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Strategic site selection of microalgae industry in the Philippines using analytic hierarchy process

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Microalgae are microorganisms which converts sunlight and carbon dioxide to useful biomass. It consists of high-valued contents such as protein, carbohydrates, lipids and pigments which can yield various industrial products: nutraceuticals, animal feeds, and biofuels. Since the Philippines was found to have an abundance of microalgae species due to its tropical climate and archipelagic nature, a strategic multi-criteria site selection decision structure must first be established for potential deployment of cultivation and processing locations involving multiple industries. Analytic hierarchy process (AHP) was utilized to develop the strategic decision structure of the study. A survey from a panel of stakeholders was conducted to identify the prioritization between criteria via pairwise comparison method. The results revealed the preferred regions of the Philippines suitable for an anticipatory microalgal industry. The developed decision structure aims to aid policy makers and stakeholders for the deployment of the emerging industry. Future work involves the consideration of uncertainty of judgment from the panel of stakeholders.

1. Introduction

Unprecedented rise in the cost of conventional fuels as well as the ongoing concern for global warming and climate change have provided the impetus in the quest for sustainable and renewable source of energy, for which microalgae have become a mainstream. Several distinguishing characteristics of microalgae feedstock include concordance with food security, wastewater treatment potential, carbon dioxide sequestration, round-the-clock production and less nutrient input (Brennan and Owende, 2010). However, they have yet to reach commercialization stage due to relatively lower energy ratios caused by extensive energy input (Lam and Lee, 2012).

While these are true, harnessing microalgae biomass also presents another opportunity for cogeneration of value-added products aside from biofuels. Various compounds present in microalgae such as proteins, carbohydrates, lipids and other chemical compounds can be utilized in many aspects such as for power generation, health, animal feed and nutraceuticals (Becker, 2008). Sustainable production from microalgae biomass can therefore be achieved if co-generation of its high value-products is permitted. Kirrolia et al (2013) argued that in order for microalgae biofuel production to become sustainable, co-production of other products should be established.

Several sustainability studies are also being done which consider cogeneration of microalgae products. A microalgal multi-functional bioenergy system, aimed at optimising the whole microalgal products supply chain while maximising economic potential and minimising environmental impact, was established by Ubando (2014). Garcia Prieto et al (2014) formulated an optimisation model of a microalgae biorefinery producing both biodiesel and PHB biopolymer. Meanwhile, analysis of the composition of microalgae biomass products was examined by Pinzón Frias et al (2014) and ranked these obtainable products based on a certain techno-economic criteria.

The Philippines, having a tropical climate and an archipelagic nature, was found to boast a great abundance of numerous microalgae species. As the global demand for microalgal products is sure to elevate the economic status of the country, it is likely that a potential microalgae industry would be

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established in the near future. While this is true, there is still a gap in the strategic planning of the deployment of this emerging industry. This includes the systematic selection of the best cultivation and processing sites as source of useful microalgal biomass.

A multi-criteria decision-making (MCDM) methodology was employed to facilitate this type of analysis. The analytic hierarchy process (AHP) is a very promising MCDM procedure, developed by Saaty in the 1970s (Saaty, 1980). It is widely-renowned for its application to energy-related decision analysis and it is highly suitable for this study as it combines both qualitative and quantitative information (Pohekar and Ramachandran, 2004). Given a set of multiple criteria which are to be considered simultaneously, the AHP identifies the best alternative while giving a ranking of all the possible choices or alternatives (Saaty, 1980). More promising features in using the AHP as a decision-making tool are its ability to handle inconsistencies with regards to making subjective judgments as well as its ease of use (Harker, 1987).

After extensive literature review and expert insights, relevant data regarding stakeholder prioritization via pairwise comparisons and regional performance indicators were recorded. A sensitivity analysis was also done aimed at detailed analysis between the input-output relationship of the developed AHP model.

2. Methodology

2.1 AHP structure

In structuring the significant decision-making methodology, factors which comprise the problem are decomposed and structured into a hierarchy. An identified set of criteria was enumerated, with the main criteria as natural resources, social acceptability, economic cost and present industries. The four main criteria are further expounded by respective sub-criteria. Finally, the set of choices or alternatives includes all of the 17 regions in the Philippines.

Natural resources include those which are necessary for microalgal cultivation. For a phototropic type of production, microalgae grow in aqueous media, absorbing carbon dioxide and sunlight or any artificial lighting (Brennan and Owende, 2010). Other inorganic nutrients may also be provided as fertilizers to accelerate algae production, and these include nitrogen and phosphorus (Brennan and Owende, 2010). Land area is also a major requirement for establishing appropriate facilities to serve this purpose and to store the generated biomass. For the socio-economic aspect, acceptance of the society for the deployment of this industry must be taken into consideration. Job creation is expected and must be highly matched by the potential labor force of the regions where they are situated. Poverty index is also affected as more jobless people are employed. Meanwhile, the economic or financial performance of this possible industry can be best monitored in terms of the costs of the resources required – water, fertilizer and electricity, as well as income to labourers. Another consideration for the strategic implementation of a multi-functional microalgal industry is its proximity to several present industries which can be served by microalgae value-added products. These are, but not limited to, aquaculture, poultry, swine, carabao, cow and biofuels. Ubando et al (2015) also proposed a similar hierarchal structure, but only considered biofuels industry as the sole beneficiary of the microalgae product.

The Philippine archipelago, consisting of 7,107 islands, is divided into three groups. Luzon in the northern part has the largest land area and is comprised of a total of eight regions, including the National Capital Region (NCR). Mindanao, the second largest land area, is situated in the south and is comprised of six regions. Lastly, Visayas, which consists of only three regions with many islands, is located at the central part. Altogether, the three main island groups comprise the 17 regions in the Philippines.

The final AHP structure consisting of the goal, main and sub-criteria and the alternatives is depicted in Figure 1.

2.2 Stakeholder prioritization and sensitivity analysis

A survey was conducted to evaluate stakeholder prioritization between the enumerated criteria via pairwise comparison. The stakeholders were selected from various members of national and local government agencies, academe and private companies who could be affected by the emergence of a possible microalgae industry. The authors adapted a 9-point fundamental scale obtained from Saaty (1980), to quantify the judgments. Meanwhile, the pairwise comparison matrix was generated as an n by n matrix in which n is the number of main criteria, or the number of sub-criteria relative to each main criterion. The entries for the elements in the upper echelon were the priority weights ratio of the two criteria evaluated by the stakeholders, or regional data obtained from various references. The entries for the remaining cells were the reciprocals of the weight between previously evaluated criteria. The pairwise comparison matrix for the main and sub-criteria were checked for consistency, and were normalized using the eigenvector method. This theoretical foundation and detailed methodology of the AHP can be found in Saaty (1980). For the sensitivity analysis, the main criteria and the present industries sub-criteria were tested through intended distribution of priority weights to observe the effects on the regional ranking. For this purpose, a value of 75 % was placed on one criterion and the remainder was divided equally among the remaining criteria. The intended prioritisation was done as multiple scenarios to test all the main criteria and the present industries sub-criteria. Priority weights in the criteria not being evaluated were held constant. A total of 10 scenarios were generated in which 4 scenarios were appropriated to the four main criteria and the remaining 6 for present industries sub-criteria.

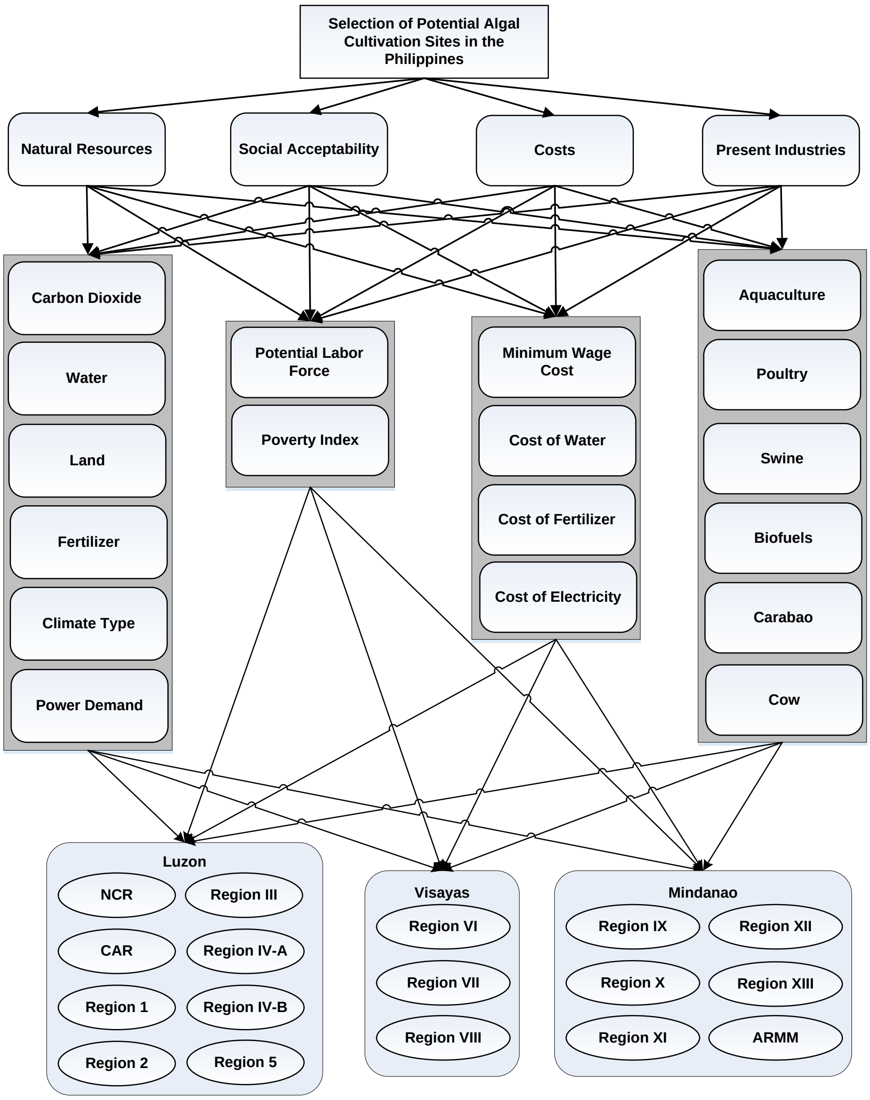

Figure 1: Analytic hierarchy process structure in the evaluation of the most suitable microalgal cultivation sites in the Philippines

3. Results and Discussion

3.1 Survey results

The priority distribution, in percentages, for the main and sub-criteria is shown in Figure 2. The main criteria distribution favoured the natural resources criterion followed by social acceptability. Meanwhile the highest obtaining sub-criteria are as follows: water supply for natural resources, potential labour force for social acceptability, minimum wage for costs and swine and poultry for present industries.

3.2 Results of the AHP

Table 1 presents the complete ranking of all the Philippine regions with their corresponding percentages. The overall results reveal that region XII (Soccsksargen) in Mindanao is the most preferred cultivation site for microalgae biomass production in the Philippines. This is followed by region IV-A (CALABARZON) in Luzon. Of the three regions in Visayas, region VI (Western Visayas) obtained the highest weight. Analysis of the data revealed that the top three regions show relatively high values in terms of regional performance indicators – water supply for region XII, and carbon dioxide sources shared by both regions III and IV-A. These sub-criteria belong to natural resources main criteria which obtained the highest percentage of importance at 40 %. Meanwhile, a graphical representation of Table 1 is depicted in Figure 3. The weights were classified into five ranges of values which were represented by five different shades in the figure.

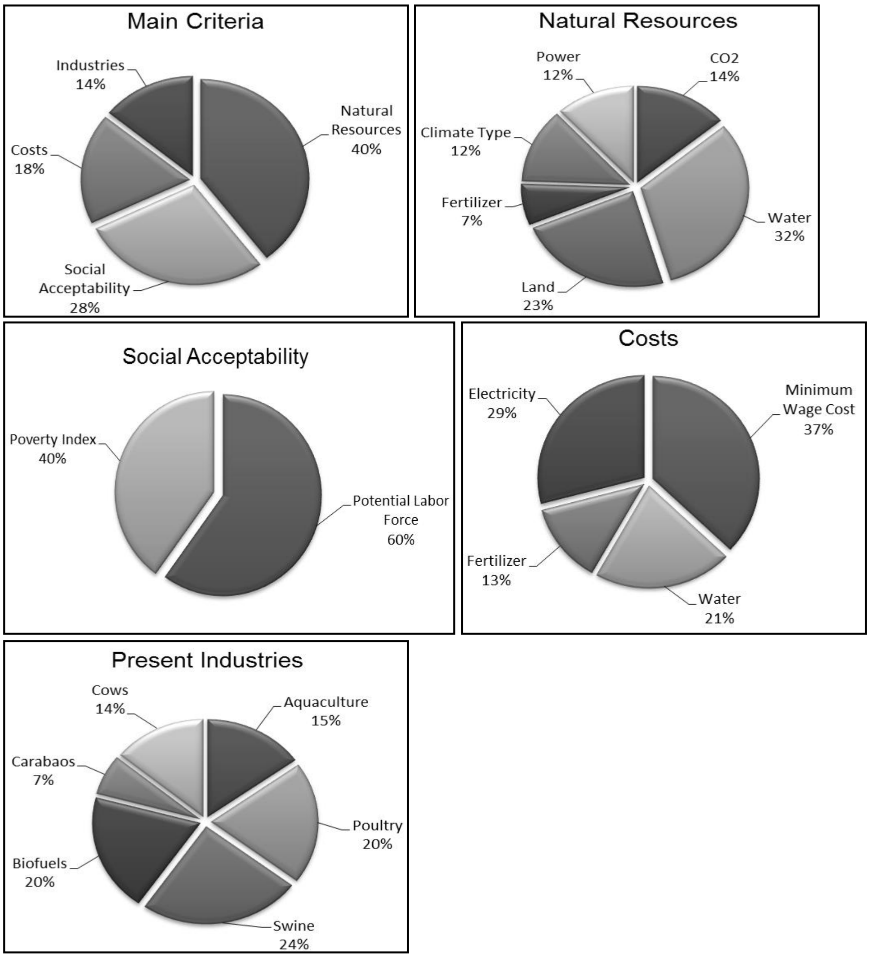

Figure 2: Percentage weight of a) Main Criteria, b) Natural resources, c) social acceptability, d) Cost, and e) Present industries

3.3 Results of the Sensitivity Analysis

The results of the 10 scenarios generated were summarised in Table 3. It can be observed that all of these scenarios generally bring up the top-performing regions in the general AHP ranking even though priority weight distribution for some criteria were intentionally changed. This indicates that these top-performing regions are adaptable to anticipatory changes especially with regards to the priority weights to be given by additional surveys.

Table 1: Ranking of the Philippine regions with the corresponding normalized weight

Ranking	Region			%
1	XII	Mindanao	Soccsksargen	11.22
2	IV-A	Luzon	CALABARZON	9.12
3	III	Luzon	Central Luzon	7.78
4	X	Mindanao	Northern Mindanao	6.84
5	NCR	Luzon	National Capital Region	6.57
6	VI	Visayas	Western Visayas	6.17
7	VII	Visayas	Central Visayas	6.00
8	V	Luzon	Bicol Region	5.94
9	IX	Mindanao	Zamboanga Peninsula	5.61
10	XI	Mindanao	Davao Region	5.45
11	I	Luzon	Ilocos Region	5.24
12	ARMM	Mindanao	Autonomous Region of Muslim Mindanao	4.61
13	IV-B	Luzon	MIMAROPA	4.51
14	VIII	Visayas	Eastern Visayas	4.32
15	II	Luzon	Cagayan Valley	4.30
16	XIII	Mindanao	Caraga	3.26
17	CAR	Luzon	Cordillera Administrative Region	3.08
			Total	100

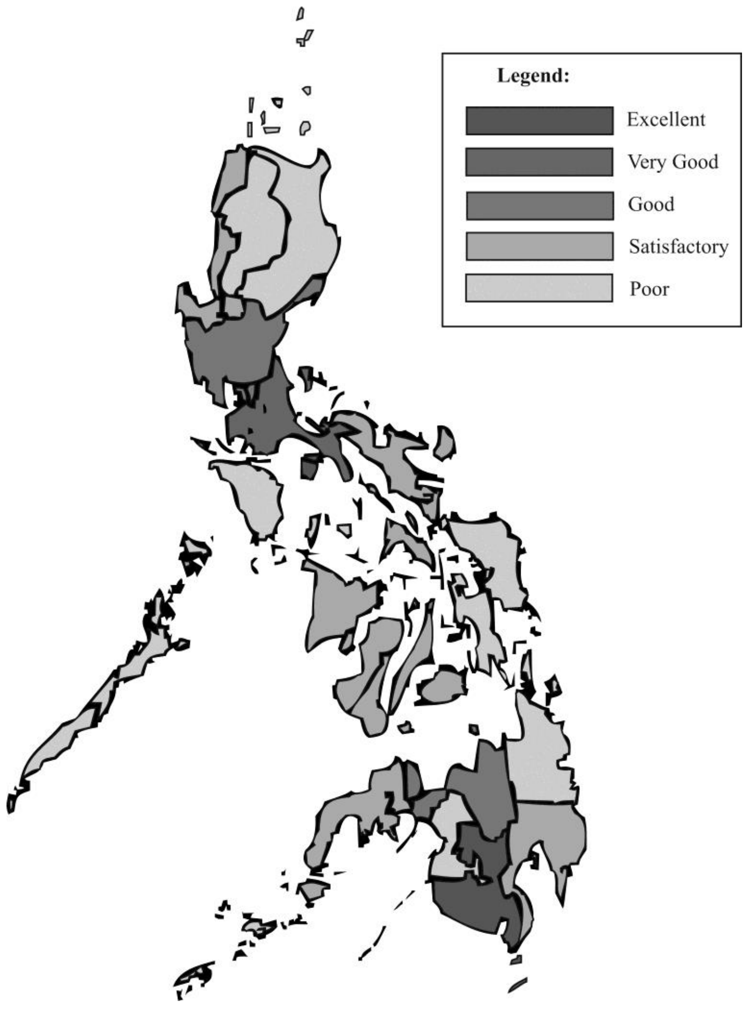

Figure 3: Preferred microalgal cultivation and processing sites in the Philippines

Table 2: Summary of the sensitivity analysis

Scenario	Preference (Given 75% weight)	1st	%	2nd	%	3rd	%
1	Main Criteria – Natural Resources	XII	16.17	IV-A	9.28	III	7.60
2	Main Criteria – Social Acceptability	IV-A	8.92	III	7.98	NCR	7.71
3	Main Criteria – Cost	XII	7.19	IV-A	6.73	III	6.54
4	Main Criteria – Present Industries	IV-A	13.04	III	10.15	VI	9.91
5	Industry Sub-criteria – Aquaculture	XII	10.92	IV-A	8.42	III	7.47
6	Industry Sub-criteria – Poultry	XII	11.18	IV-A	9.24	III	8.57
7	Industry Sub-criteria – Swine	XII	11.48	IV-A	8.90	III	8.21
8	Industry Sub-criteria – Biofuels	XII	10.82	IV-A	10.18	NCR	10.14
9	Industry Sub-criteria – Carabao	XII	11.59	IV-A	8.20	III	7.37
10	Industry Sub-criteria – Cow	XII	11.59	IV-A	8.62	III	7.34

4. Conclusions

A multi-criteria decision structure using analytic hierarchy process was developed to evaluate the most suitable microalgal cultivation and processing sites in the Philippines. Of the 17 regions, the most preferred are regions XII, IV-A and III. The sensitivity analysis performed provided grounds that these regions are really promising to serve this purpose very well. However, it is still best to consider the latter two regions due to their proximity to the national capital. Future work involves the consideration of participation of more stakeholders as well as addressing the uncertainty of judgment from this panel of stakeholders.

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