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Biodiesel from microalgae: The use of multi-criteria decision analysis for strain selection

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HIGHLIGHTS

- Multi-Criteria Decision Analysis (MCDA) methodologies adopted to select microalgae strains.
- Six microalgae strains and five MCDA methods considered for biodiesel production.
- Most important evaluation criteria are lipid content and growth rate.
- *Scenedesmus* sp. is selected as the best microalgae strain for biodiesel production.
- Analytic Hierarchy Process (AHP) method is the most comprehensive of the five MCDA methods.

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ABSTRACT

Microalgae strain selection is a vital step in the production of biodiesel from microalgae. In this study, Multi-Criteria Decision Analysis (MCDA) methodologies are adopted to resolve this problem. The aim of this study is to identify the best microalgae strain for viable biodiesel production. The microalgae strains considered here are *Heynigia* sp., *Scenedesmus* sp., *Niracticinium* sp., *Chlorella vulgaris*, *Chlorella sorokiniana* and *Auxenochlorella protothecoides*. The five MCDA methods used to evaluate different strains of microalgae are *Analytic Hierarchy Process* (*AHP*), *Weighted Sum Method* (*WSM*), *Weighted Product Method* (*WPM*), *Discrete Compromise Programming* (*DCP*) and *Technique for the Order of Preference to the Ideal Solution* (*TOPSIS*). Pairwise comparison matrices are used to determine the weights of the evaluation criteria and it is observed that the most important evaluation criteria are lipid content and growth rate. From the results, *Scenedesmus* sp. is selected as the best microalgae strain among the six alternatives due to its high lipid content and relatively fast growth rate. The AHP is the most comprehensive of the five MCDA methods because it considers the importance of each criterion and inconsistencies in the rankings are verified. The implementation of the MCDA methods and the results from this study provide an idea of how MCDA can be applied in microalgae strain selection.

1. Introduction

The interest in renewable energy sources such as biofuels is increasing due to unstable crude oil prices, possible dwindling of fossil fuel reserves, lingering concerns about the environment, and the need for energy security [1]. The conversion of biomass resources results in biofuels; these resources are energy sources that can be replenished naturally at almost the same rate as they are used. Wood, crops, waste, animal residue and organic marine life (such as algae) are various forms of biomass.

Biofuels have oxygen levels of 10–45 wt% (dry), while fossil-based fuels have essentially none, making the chemical properties of biofuels very different from those of their fossil-based counterparts [2]. This high oxygen content leads to more efficient and "cleaner" combustion. Biofuels typically have very low sulphur and nitrogen levels, thus reducing the levels of sulphur and nitrogen oxide released upon combustion [3].

CO_2 neutrality is a primary advantage of biofuels [1]. This is based on the concept that during the growth phase of biomass, it consumes as much CO_2 as is released when burnt as a biofuel (i.e. the same number of carbon atoms are recycled).

Microalgae is a third generation biofuel source with several advantages over terrestrial crops owing to its high potential yield of biofuels and relatively faster growth rates [4]. CO_2 can be captured and used in large scale cultivation of algae for biofuel production [2]. Fig. 1 illustrates CO_2 mitigation (carbon neutrality) using microalgae as an energy resource.

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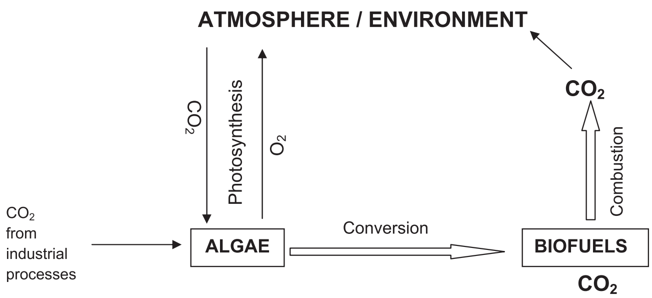

Fig. 1. CO_2 mitigation using algae [2].

Microalgae can be grown on non-arable land or in large water bodies utilizing ocean or waste water; hence eliminating the competition for land and fresh water with food crops. With wastewater containing nutrients such as urea, nitrogen, phosphorus and potassium, the cultivation of microalgae can be mutually beneficial because the microalgae can utilize the nutrients for growth while the wastewater is treated by the algae [5].

The process of producing biodiesel from microalgae can be summarized in four major steps: (1) Microalgae cultivation; (2) harvesting; (3) algal oil extraction; (4) transesterification to produce biodiesel.

MCDA involves making decisions in the presence of multiple, potentially conflicting criteria. The goal of MCDA is the selection of the "best" alternative from pre-specified alternatives described in terms of multiple attributes [6,7]. The first complete exposition of MCDA was given in 1976 by Keeney and Raiffa [8].

Previous studies indicate that more than 50,000 species of microalgae exist, but only about 30,000 have been studied and analysed [5]. These strains have different physical, chemical and biological properties, and can affect the production process in different ways. These differences make microalgae strain selection an important task.

There is insufficient information in literature about the application of MCDA in microalgae strain selection for biodiesel production. This study aims to address this insufficiency by evaluating six microalgae strains using six MCDA methods to determine the best strain for biodiesel production. In the methodology adopted, the relative importance of the decision maker's opinions of the criteria is determined by a pairwise comparison matrix using linguistic-to-numerical characterizations developed by Thomas Saaty in 1980 [9]. Table 1a shows a summary of the advantages and disadvantages of the common MCDA methods.

Table 1a
Advantages and disadvantages of MCDA methods.

MCDA methods	Advantages	Disadvantages
AHP	• Flexible and checks inconsistencies • No bias in decision making	• More numbers of pairwise comparison is required • Important information may be lost due to the use of additive aggregation
WSM	• Strong in a single dimensional problem	• Difficult to implement in a multi-dimensional problem
WPM	• Uses relative values rather than actual	• No solution with equal weights of Decision Makings
DCP	• Produces more discrimination and result in a non-equal ranking	• Influenced by the actual magnitude of the basic data
TOPSIS	• Easy to use and program • Same number of steps irrespective of the number of attributes	• Difficult to weight and keep consistency of judgement

2. Properties of microalgae for biodiesel production

The criteria that can influence microalgae strain selection can be grouped into the technical, environmental, economic and social aspects [3]. These are presented in Table 1b. The most important properties of microalgae for biodiesel production are growth rate, lipid content, fatty acid profile and ease of harvesting [4].

2.1. Properties of microalgae and their effects on biodiesel

2.1.1. Growth rate

Microalgae can double their biomass yields in timeframes as short as 3.5 h and the average harvesting cycle is about 1–10 days [1]. This rapid growth potential makes microalgae a viable feedstock for commercial biodiesel production [10].

2.1.2. Lipid content

From various literature sources, the lipid content of microalgae biomass can range from 4.5% to 80% of its dry weight and these lipids are in the form of oils [11]. The lipid content of a microalgae strain is directly proportional to the quantity of biodiesel produced; therefore the use of high lipid – producing strains result in high yields of biodiesel. Microalgae oil contains neutral and polar lipids. Neutral lipids or Triglycerides (TAG) are the most desirable components for biodiesel production from microalgae [4,10]. The quantity (by dry weight) and quality of the lipids contained in a microalgae strain are very important criteria for biodiesel production. Strains capable of producing more than 50% dry weight of extractable oils are viable for industrial biodiesel production [1].

2.1.3. Fatty acid profile

TAGs are esters of glycerol and three fatty acids. The fatty acids contained in microalgae oil are: Free Fatty Acids (FFA), Monounsaturated Fatty Acids (MUFA), Polyunsaturated Fatty Acids (PUFA), and Saturated Fatty Acids (SUFA) [12]. Higher percentages (by composition) of SUFA and MUFA result in biodiesel with enhanced energy yields, higher oxidative stability and higher cetane number; however, these high percentages will also lead to

Table 1b
Evaluation criteria used in MCDA for microalgae strain selection [3,10].

Aspects	Technical	Environmental	Economic	Social
Criteria	Energy content	Land/ waterbody use	Microalgae (raw material) cost	Competition for food
	Energy efficiency	Water quality/ requirement	Investment cost	Technological development
	Ease of harvesting[a]	Biodiversity and aquatic life	Cost of cultivation / nutrients	Sustainable development
	Primary energy ratio	CO_2 sequestration ability	Cost of harvesting	Social acceptability
	Biomass content	Cultivation methods	Co-utilization	Job creation
	Oil content	Pollution	Robustness	Social benefits
	Lipid content[a]	Chemical usage	Storage cost	Others
	Fatty acid profile[a]	Light intensity	Transportation Cost	
	Growth rate[a]	Resistance to contamination	Payback period	
	Reliability	Particles emission	Others	
	Safety	Impact on ecosystems		
	Availability of nutrients	Visual impact		
	Others			

[a] Used in this study.