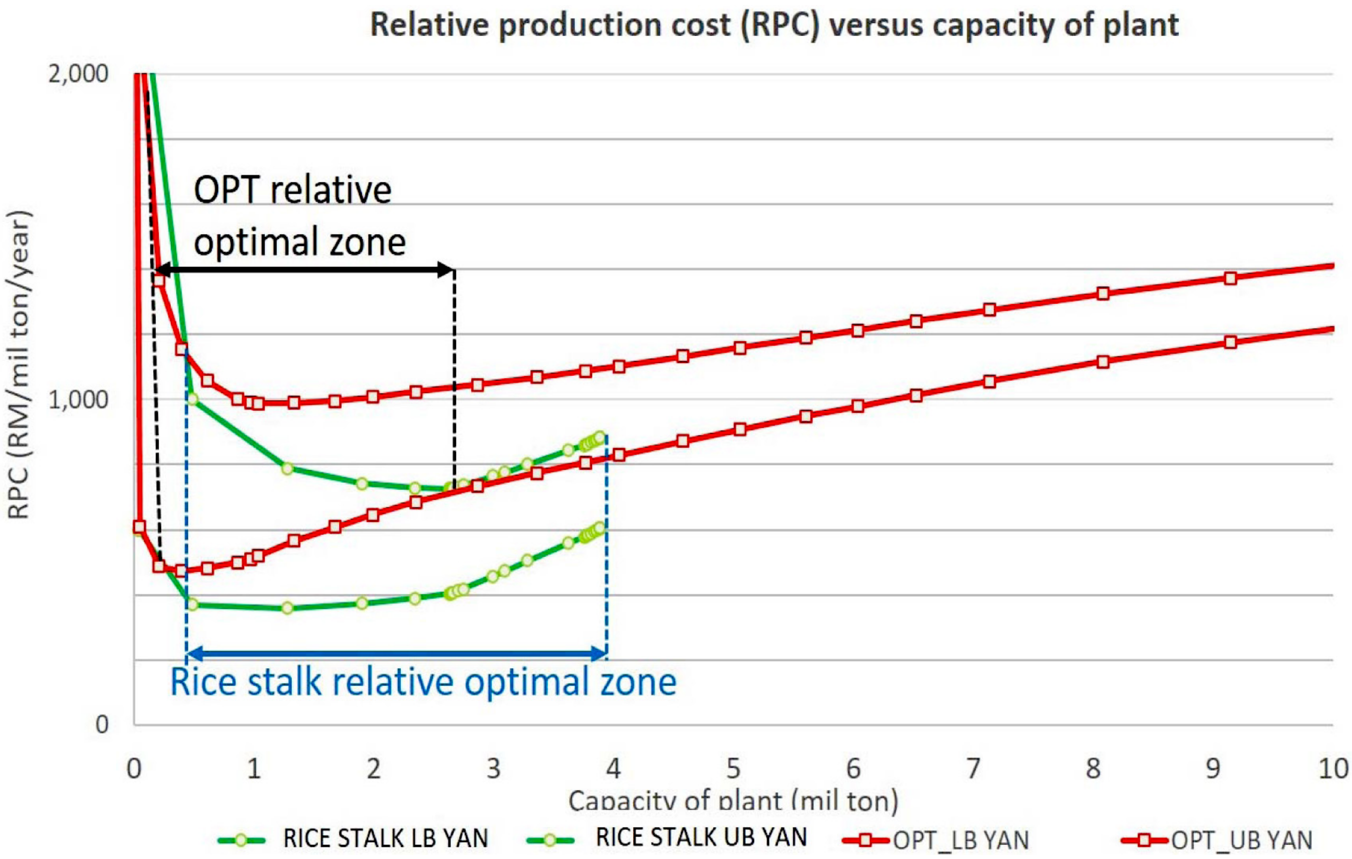


Figure 5. Relative production costs (RPC) versus the capacity of biorefinery plants at the optimal location of paddy residues

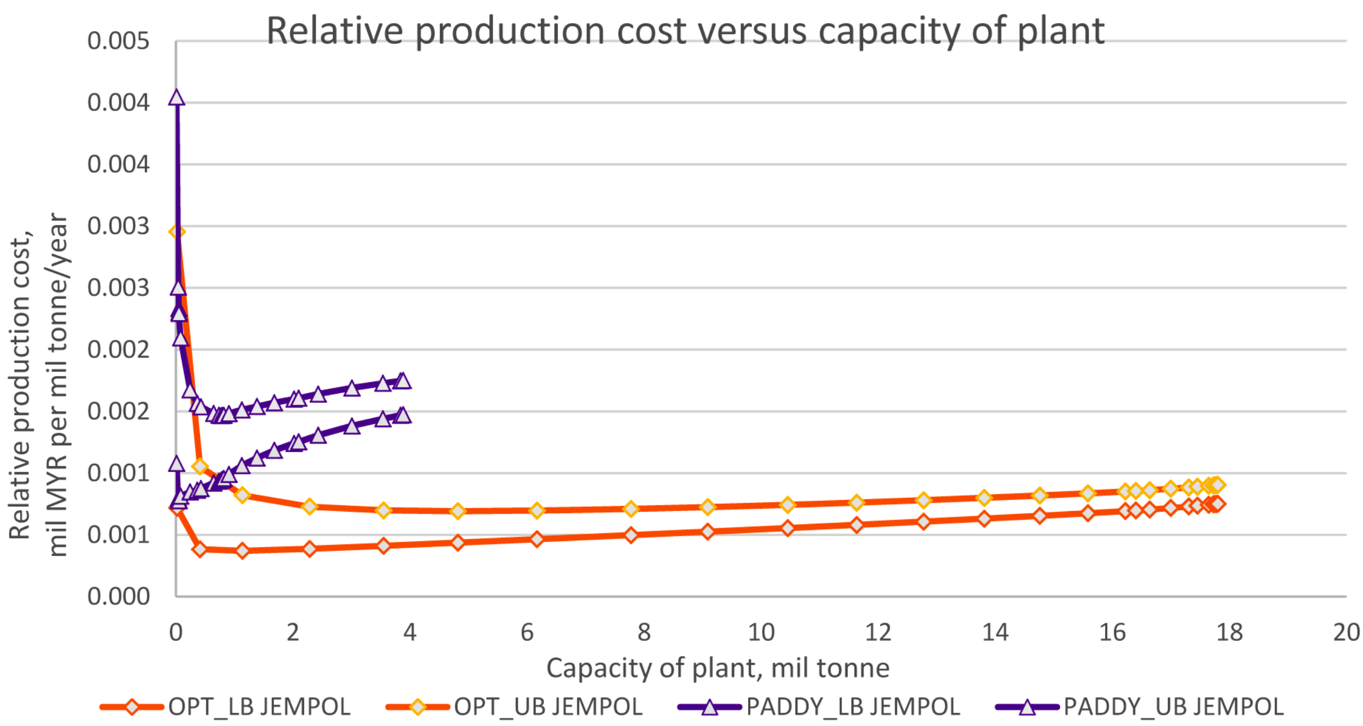


Figure 6. Relative production costs (RPC) versus the capacity of biorefinery plants at the optimal location of oil palm trunks

CONCLUSIONS

The model could estimate the production cost curves of biorefineries in different scenarios. The data indicated that the geographical structure of the biomass resources in Peninsular Malaysia was the main factor in deciding the optimal location of the biorefinery plants. Based on the simulation method used, the location strategy, input capacity and production cost range of the biorefineries could be derived. This method is useful as a decision and policy making tool for the implementation of biorefineries for aviation uses.

ACKNOWLEDGEMENTS

The authors would like to express sincere gratitude to the Airbus Group-AMIC for funding this research and to CIRAD for providing supervisory support.

REFERENCES

Davidson, C., Newes, E., Schwab, A., Vimmerstedt, L., 2014, July. "An Overview of Aviation Fuel Markets for Biofuels Stakeholder", Technical Report NREL/TP-6A20-60254, National Renewable Energy Laboratory. Retrieve from http://www.nrel.gov/docs/

International Air Transport Association, 2011, Advance Aviation Biofuel Flight Path, Montreal-Geneva.

U.S. Department of Energy, Energy Information Administration, Independent Statistics & Analysis, February 2016, Consumption of Jet Fuel, Malaysia, Annual. Retrieved from http://www.eia.gov/

Heminghaus, G., Boval, T., Bacha, J., Barnes, F., Franklin, M., Gibbs, L., Hogue, N., Jones, J., Lesnini, D., Lind, J., Morris, J. (2006). Aviation Fuels Technical Review, Chevron Corporation. Retrieve from http://www.cgabusinessdesk.com/document/

Coordinating Research Council, Inc. (2004) Handbook of Aviation Fuel Properties (3rd ed.). CRC Report No. 635

International Air Transport Association (2016), Current price of aviation jet fuel. Retrieved from http://www.iata.org/publications/economics/fuel-monitor/

International Air Transport Association (2013), IATA Technology Roadmap (4th ed.). Retrieved from https://www.iata.org/whatwedo/environment/document

Air Transport Action Group (2014), Aviation Benefits Beyond Borders. Retrieved from http://www.aviationbenefits.org/media

Edwards, T., US Air Force Research Laboratory, "Kerosene Fuels for Aerospace Propulsion – Composition and Properties", proceedings of 38th American Institute of Aeronautics and Astronautics (AIAA/ASME/SAE/ASEE) Joint Propulsion Conference & Exhibit, 7-10 July 2002, Indiana, US.

ASTM Standard D 1655, 2015de1, "Standard Specification for Aviation Turbine Fuels," ASTM International, West Conshohocken, PA, 2015, DOI: 10.1520/D1655-15DE01, www.astm.org.

ASTM Standard D 7566, 2015c, "Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbon," ASTM International, West Conshohocken, PA, 2015, DOI: 10.1520/D7566-15C, www.astm.org.

Radich, T., 2015, The Flight Paths for Biojet Fuel. Independent Statistics & Analysis, U.S. Energy Information Administration. Retrieve from http://www.eia.gov

Schill, R.S., 2008, Roundtable for Sustainable Biofuels releases proposed standards for review, Biomass Magazine. Retrieve from http://www.biomassmagazine.com/articles

ICTSD Biores, 2011, Sustainability Criteria for Biofuels Up and Running, International Centre for Trade and Sustainable Development. Retrieve from http://www.ictsd.org/bridges-news/biores/news/

Roda, J.M., Goralski, M., Benoist. A., Baptiste, A., Boudjema, V., Galanos, T., Georget, M., Hévin, J.E., Lavergne, S., Eychenne, F., Liew, K.E., Schwob, C., Djama M., Tahir, P.M. (2015). Sustainability of bio-jetfuel in Malaysia. Malaysia, Centre of International Cooperation in Agronomy Research for Development (CIRAD)

Huerta, M., Federal Aviation Administration speech, CAAFI General Meeting, January 28, 2014., Retrieve from http://www.faa.gov/news/speeches

Towker, G., Sinnot, R.K., 2012, Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design, 2nd Edition.

Air Transport Action Group (2016), Fact Sheet: Delivering Fuel Efficiency. Retrieved from http://www.atag.org/component/

Capareda, S., 2013, Introduction to Biomass Energy Conversions, CRC Press, 2013.

Anonymous. GRASS GIS manual. https://grass.osgeo.org/grass70/manuals/index.html

Després, G & Roda, J-M, 2015. Industrial scenarios for jetfuel process from biomass Peninsular Malaysia. Report for Centre of Excellence of Biomass Valorizations for Aviation (UPM-CIRAD-AMIC), Malaysia.

Mazraati, M. (2010). "World aviation fuel demand outlook", OPEC Energy Review, 34(1), 42–72. http://doi.org/10.1111/j.1753-0237.2010.00174.x