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## Risk analysis and development of algae biofuel from aquatic and terrestrial systems

Isa Elegbede<sup>a\*</sup>, Saheed Matemilola<sup>b</sup>, Fatima Kies<sup>c</sup>, Oluwaseun Fadeyi<sup>d</sup>, Abdulwakil Saba<sup>g</sup>,  
Patricio De Los Rios<sup>f</sup>, Falilu Adekunbi<sup>e</sup>, Aderonke Lawal-Are<sup>c</sup>, Hakeem Fashina-Bombata<sup>g</sup>

<sup>a</sup>Department of Environmental Planning, Brandenburg University of Technology, Cottbus-Senftenberg, Germany

<sup>b</sup>Department of Public Law with Reference to the Law of Environment and Planning, Brandenburg University of Technology,  
Cottbus-Senftenberg, Germany

<sup>c</sup>Department of the Environment and Earth, University of Milano Bicocca, Italy

<sup>d</sup>Department of Geology, University of Trier, Behringstraße 21, 54296 Trier, Germany

<sup>e</sup>Department of Marine Sciences, University of Lagos, Akoka, Lagos, Nigeria

<sup>f</sup>Escuela de Ciencias Ambientales, Facultad de Recursos Naturales, Universidad Católica de Temuco, Casilla 15-D, Temuco, Chile

<sup>g</sup>Department of Fisheries, Lagos State University, Ojo, Lagos, Nigeria

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### Abstract

Production of algae biofuel from aquatic and terrestrial systems are global emerging strategies for the reduction of the overreliance on fossil fuel based on its potentials to promote the green environment, which can be a panacea to the global warming, climate change and other earthly challenges affecting global evolution. Algae as bioenergetic resource has the capacity to solve the uneven energy supply of developing countries. This study adopts an exploratory research approach and uses a contextual SWOT model to assess what needs to be done on the premise of the prevailing situation in Nigeria and strategically analyzes the risk and potential benefits of biodiesel production from algae. The model helps to examine the strength, weaknesses, opportunities, and threats of the algae biofuel production and utilization peculiar to Nigeria. The result showed that there are prospects for the algae biofuel implementation in Nigeria, though with various limitations. Some of the challenges anticipated could be resolved with adequate government and private stakeholders support in terms of policies, funding and sustainable management. The main focus of this paper is on micro-algae, known for their rapid growth rate and suitability as feedstock for biodiesel (third generation of bio energy). With Nigeria's total economic dependence on petroleum oils, algae derived biofuel could provide options as well as aid environmental sustainability.

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\* Corresponding author.

E-mail address: [Isaelegbede@gmail.com](mailto:Isaelegbede@gmail.com)

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## 1. Introduction

Conventional energy sources such as oil, coal, and natural gas are very important for economic development [1]. However, the negative impacts of these energy sources on the environment as well as human health results in continuous search for alternative cleaner, greener and more sustainable energy sources, which is the main feature of the third generation of bioenergy.

Energy sources in most developing countries are still very crude and coal remains one of the most widely used in these nations. With the decision of the Kyoto Protocol on greenhouse gas (GHG) reduction, phasing out of coal may be inevitable [1] implying the acceptance of newer sources. Algal derived biofuels are global emerging energy sources poised to help reduce the overreliance on fossil fuels due to their potential to promote green environment, a panacea to global warming, climate change and other earthly challenges affecting the globe. Being signatory to the Kyoto Protocol, Nigeria's shift away from coal and natural gas can be fast-tracked giving room for more sustainable energy development. Algae present such opportunity to help develop biofuels, thus reducing the monopoly of petroleum as the main energy source in Nigeria [2]. Hence, this study evaluates critically the potentials of optimizing the development of biofuels (biodiesel, bioethanol etc.), from algae in the Nigerian context using an analytical-based strength, weaknesses, opportunities, and threats (SWOT) approach.

### Nomenclature

A	Metric-Tonnes
B	Naira

## 2. Methodology

This research is an exploratory type of research because there are paucity of information on algae biofuel production in Nigeria (Fig. 1). However, secondary information were considered. This article adopts SWOT analysis as the main approach and also present strategies for development, production, and harvest of algae biofuel which is applicable for Nigeria. It is a well-known acronym that refers to the strengths, weaknesses, opportunities, and threats of an ongoing developmental process or organizational service. It is a strategic analytical tool that can be used to evaluate the rate at which development of an initiated process is taking place with respect to factors (internal and external) which may either aid or retard such a process, thus enhancing decision making. In the context of this paper, the process refers to the development of a platform for algal biofuel production and usage in Nigeria, internal and external factors include; cost of production, population, economics of dependence on petroleum and environmental sustainability amongst others.

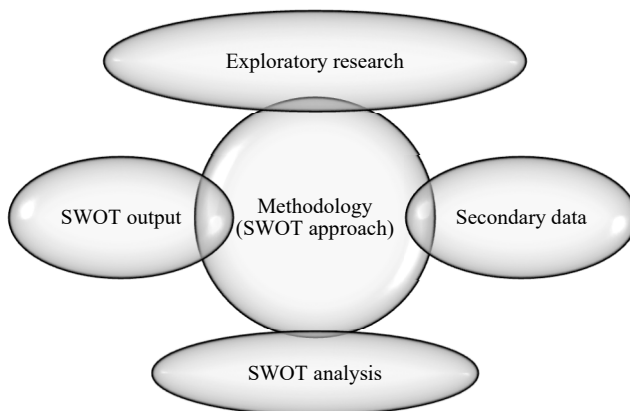


Fig. 1. Research methodology of the study.

Drawing the pros and cons of these factors through SWOT analysis will determine the success of algae development process, since SWOT analysis adopts possible and favourable strategies which are relevant to stakeholders and decision-makers including the prospects and sustainability of the products [3]. SWOT analysis is essential to make an in-sight research of the promotion and thus diffusion of algae-based biofuels in Nigeria, which can further make apparent the merit and demerit aspects of the projects [4–6]. It is interesting to note that the application of SWOT in the production of algae biofuel production in Nigeria will contribute to the qualitative analysis of the process. This would be incorporated into the planning phase and considered for support by decision makers and stakeholders [3]. The components of the tool include the positive and negative, internal and external structures of the strengths, weaknesses, opportunities, and threats for the prospective macro and micro algae biofuel production in Nigeria (Table 1). With SWOT analysis, we intend to analyze possible benefits derivable from development of algal biofuel within the premise of possible setbacks which can hinder the scientific progress of making the developmental process worthwhile. The next section elaborates on the findings and outcomes including discussion.

### 3. Results and Discussions

#### 3.1. SWOT analysis

##### 3.1.1. Strengths

Nigeria has a wide range of prospects for macro and micro algae biofuel (biodiesel and bioethanol) production, which include resources that are available in abundance vis-a-vis water, sunlight, space, different algae species etc. According to Table 1, algae biofuel possesses low to zero CO<sub>2</sub> emission thereby creating prospects for carbon emission trading. This is however different from the fossil source of energy. Carbon neutrality, self-reliance of energy supply at commercial scale, global warming reduction, and upgrading of the low-income status and rural life among other benefits contribute to the effectiveness of the biofuel. The fuel produced from algae has higher Octane Number (CN) and some possess better fuel quality than the fossil fuel [7].

Table 1. SWOT analysis of algae biofuel (biodiesel, bioethanol etc.) production in Nigeria [4, 6, 8, 9, 10].

	Positive	Negative
Internal	Strengths	Weaknesses
	<p>Prospect for carbon emission trading.</p> <p>They are ubiquitous.</p> <p>They generate different kinds of value products (e.g. oxygen), useful for various purposes (oxygen is taken up by humans, hence, it is important for life).</p> <p>They are useful for carbon capture and sequestration.</p> <p>Adaptability of various types of algae to different growing media, locations and aquatic bodies such as freshwater, marine and brackish environment.</p>	<p>The commercial productions are still expensive.</p> <p>Social and environmental suitability issues are still unresolved due to inadequate funding.</p> <p>Unavailability of data.</p> <p>More is still needed on the life cycle assessment (LCA) of the project.</p> <p>Getting desired species characteristics such as lipid and harvest ability.</p> <p>Basic concepts of the biochemical pathways (pre-treatment, conversion and refining techniques for algae biomass) for micro-algae processing are yet to be fully understood.</p> <p>Insufficient and inadequate government policies and framework.</p>
External	Opportunities	Threats
	<p>Provision of alternative source to fossil fuel production.</p> <p>The mixtures of algae biofuel with fossil fuel reduce sulfur content &amp; improve quality.</p> <p>Pollution is minimized if industrial wastes are transferred to algae production medium.</p> <p>Lipid synthesis can induce genetic manipulation to achieve desired algae species.</p>	<p>Economic viability and market acceptance are still uncertain.</p> <p>Atmospheric CO<sub>2</sub> is not highly soluble in water, these reduces lipid or biomass yield from cultivation.</p> <p>pH increases due to conversion to carbonic acid, hence result in ionization.</p> <p>The difficulty of sunlight radiation to penetrate into the depth of large algae bloom.</p> <p>Disposal of biomass residue after processing may pose challenge due to the waste management issues in Nigeria.</p> <p>Economic analysis of WTP and WTA should be considered.</p> <p>Challenges on the social issues of the GMA</p> <p>Competition and discovery of other renewable fuel or energy.</p> <p>Increase and discovery of fossil fuel in some regions.</p>

Macro and microalgae biofuel production are capable of consuming carbon emission as they grow and used for carbon capture and sequestration, which is a strategy in global warming reduction. The macro and microalgae can be cultured in any medium location, and environment including wastewater, sewage plants, freshwater, marine and brackish environments. It does not compete with food; invariably the quality of land and space is not a factor for algae production. The product from algae can generate many valued products that can reduce the biofuel cost. Algae, on one hand, can be utilized for various industrial and medicinal applications [6–8].

### 3.1.2. Weaknesses

Commercial production is not yet stable due to high cost and complexity of the bio-refinery processes involved. Some of the social and environmental suitability issues are still debated and unresolved due to funding and unavailability of data. Various researches on the Life Cycle Assessment (LCA) of algae biofuel are yet to be engaged, there are challenges of getting macro and microalgae species with desired characteristics such as lipid content and harvestability properties. Although, genetically modified algae (GMA) is a possible remedy, it is still facing social acceptability issues [8]. The basic processes (such as cultivation and pre-treatment) for generating biodiesel from micro-algae are not well understood, thus serving as a setback for the entire process. Macro and microalgae recovery from growth media is not easy due to small structural form and the difficulties in cell membrane separation is hard [9], also there are insufficient and inadequate government policies and framework for algae biofuel production [6] (Table 1).

### 3.1.3. Opportunities

Production of biofuel in Nigeria could be an alternative source to fossil fuel consumption/production. Apart from providing small-scale business opportunities, the algae biofuel can generate other useful products. The mixture of biofuel with petroleum fuel will reduce the sulphur content of the resultant fuel and create improved quality of lubrication and low aromatic properties. An environmentally acceptable fuel will be produced as a result. Nigeria has a huge population and the need for a cheap and affordable energy is high, interestingly, algae biofuel production could be a solution to the problem [7]. More bioenergy products can be produced without detrimental effects on the environment. There are prospects for solving technological challenges facing the extensive commercial algae biofuel production in the future. Environmental pollution will be minimized and reduced if waste (toxic and non-toxic) from industry can be reduced by transferring it to algae production media, which will save CO<sub>2</sub> emission cost [11]. Lipid synthesis can be induced by the second metabolism due to different stress on the algae, genetic manipulation is possible to achieve desired traits of the algae species (Table 1) [6, 9].

### 3.1.4. Threats

The threats and uncertainty associated with algae biofuel production are enormous. Economic analysis is a threat, in form of cost and expenditure. Economic viability would be achieved if the capital and operational costs of production are reduced and alternative pathways are chosen. The market acceptability is not certain. They still compete with other biomass materials like bacteria or organic kerosene oil (shale oil which is an unconventional oil) [11]. CO<sub>2</sub> from the atmosphere is not highly soluble in water, this can reduce lipid or biomass yield from cultivation of the algae. The use of the CO<sub>2</sub> by algae could lead to uncontrolled pH rise after the conversion to carbonic acid, hence results in ionization in the algae production medium. There could be the difficulty of sunlight radiation penetrating the depth of large algae bloom.

Left-over (residue) of microalgae biomass should not be disposed carelessly after extraction to avoid pollution, it can also be further processed as high quality protein meal for animal feed. Furthermore they can be used to produce other types of biogases, however, if these opportunities are not explored, they should be controlled of landfilling to prevent leachate migration to groundwater. This may be useful for disposal since algae is a plant and will decompose rapidly when landfilled. Economic analysis should be encompassing e.g. Willingness To Pay (WTP), i.e., the total amount of money an individual (citizen) is willing to give for having algae biofuel and Willingness To Accept (WTA), i.e., the total amount of money an individual (citizen) is willing to receive with the over reliance on petroleum-based energy source. These are issues that should be considered for decision-making process [9]. Future demand is another threat, if the interest and demand for biofuel fall in the future, this will have a negative repercussion on the industry. There are issues on social and market acceptance. If the GMA approach is adopted, stakeholders might be against it and the authority regulations might be a constraint due to competition with other renewable fuels or with other forms of energy, including the increase and discovery of fossil fuel in some regions. These could delay the expected growth of algae biofuel production and thereafter affect its cost [6–8]. Based on the results of the strategic analysis and the possibilities of algae production in Nigeria, implementation model is expected to actualize the proposed motive of algae biofuel production. After considering the possibilities and constraints of producing algae biofuel in Nigeria. The next section discusses the production strategy for development of algae biofuel.

## 3.2. *Strategies for development, production, and harvesting of algae*

For the SWOT analysis to meet the need of this study, we critically examine the processes involved before biofuel is eventually generated from algae. The algal biofuel (biodiesel and bioethanol) development strategies are mainly dependent on cultivation and harvesting cultures, processing and all economics involved till the sustainable biofuel is produced. These factors are faced with sustainability (environment, socio-economic and institutional) challenges. Nevertheless, developing countries like Nigeria can tap into the many ideas available from several types of research on algae as alternative energy source. Subsequent subsections of this paper thus present details on prevailing cultivation techniques that can be adopted for biofuel production as well as harvesting, processing, and economics of the algae. Hence, creating a wide range of options for selection of best practices [6, 12].

### 3.2.1. Cultivation techniques

The methods adopted for cultivation are often a function of size of the algae. Algae is predominant, they can be cultured in aquatic or terrestrial systems, which can be in a closed or open loop system or allowed to float on water surface (Fig. 2) [13]. In the open land system otherwise referred to as ponds, only a few dominant species have the potential of survival, there are often the result of competition and predation among other factors. Many researchers have worked written on the effect of temperature in open land system. Some have argued that this method is flawed by lack of temperature regulation, while others are of the opinion that any temperature could just be satisfactory. In a closed loop setting on land, a tubular photobioreactor system is the most effective option [13, 14].

Some types of Photobioreactors use polyethylene materials though expensive, scalability flaws are continuously being researched upon. Furthermore, transparent materials and polyethylene although eliminate the challenges faced as a result of extreme temperatures and competition for survival. There are problems with cultured algae exhibiting excessive sensitivity to the closed environmental factor which often result in shorter life span [15]. Other modern photobioreactor types include; plate photobioreactor, photobioreactor with a fermentation tank, etc. Algae are most suited to offshore cultivation in areas not frequently used as sea routes or other human activities, as well as in protected water areas not very far from the shore. Rope systems (vertical, horizontal or hybrid) all help seaweed to tap maximum sunlight [16–18]. It has been noticed that ropes often develop faults with time which may result in the loss of biomass through wash-off. However, an alternative to this is the use of rings to compliment the function of ropes. Here, the ropes are arranged at the base for attachment by especially macroalgae (Seaweed). This has been experimented to provide excellent results but is more costly compared to the use of rings only. There are so many on-going researches aimed at arriving at the very best algae cultivation method which caters for the various problems that may arise from excessive temperature exchange, biomass wash-off and other cultivation related challenges [13, 16–20].



Fig. 2. Production phases of biofuel from Algae. Modified from [21].

### 3.2.2. Harvesting cultured algae

Harvesting continues to be a major challenge militating against optimum gains in algae biofuel production. Although the goal of the algae biofuel production is to produce a high volume of biofuel from a relatively small pond surface or photobioreactor area, energy input is usually high resulting in high cost accrued from this phase [22]. Harvesting procedure takes different forms depending on the cultured species, the prevailing conditions under which it has been cultivated as well as the densely packed cells. The subsequent purpose of harvested biomass also influences the choice of harvesting method since different processes require a unique volume of water [23].

Harvesting basically constitutes the separation of microalgae biomass from water. Common methods adopted for harvesting cultivated algae include; sedimentation, flotation, centrifugation and filtration [23]. However, research has it that a specialized kind of flocculation; bio-flocculation is the most cost-effective single method around [24]. Little or no flocculation chemicals are used; this has therefore increased the awareness for further studies on the method. Sedimentation is flawed as it is characterized by poor settling rate due to tiny microalgae sizes [15]. While centrifugation uses up excessive energy though offers a reasonable rate of harvest, filtering suffers from continuous clogging issues which results in quite low harvesting efficiency [15, 24]. Filtration succeeds more with sizes of microalgae bigger than 70  $\mu\text{m}$  [22]. However, microfiltration and ultrafiltration techniques can be used for sizes less than this. This also poses a new problem of regular changing of membrane material as well as regular pumping, thus leading to increased energy use and high cost of maintenance [15]. In general, [25] opined that a combination of several harvesting methods yield better results.

### 3.2.3. The way forward

The incessant increment in the prices of petroleum products in Nigeria is rather worrisome. Economic activities which should have an overall positive effect on the growth of the country's Gross Domestic Product (GDP), are being slowed down due to scarcity as well as hike in pump prices of petroleum products when available. As such, the search for alternative energy sources should no longer remain a mere paper research. Harnessing resources for speedy implementation of the processes for alternative energy sources such as biodiesel production from algae, if given the needed impetus, will go a long way in boosting economic returns. Automotive Gas Oil (AGO) (diesel) currently sells at ₦200 (\$0.62) per liter in Nigeria, making it one of the most expensive around the world [26]; carbon emission has increased tremendously from 0.075 Metric-Tonnes in 1960 to 0.537 Metric-Tonnes [27]. With this prevailing situation, it is important to look inwards at the available structures on which biodiesel production from micro-algae will thrive. Nigeria possesses many different kinds of aquatic environment (freshwater, brackish and marine environment) suitable for algae cultivation. This is one potential advantage. In terms of manpower, there is a rich population of renewable energy experts focused on renewable energy solutions hence, constant training of such individuals will enhance the development of the process thereby leading to job creation for the growing population. At commencement phase, research should focus on the best species suitable for algae cultivation in Nigeria. This species should be chosen on the basis of cost effectiveness to avoid discouragement of the outcome when the expected results are not initially met. Bio-flocculation method of harvesting may be adopted for the initial phase of the project, being the best single method available [24]. Moreso, a combination of two or more harvesting methods although very good [25] may accrue more cost, making the process expensive. Besides creation of jobs, other long-term benefits that are derivable from the production of biofuel from algae includes; reduction in transportation fares, increase in the number of manufacturing firms which depend on biofuel for power generation and a healthier environment. The SWOT analysis (Table 1) further discusses other potential benefits. In terms of the risk associated with the process, expected results may not be achieved immediately. This means that a lot of work has to be done to achieve the opportunities (Table 1) derivable from the biofuel production from algae, this could, however, serve as a form of discouragement to stakeholders who may be looking forward to quick solutions to the issue of over-reliance on petroleum-based energy sources. Algae biofuel residue can be used for animal feed and as soil replenishment agent which can create social innovation by solving overgrazing or Fulani cattle farmers feuds with local farmers or to alleviate nomadic migration of cattle and herdsmen from north to south of Nigeria which has created a lot of danger and havoc to the peace of communities. A biofuel residue bank project can help to develop cattle ranch in Southern Nigeria.

## 4. Conclusions

The opportunity of algae biofuel as a third generation of bioenergy has the potential to generate abundant sustainable energy which can be an alternative to fossil energy. Production of algal biofuel also serves as a sustainable solution to challenges related to production and use of fossil fuel energy. Nigeria is endowed with various resources which make it a venture that can be invested and improvised to suit the peculiar status of its energy needs. Opportunities are enormous for algae production in Nigeria vis-à-vis food production, energy, and medical use. There are also constraints that affect the production of biofuel from algae. However, some challenges considered can be resolved through collaborative research and creation of best practices and methods of massive algal species cultivation. Adequate economic and technological support can assist in making Nigeria an excellent beneficiary of clean renewable, climate friendly algae bioenergy program.

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