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Application of a Fuzzy Mathematical Programming Approach with in the Optimal Design of an Algal Bioenergy Park with Product Price Variability

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Abstract: : Utilization of microalgae can serve as a feasible alternative to traditional biofuel crops given their minimal land and clean water requirement, as well as their faster growth rate. Concerns in the commercialization of algal biofuels include economic viability, environmental impact, and energy requirement. An alternative approach to address these concerns involves the conglomeration of various synergistic industries in the production of algal biofuels via development of an algal bioenergy park (ABP). ABP is a special case of an eco-industrial park also has two types of industry tenants: anchor and support. The approach applies the principle of industrial symbiosis or the collaboration between concerned companies by means of exchanging by-products and energy surplus within the ABP. Hence, reducing the overall waste and environmental emission, and improving the efficiency of the each company. However, the designs of a complex network of companies with product stream dependencies with the other industry tenants require a systematic approach. A fuzzy modelling approach is proposed to determine optimum targets in production levels, profit, and environmental footprint through the linear membership function via the degree of satisfaction parameter. An extension of the model involving the one-by-one introduction of support tenants is conducted to determine their respective effects on the net profit and environmental footprints of the ABP. The product variability was also taken into consideration depending on the retailer of the ABP input products and the consumer of the ABP output products. Effects of markdown pricing percentage applied on prices of sales within the ABP are also investigated. Results of the study can be utilized in conducting preliminary analyses on the feasibility and acceptance of a support tenant to partake in the industrial symbiosis. Initial insights on the appropriate markdown pricing percentage can also be determined.

Key Words: Algal Bioenergy Park; Fuzzy Mathematical Programming Approach; Optimization; Markdown Product Pricing; Environmental Footprint

1. INTRODUCTION

Studies in the production of renewable energy such as the multi-criterion optimization (MCO) of biomass synthesis and supply chains (*Čuček et al.*, 2012) and optimal life cycle systems modelling of bioenergy systems (Tan et al., 2009) signified their potential in reducing greenhouse-gas (GHG) emissions and energy costs to address concerns such as increasing transportation costs (Bouyamourn, 2015). Crop-grown biofuels have several promising features; however concerns such as the need for arable lands and significant amounts of fresh water, as well as slow growth rates, hamper its potential. A suitable alternative is the use of microalgae which offer minimal energy to space requirement ratio, fast growth rate, and survivability in wastewater at certain nutrient thresholds (Lardon et al., 2009). However, economic viability, energy consumption, and environmental impacts are pressing concerns in the commercialization of algal biofuels. An approach considered by Ubando et al. (2015) implements the concept of industrial symbiosis in an algal bioenergy park (ABP) comprising of three anchor tenants or the main members and two support tenants or potential members. An integrated microalgae to biodiesel (IMB) plant, ethanol plant, and a cement factory constitute to the anchor tenants while a combined heat and power (CHP) plant, and an anaerobic digestion plant (ADP) for the support tenants. A fuzzy logic optimization process is utilized to maximize profits, minimize environmental footprints, and satisfy product to a certain degree of satisfaction. The study being conducted serves as an extension of the aforementioned model by taking into account the differences in within ABP price, wholesale price, and retail price, as well as the individual impact of integrating the support tenants to the ABP one at a time and the effect of markdown pricing percentage applied on sales within the algal bioenergy park. Effects of integrating one support tenant only and implementation of a markdown contract among stakeholders are also taken into account.

2. METHODOLOGY

2.1 Fuzzy Optimization Approach

Fuzzy programming models involve establishing an optimization procedure for the necessary product and footprint streams given a flexible target production levels, target footprint levels, and target profit levels satisfied to a degree indicated by λ (Tan et al., 2009).The degree of satisfaction λ is introduced as an influencing factor to the multiple objectives through a piecewise linear membership function. The variable is used as means of stating the multiple objectives into a single objective function:

$$\mathrm{MAX} = \lambda \quad \text{(Eq.1)}$$

Equations governing the product and environmental streams of the model are as indicated below:

$$\mathbf{Ax} = \mathbf{y} \quad \text{(Eq. 2)}$$

$$\mathbf{Bx} = \mathbf{z} \quad \text{(Eq. 3)}$$

$$\mathbf{y} = \Sigma\, y_i \qquad \forall\ i \quad \text{(Eq. 4)}$$

$$y_i \geq y_i^a + \lambda(y_i^b - y_i^a) \quad \text{(Eq. 5)}$$

$$y_i \leq y_i^d + \lambda(y_i^c - y_i^d) \quad \text{(Eq. 6)}$$

$$\mathbf{z} \leq \mathbf{z}^U + \lambda(\mathbf{z}^L - \mathbf{z}^U) \qquad \text{(Eq. 7)}$$

where:

$\mathbf{A}$ = technology matrix
$\mathbf{B}$ = environmental stream matrix
$\mathbf{x}$ = process scaling factor
$\mathbf{y}$ = net product output vector of the bioenergy park
$\mathbf{y}^a$, $\mathbf{y}^b$, $\mathbf{y}^c$, $\mathbf{y}^d$ = fuzzy trapezoidal demand limits
$\mathbf{z}$ = environmental footprint vector.
$\mathbf{z}^U$= upper environmental footprint limit
$\mathbf{z}^L$= lower environmental footprint limit

Equations 5 and 6 define the trapezoidal fuzzy membership functions with product limits set by the concerned stakeholders. Equation 7 defines the minimum fuzzy linear membership function for the allowable environmental footprints. To properly execute the flow of products within and outside the industrial symbiosis, the following equation is taken into account:

$$\Sigma\, (\mathbf{x}_{1ij} + \mathbf{x}_{2ij} + \mathbf{x}_{3ij} + \mathbf{x}_{4ij}) = \mathbf{x} \quad \text{(Eq. 8)}$$

$$\mathbf{A}(\mathbf{x}_{1ij}) = -\mathbf{A}(\mathbf{x}_{3ij}) \quad \text{(Eq. 9)}$$

where:

$\mathbf{x}_{1ij}$ = process scaling factor for products bought within the ABP
$\mathbf{x}_{2ij}$ = products bought outside the ABP

$\mathbf{x}_{3ij}$ = products sold within the ABP
$\mathbf{x}_{4ij}$ = products sold outside the ABP.

Equation 8 divides variable x into four variables. On the other hand, Equation 9 ensures that the amount of a certain product that is bought within the ABP equals the amount of said type of product which is sold within the ABP. The following equations below define the annual profit **AP** of the company:

$$AP = AGP - ACC \quad \text{(Eq. 10)}$$

where:

AP = annual profit
AGP = annual gross profit
ACC = annual capitalized costs

A maximum fuzzy linear membership function defines the annual profit for each stakeholder as presented below:

$$AP \geq AP^{L} + \lambda(AP^{U} - AP^{L}) \quad \text{(Eq. 11)}$$

where:

AP^{L} = lower limit of the annual profit for each company
AP^{U} = upper limit of the annual profit for each company.

The limits are set by the company owners in accord to their target profits.

2.2 Markdown Product Pricing

The companies involved in the ABP can sell their products to either their co-tenants or to the external market. Similarly, the stakeholders can outsource their input raw materials or obtain them within the ABP provided that the concerned product is an output of one of the tenants. The equation below presents the relationship between different types of prices considered.

$$cSo_i > cPo_i > cPw_i = cSw_i \quad \text{(Eq. 12)}$$

where:

cPwi = ABP discounted buying price
cPoi = wholesale price
cSwi = ABP discounted selling price
cSoi = retail price

Markdown contract involves an agreement between a supplier and a business associate wherein the former offers his products to the latter at a discounted or markdown price whjch can lead to increased market demand (Chung et al., 2011). Implications in using the said price-break strategy on the ABP are investigated in the following case studies

2.3 CASE STUDY

The technology matrix, product demand limits, footprint limits, and annual profit targets for the algal bioenergy park design are obtained from the study of Ubando et al. (2015). Table 1 presents the prices and profit margins for the products involved. The first case involves comparing the results of the following subcases:a) anchor tenants only, b) without CHP, c) without ADP, d) all tenants. The results are compared with those obtained from the study of Ubando et al. (2015). The subsequent cases involve analyzing the effects of increasing markdown pricing percentage of 10%, 20%, and 30% on each subcase or ABP tenant configuration.

Table 1: Different pricing of each product in the algal bioenergy park

(US$/kg)	Buying Price Outside	Profit Margin	References
Nutrients	0.008	----	Ubando et al.(2015)
Carbon Dioxide	0.004	1.4	Godec(2014), Chamberlin (2015)
Treated Water	0.0013	1.23	Ubando et al.(2015), Ycharts(2015)
Electricity	0.025	1.12	Ubando et al.(2015), Ycharts(2015)
Heat (US$/MJ)	0.021	1.27	Ubando et al.(2015), Macroaxis Inc. (2015)

Algal Biomass	0.47	1.70	Ubando et al.(2015), Hyoten (2013)
Bio-solid Waste	0.047	1.70	Ubando et al.(2015), 10% of Algal Biomass
Wet Biomass	0.0275	1.20	E4tech (2010), Ubando et al.(2015)
Natural gas	0.23	----	Ubando et al.(2015)
Waste water	0.0017	1.23	Ubando et al. (2015), Profit Margin Same as Treated Water
Microalgal Culture	0.588	----	Ubando et al.(2015)
Bioethanol	6.5	1.05	Ubando et al.(2015), Ycharts(2015)
Limestone	0.01	----	Ubando et al.(2015)
(US$/kg)	Selling Price Outside	Profit Margin	Reference
Biogas	0.23	----	Ubando et al.(2015)
Bio-oil	5.32	----	Ubando et al.(2015)
Biodiesel	0.0013	----	Ubando et al.(2015)
Glycerol	0.025	----	Ubando et al.(2015)
Cement	0.021	----	Ubando et al.(2015)

3. RESULTS AND DISCUSSION

At base pricing, the obtained net present value for the anchor tenants only case is less than the results obtained from Ubando et al. (2015) while the an inverse behaviour is exhibited by the all tenants case. The environmental footprints of both cases are lower when product price variability is introduced. In Table 2, the case involving all tenants yielded the highest overall net present value of US$10257.25M/Y followed by the case without the ADP. Moreover, the ADP-absent subcase yielded higher overall gross profits compared that without CHP.

The highest net present value for each of the ABP setup cases with the exception of the anchor tenants only-case is obtained under a markdown pricing percentage of 30% as listed in Table 3. For the cases involving the exclusion of only the CHP plant or the exclusion of only the ADP , an increase in net present value is yielded as the markdown % is increased. The net present value of anchor tenants only-case remains constant in all the set discount percentages. Environmental footprints of the anchor tenants only-case and that of the case which excludes only the ADP exhibits a similar behaviour. As for the case which excludes only the CHP plant, the environmental footprints increase with respect to rising markdown percentages. With regards the satisfaction parameter λ of each ABP setup when applied with varying discount pricing, the magnitudes are observed to have no variations with the exception of the all tenants-case wherein λ gradually increases as the discount percentage is increased.

4. CONCLUSIONS

The application of fuzzy mathematical programming model on the optimization of an ABP design led to the determination of the optimal satisfaction parameter λ for each of the ABP configurations at varying markdown pricing percentage. A generally directly proportional relationship exists between the net present value of the ABP setup and the increasing discount percentage. The investigatory procedures implemented in the study may be utilized for preliminary analyses on the tenants to be considered, as well as the pricing strategy, in the optimal configuration of algal bioenergy parks. Recommendations for future undertakings include the determination of an optimal markdown pricing percentage and impact of inflation in the concerned set-up. Pareto analyses on the overall gross profits can also be performed and given thorough investigation.

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Table 2: Results using Base Pricing

Base Pricing				
Gross Profit	**Anchor Tenants**	**WO CHP**	**WO ADP**	**All Tenants**
IMB Plant	83.32	90.94	98.56	106.18
Ethanol Plant	199.92	196.44	192.97	189.49
Cements Factory	269.93	265.78	261.63	257.48
CHP Plant	--	--	1069.44	1073.19
ADP	--	47.63	--	46.73
Overall	553.16	630.04	1658.75	1754.17
Net Present Value	3234.5	3684.1	9699.32	10257.25
λ	0.390	0.288	0.780	0.224
Environmental Footprint				
CO_2 of raw materials(kg/s)	46.85	64.34	2172.71	2399.40
CO_2 of plant (kg/s)	73.37	81.40	90.08	97.70
Water of plant (kg/s)	198.33	265.68	2273.27	2537.57
Land (1×10^3 m^2)	479.44	979.34	7269.74	8375.09
Nitrogen of plants (1×10^{-3} kg/s)	121.98	127.68	126.91	127.75

Table 3: Most Satisfactory Results Using Markdown Pricing Scheme

Highest Overall Gross Profit			
Gross Profit	**WO CHP**	**WO ADP**	**All Tenants**
Markdown %	30%	30%	30%
IMB Plant	92.18	119.59	279.99
Ethanol Plant	233.42	199.91	199.91
Cements Factory	269.93	280.21	269.93
CHP Plant	--	1069.44	969.71
ADP	47.63	--	46.72
Overall	643.16	1669.14	1766.27
Net Present Value	3760.81	9760.07	10328.04
λ	0.288	0.780	0.237
Environmental Footprint			
CO_2 of raw materials(kg/s)	65.55	2172.71	2399.36
CO_2 of plant (kg/s)	81.77	90.08	97.70
Water of plant (kg/s)	266.12	2273.27	2535.74
Land (1×10^3 m^2)	996.37	7269.74	8355.36
Nitrogen of plants (1×10^{-3} kg/s)	131.06	126.91	127.75

6. REFERENCES

Bouyamourn, A. (2015, September 14). *Rising Fuel Costs Accelerate Abu Dhabi Consumer Price Inflation*. Retrieved November 12, 2015, from http://www.thenational.ae/business/economy/rising-fuel-costs-accelerate-abu-dhabi-consumer-price-inflation

Chamberlin, A. (2015, March 9). *A snapshot of Kinder Morgan*. Retrieved October 25, 2015, from http://marketrealist.com/2015/03/key-overview-kinder-morgan/

Chung, W., Talluri, S., & Narasimhan, R. (2011). Price Markdown Scheme in a Multi-echelon Supply Chain in a High-tech Industry. *European Journal of Operational Research , 215*, 581-589.

Čuček, L., Varbanov, P. S., KlemeŠ, J. J., & Kravanja, Z. (2012). Total Footprints-based Multi-criteria Optimisation of Regional Biomass Energy Supply Chains. *Energy , 44*, 135-145.

E4tech. (2010, January). *Biomass Prices in the Heat and Electricity Sectors in the UK*. Retrieved October 24, 2015, from http://www.rhincentive.co.uk/library/regulation/100201Biomass_prices.pdf

Godec, M. L. (2014). *Carbon Dioxide Enhanced Oil Recovery*. Retrieved October 27, 2015, from http://www.aogr.com/magazine/editors-choice/industrial-co2-supply-crucial-for-eor

Hyoten, E. (2013, May 23). *Algae as Renewable Energy* . Retrieved November 10, 2015, from https://www.esmap.org/sites/esmap.org/files/ESMAP%20IFC%20RE%20Training%20VTT%20Hytonen_Small1.pdf

Lardon, L., Hélias, A., Sialve, B., Steyer, J. P., & Bernard, O. (2009). Life-Cycle Assessment of Biodiesel Production from Microalgae. *Environmental Science & Technology , 43* (17), 6475-6481.

Macroaxis Inc. (2015). *FORTUM OYJ Profit Margin*. Retrieved October 28, 2015, from https://www.macroaxis.com/invest/ratio/0HAH.L--Profit-Margin

Tan, R. R., Ballacillo, J. B., Aviso, K. B., & Culaba, A. B. (2009). A Fuzzy Multiple-objective Approach to the Optimization of Bioenergy Systems Footprints. *Chemical Engineering Research and Design , 87*, 1160-1170.

Ubando, A. T., Culaba, A. B., Aviso, K. B., Tan, R. R., Cuello, J. L., Ng, D. K., et al. (2015). Fuzzy Mathematical Programming Approach in the Optimal Design of an Algal Bioenergy Park. *Chemical Engineering Transactions , 45*.

Ycharts. (2015). *American Electric Power Profit Margin (Quarterly)*. Retrieved October 21, 2015, from https://ycharts.com/companies/AEP/profit_margin

Ycharts. (2015). *American Water Works Co Profit Margin (Quarterly)*. Retrieved October 21, 2015, from https://ycharts.com/companies/AWK/profit_margin

Ycharts. (2015). *Pacific Ethanol Profit Margin (Quarterly)*. Retrieved October 21, 2015, from https://ycharts.com/companies/PEIX/profit_margin

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