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# A Systematic Review of Economic and Government Policy Issues in the Production of Biofuels by Microalgae

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**Abstract**
Research has shown that the initial supply and environmental benefits of conventional biofuels may have been exaggerated, even if they have strong legal support. Due to negative externalities related to the distribution of resources and food, the long-term viability of switching to biofuels is being called into question more and more. This study highlights the need for additional research into a third-generation feedstock based on algae while examining the advantages and disadvantages of traditional biofuels. Given the many benefits of this technology, the study offers recommendations on how a regulatory framework may support microalgae as a source of biofuels.

**Keywords**: Microalgae, biofuel, Government policy issues, Economic, Production

## Introduction

One major issue is the safety of the fossil fuel supply, particularly in the context of transportation. The vast majority of automobiles, both private and commercial, are propelled by liquid fuel combustion engines. Therefore, implementing alternate modes of transportation, like electric cars, increases the expenses of technology and money, particularly for customers. Therefore, replacing a large portion of personal and commercial transportation with electric vehicles may not be financially feasible. Biofuels, or liquid fuels made from organic plant matter, are more similar choices (Mata et al., 2010). Biofuels can more readily replace gasoline and diesel with little engine modification due to their comparable combustion characteristics. Biofuels can be broadly classified into two categories: biodiesel, which is derived from lipids (fats), and biopetrol, also known as ethanol, which is derived from carbohydrates (sugars). These biofuels are thought to provide further socioeconomic advantages in addition to lowering net carbon emissions and originating from a renewable source (Hall & Scrase, 1998). In many nations, biofuels have become more and more popular, especially with official backing. These include ethanol produced from sugarcane in Brazil (Ajanovic, 2011), biodiesel produced from soybeans and maize (biopetrol) in the United States (Hill et al., 2006), and biodiesel produced from rapeseed in Europe (Escobar et al., 2009).

## Categorisation of Biofuels

Biofuels are often classified according to the kind of feedstock they use. Biofuels derived from terrestrial feedstock are referred to as conventional biofuels. They are further separated into biofuels of the first and second generations. The most popular food-based feedstock for first-generation biofuels is ethanol made from maize or sugarcane molasses in addition to wheat starch (Puri et al., 2012). Next in line are biodiesels made from soybeans, rapeseed/canola, and palm oil (O'Connell et al., 2007); the latter is being utilised more and more in China, India, and Southeast Asia

(Gasparatos et al., 2012). Energy-producing second-generation biofuels are made from non-edible lignocellulosic crops (Lunnan, 1997). Firewood, perennial grass, forest and plantation wastes for biopetrol (O'Connell et al., 2007), sugarcane crop leftovers (bagasse) (Kosinkova et al., 2015), and jatropha for biodiesel (Carriquiry et al., 2011) comprise the majority of these non-edible plant biomass sources.

**Problems with traditional biofuels**

Many traditional biofuels have uncompetitive retail prices because of their higher production costs (Hill et al., 2006). An excellent illustration of how government support in the form of tax credit programs and blending regulations has allowed some types of sugarcane ethanol to enter the consumer gasoline market is Brazil (Goldemberg & Just, 2009).

**Energy Return**

It has been shown that the energy return from conventional biofuels is much less promising than expected when compared to the Energy Return on Investment (EROI) function. The difference between the production energy and the usable energy produced by the finished biofuel is computed by the EROI. First- and second-generation biofuels, which often need energy-intensive manufacture, have been shown to have a far lower EROI than gasoline and diesel. The EROI was particularly low for corn ethanol, a major biofuel in the United States. Second-generation variants are the more promising option for ethanol from both an EROI view and an energy return per area of cropland (Puri et al., 2012) because they concentrate on fast-growing perennial crops that can produce up to ten times more energy than other bioenergy outputs (Berndes et al., 2003). Additionally, they use a little less energy (Hill et al., 2006). It was discovered that most second-generation feedstocks have EROIs comparable to fossil fuels.

**Benefits of net carbon emission**s

In comparison to fossil fuels, a number of studies have demonstrated a 90% reduction in greenhouse gas (GHG) emissions (Menichetti & Otto, 2009). The GHG reductions from production and consumption may be counterbalanced by the loss of standing carbon sinks caused by the conversion of land for the production of biofuel feedstock, particularly from deforestation (Lapola et al., 2010; Vang et al., 2012). The "payback" period for achieving net emissions reductions is long, since land clearance is thought to release more carbon (17–420 times). Due to the loss of forests and rainforests, biodiesels produced from palm oil in Southeast Asia (Berndes et al., 2003) and Jatropha in Mozambique (Vang et al., 2012) have been determined to have the longest relative carbon debt recovery timelines. Indirect GHG costs have also been influenced by land changes brought about by the conversion of existing agricultural land (Lapola et al., 2010).

**Self-reliance in energy production**

A potential benefit of biofuels is the potential for a certain degree of energy independence. Examples of this include increased fuel security and reduced reliance on imports. Both Brazilian national policy and smaller community-level initiatives in different parts of Africa have accomplished this (PAC, 2009), the latter of which offers an example of the additional advantages of self-sustaining fuel sources in isolated, landlocked locations (Hill et al., 2006). The fuel's accessibility benefits growing cities' local-level trade, employment, productivity, and commerce (PAC, 2009). According to Hill et al. (2006), the related job opportunities include both lower-skilled jobs like those in agriculture and higher-skilled jobs like those in research and development (like engine innovations in Brazil). However, it has been demonstrated that policies and incentives for the blending of biofuels have the potential to produce a "green paradox" that both encourages the production of biofuels and raises demand for fossil fuels (Grafton et al., 2010). The US's ethanol tax credit schemes were ineffective when combined with fuel restrictions, according to a study by de Gorter & Just (de Gorter & Just, 2020). This could lead to a greater reliance on imports of fossil fuels.

**Implications for agricultural resources and food costs**

The increasing demand for conventional biofuel may lead to problems with agricultural crop and resource allocation opportunity costs (SVRK & Elder, 2009). Competition for these inputs in food production is the cause of this. Quantitative assessments show that biofuels affect food prices more than energy prices (Berndes et al., 2003), especially when first-generation feedstocks are utilised. Growing demand for first-generation biofuel is expected to raise agricultural and livestock prices by 5% to 15%, and ethanol requirements have been held responsible for up to 40% of maize price increases in the USA (Fischer et al., 2009). Food becomes less accessible and affordable as a result, which exacerbates the world's hunger crisis. Conflicting evidence, however, suggests that other factors may be


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to blame for increases in food prices. Food prices wouldn't be immediately impacted by the slow adoption of biofuels since there wouldn't be enough competition for agricultural resources (Groth & Bentzen, 2013). Numerous reasons, such as population growth, erratic weather patterns, growing energy prices (Bastianin et al., 2013), and—most significantly—speculation about investments (Ghosh, 2010), have been proposed to have a greater impact on rising food prices. One possible concern with the increasing demand for biofuels is the effect on water and land resources (Kosinkova et al., 2015). Conventional biofuels are not sustainable, as evidenced by the world's growing population and finite amount of arable land (Chisti, 2008). The demand for arable land would rise by 44% by 2020 (Menichetti & Otto, 2009), but this would only cover a small percentage of petroleum usage (Goldemberg, 2007). Additionally, it has been noted in the past that the pressure farmers experience to switch to food crops has an impact on US food prices (Ash & Dohlman, 2007). This need for arable land has also resulted in enormous deforestation for palm oil in Southeast Asia (O'Connell et al., 2010) and sugarcane and soybeans in Brazil (Lapola et al., 2010), which has reduced carbon stocks and ecosystem biodiversity (Vang et al., 2012). Furthermore, it has been discovered that second-generation feedstocks cause land problems for food and fodder, especially in rural regions with low incomes (Escobar et al., 2009). The water-intensive aspect of the biofuel feedstock development process has also been linked to trade-off issues with water distribution. In both Brazil (Menichetti & Otto, 2009) and the United States (Pimentel, 2003), it has been shown that estimates of water demand are so understated that they surpass the rates of natural replenishment from aquifers.

**Algae-based biofuels**

Numerous issues are resolved by the development of third-generation biofuels made from algae (Pimentel, 2003), including the impact of crop and resource allocation on food production (Kosinkova et al., 2015). The past ten years have seen a significant increase in interest in algae's potential as a feedstock for biofuel. It has been shown that seaweed and other marine macroalgae contain sugars that can be converted into bioethanol (Carriquiry et al., 2011). Additionally, the viability of producing biodiesel from macroalgae has been suggested (Goldemberg & Guarabassi, 2009). However, microalgae's ability to grow and accumulate lipids suggests that it has increasing potential for producing biodiesel (Kosinkova et al., 2015). With bioethanol accounting for only 64 per cent of the energy content of biodiesel (PAC, 2009), the latter is more likely to become a sustainable and feasible alternative to fossil fuels, which necessitates further research and attention for the remainder of this review. According to Sheehan et al. (1998, the high production efficiency of microalgae biofuels will boost fuel security for both current and future fuel demands, which supports government investment in the US (Scott & Bryner, 2006). A lot of microalgae are cultivated in nutrient-and $CO_2$-rich growth media in artificially controlled environments, including open raceway ponds or closed tubes called photobioreactors (PBRs) (Puri et al., 2012). The biomass from the cultivated algae is then treated like other lipid-based feedstock to produce biodiesel. It is also possible to make ethanol by fermenting the carbohydrates in cells. In the process of producing microalgae biodiesel, the following processes can show the sustainability and viability of microalgae: cultivation (Stephenson et al., 2010), harvesting (Batten et al., 2013), lipid extraction, and conversion to biodiesel. Research by Stephenson et al. (2010) and Brentner et al. (2011) shows several paths at each stage of the process that could affect the amount of biomass/biodiesel produced and the ultimate cost per unit.

**Financial feasibility**

According to Davis et al. (2011), microalgae biofuels are not yet competitive with fossil fuels, similar to most first and second-generation biofuels, which primarily depend on subsidies to be commercially viable and competitive. However, they may be viable as aviation fuels due to their compact energy properties, and airline companies have expressed interest in them throughout the pilot and research stages (APAC, 2013). Culture and processing should also be enhanced; the latter would focus on reducing capital costs by using less costly equipment designed specifically for microalgae processing (Davis et al., 2011). Cost savings could potentially be substantial if $CO_2$, fertiliser, and water are purchased at a discount or recycled after production (Stephenson et al., 2010). In the USA (Pate et al., 2011, O.F. Omamuyovwe et al., 2025) and other places, the primary barriers to the practical production of microalgae are thought to be adequate supply of $CO_2$, fertilisers, and water in particular. Additional by-products with commercial value could be produced by microalgae. About 30% of biomass gathered is made up of lipids; the remaining components include energy-related products like bio-gas (Pate et al., 2011), ethanol (Slade & Bauen, 2013), fuel-grade hydrogen, or even animal feed (Alam et al., 2012). According to Alam et al. (2012), the proper commercial application of these by-products may also be necessary for the long-term economic feasibility of microalgae as a biofuel.


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**Energy requirements**

According to Davis et al. (2011), microalgae require a lot more energy from the various pieces of equipment and capital inputs because of their quicker cultivation cycles than terrestrial feedstock. According to Stephenson et al. (2010), the poor relative net energy returns make it unsustainable and even uncompetitive. The high energy requirement of microalgae biodiesel may result in a net energy loss or, at most, a marginal gain given the technology now in use (Sheehan et al., 1998). Generally speaking, the former is found to have a more efficient energy ratio than PBRs. By assuming higher values for open-ponds, Sander and Murthy (Brentner et al., 2011) made an exception. The energy ratio increased by up to ten times during the harvesting and drying stages, indicating that open-pond farming also used less energy (Slade & Bauen, 2013). However, the highly regulated circumstances associated with PBRs have resulted in a reduced energy ratio and significantly higher cultivation energy costs. Energy expenditures were primarily related to construction and cultural circulation (Stephenson et al., 2010). As long as fossil fuels provide the majority of the energy utilised in the manufacturing process, biomass production has positive net carbon emissions, particularly for PBRs (Slade & Bauen, 2013). Improvements in algae strain and production technology could increase the possibility of positive net energy, but the high energy input requirements of PBRs have raised concerns about their feasibility given current technologies (Hulatt & Thomas, 2011).

**Advantages of microalgae for net carbon**

Microalgae convert carbon dioxide into biomass through photosynthesis, just like in terrestrial agriculture (Onianwah & Stanley, 2018). Even though it has been shown that microalgae convert more efficiently than other terrestrial feedstocks in terms of area farmed, conversion is still quite expensive (Hulatt & Thomas, 2011). Ono & Cuello (2006) determined that the net unit cost of carbon sequestration using microalgae production with a solar collector was $100 per ton of carbon dioxide. They underlined the importance of producing financially viable outcomes in order to lower net costs. Due to the regulated production environment and associated equipment that utilises electricity from fossil fuels, commercial microalgae production is also anticipated to produce positive net carbon emissions in contrast to its terrestrial counterparts (Hulatt & Thomas, 2011). Furthermore, as with traditional biofuels, the benefits of GHG sequestration attained in the upstream cultivation may be outweighed by the use of fossil fuels in the downstream processing of the biomass (Brennan & Owende, 2010). Recycling power plant exhaust gas during the cropping season has also been proposed as a way to reduce carbon emissions overall. By sparging the flue gas into the microalgae's growth medium as a carbon dioxide input, the advantages of more effective carbon bio-fixation can be introduced without compromising biomass development (Negoro, 1993). A few experimental and application studies on the efficiency of a microalgae species to use a high-concentration flue gas (sometimes simulated) supply demonstrated the feasibility and efficacy of this application beyond terrestrial agriculture (Wang et al., 2008). Despite this sequestration advantage, the overall CO2 benefit of microalgae is dependent on the emissions from subsequently using the biomass as fuel. Assuming that the assimilated CO2 is released after combustion, the net emissions schedule will be determined by the energy intensity of the biomass processing, which may involve the usage of fossil fuels (Mata et al., 2010).

**Nitrogen benefits**

Microalgae culture in the growth medium requires inorganic nutrients, especially nitrogen (Mata et al., 2010). This presents an opportunity to use microalgae to remove high concentrations of nitrate compounds from wastewater runoff, which are a major cause of eutrophication (Onianwah & Stanley, 2018). In addition to having a high nitrogen sequestration effectiveness (Woertz et al., 2009), microalgae farming is a cost-effective and chemical-free wastewater treatment technology when grown under the proper conditions. Batten et al. (2013) showed that, with wastewater treatment as the primary goal, microalgae biodiesel could be created for less than $1 per litre, assuming a waste carbon dioxide supply, while the algae ponds recycled nutrients and water. However, a wastewater-based growing medium may limit the potential for biofuel production because the production of lipids is inversely connected with nitrogen saturation in the growth conditions (Clarens et al., 2010).

**Advantages of competition for food and resources**


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Using microalgae as a feedstock can lessen the impact of first- and second-generation biofuels on food security if legislative support for transport biofuels continues to grow. Despite the possibility of supplementing human diets with some strains of microalgae (Mata et al., 2010), they are not currently a common dietary option. Microalgae biomass would therefore not directly affect the food supply, in contrast to second-generation feedstocks (Pimentel, 2003). Because microalgae grow well in wastewater, their production also lessens competition for water (Woertz et al., 2009). However, as was already indicated, the high nutrient saturation may make its production for pertinent outputs less practicable (Clarens et al., 2010). Furthermore, by concentrating on shifting feedstock cultivation away from agricultural land, both macro and microalgae can reduce the opportunity costs associated with the restricted land resources devoted to energy crops (Vang et al., 2012). Their need for arable land, whether marginal or otherwise, is lower than that of terrestrial biomass since microalgae may be cultivated artificially (Chisti, 2007). (Clarens et al., 2010). Macroalgae can be cultivated in ponds and other aquatic habitats. Overall, food security may not be significantly affected by cultivating algae for biofuels, and as was previously indicated, using this feedstock could reduce the impact of traditional feedstocks on food and agricultural resources. Large-scale forest and woodland conversion is also no longer necessary due to the decreased demand for agricultural land. This lessens the possible negative effects that conventional feedstocks have had on biodiversity loss and carbon sinks (Mata et al., 2010).

**Socio-economic Benefits**

The expansion of the microalgae biofuel industry has a number of socioeconomic benefits that could produce a socially sustainable outcome. Among the numerous aspects of social sustainability are the potential to improve living standards and more evenly distribute economic advantages across society, including urban and regional communities (Khanna et al., 2009). The most obvious of these benefits is the rise of an energy sector that can support economic expansion and job creation in rural areas while simultaneously meeting longer-term fuel demands. This stands in contrast to existing fossil fuel-based industries that depend on limited resources and traditional biofuels that are limited by resource constraints (Sheehan, 2009). Like conventional biofuels, microalgae biofuel production can contribute to the development of a sustainable, long-term sector that fosters the expansion of related occupations for people of all skill levels (Hill et al., 2006). Additionally, microalgae-based businesses offer non-metropolitan and regional areas the chance to thrive economically. Investments in bioenergy projects by the public and private sectors are frequently made to create jobs and revenue for nearby companies and communities, especially in rural areas (Domac et al., 2005). According to some, conventional biofuels have a lot of promise for the long-term expansion of farming businesses and financial gains (Khanna et al., 2009). However, given its impacts on society as a whole, including resource constraints and increased food prices, it would often be challenging to justify policy support for traditional biofuel production. However, growing microalgae alongside already-existing ancillary industries may be better. The combination of bio-fixation of waste effluents and the generation of useful co-products (such as feed and fertiliser) may prove advantageous economically for the local community in addition to boosting the revenues of seasonal enterprises (Alam et al., 2012).

**Discussion**

Further developments in biomass-based fuels are necessary, given the current reliance on liquid fuels for transportation. Until now, land-based feedstock and related production practices have received a lot of attention. When such systems first seemed to offer promise of external benefits, government funding was provided to represent the alleged non-market profits (as in the US and Brazil, for example) (Chisti, 2007). However, research has indicated that these benefits may be overstated. For instance, there is growing evidence that the loss of important carbon sinks due to the removal of land for grain cultivation, especially in tropical regions, may raise GHG levels overall. The impact on food prices and availability, as well as the subsequent loss of ecosystem services due to land conversion and clearance, casts doubt on the overall social and economic advantages of conventional biofuels. The welfare effects of these changes are complicated. The possibility of increased jobs and income from the production of crop-based biofuel, as well as improved access to gasoline, especially in lower-income areas, could offset higher food prices. Similarly, rising food prices may result in higher profits for farmers, many of whom are also often in low-income groups. Since the benefits of feedstock farming might not be evenly distributed throughout society, the empirical topic of how gains are distributed between net producers and consumers of agricultural commodities must be addressed in order to understand the overall effects on human wellbeing (Ewing & Msangi, 2009). There is a new potential for biofuel from algae, particularly microalgae, which appear to have fewer adverse externalities. Although the technology


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for its production and processing is still in its infancy, microalgae biodiesel, like most biomass-based biofuels, is still more costly than fossil fuels (Scott & Bryner, 2006). The biomass might be used to create a wide range of products, which would increase the financial viability and technical advancement potential. To date, however, no evaluation of the output distribution of possible biofuel production has been conducted to assess the feasibility of cultivating microalgae for biofuels. The high material and financial expenses associated with processing and growing microalgae are another disadvantage. In addition to the construction and maintenance of the artificial habitats, the facility requires substantial amounts of water, power, and related nutrients in order to produce enough biomass (Clarens et al., 2010). The high energy requirements imply a reliance on fossil fuel energy, at least in the short to medium term, to support the numerous downstream processes, even though waste materials may be recycled as production inputs (Yang et al., 2011) (Negoro, 1993). Notwithstanding these problems, the favourable externalities of microalgae biofuels point to possible societal advantages. Algal-based solutions not only benefit the environment but also tackle resource competitiveness problems, which can impact biodiversity and food costs. Additionally, by creating jobs and revenue, these technologies can support social sustainability, especially for local communities that rely on seasonal businesses. The development of first- and second-generation biofuels has been greatly facilitated by a number of legislative efforts. Indirect measures that protect domestic biofuel producers from lower-priced foreign suppliers include trade restrictions and biofuel blending laws (OECD, 2008), while direct supportive policies include tax cuts, lower gasoline prices (de' Gorter & Just, 2009), and infrastructure and production subsidies.US$25 billion is expected to be spent in 2017 on these initiatives, up from an anticipated US$11 billion in 2006 (OECD, 2008). By implementing relevant regulatory measures that reflect the economically efficient price, its viability as a longer-term and sustainable alternative to fossil fuels can be increased (Lee, 2011). For instance, the comparatively rapid growth in terrestrial feedstock in Brazil indicates that farmers and consumers are open to the incentives provided by these initiatives. Although microalgae production is also governed by these rules, the higher initial costs and related hazards act as an additional disincentive to investment in the sector compared to the less costly agricultural-based production. It will likely be challenging to develop a policy mix that provides appropriate incentives for third-generation biofuels while departing from conventional approaches and containing the risks involved, given the technological developments required to sustain these incentives and the fuel's practicality. However, given the potential of microalgae as a feedstock for biofuel, accepting these challenges would seem to be based more on long-term optimism than on idealistic assumptions.

## Conclusion

This study summarised the economic issues related to the first, second, and third generations of plant-based biofuels. The primary disadvantages of first- and second-generation biofuels are outlined in this research, particularly in view of the fuel vs. food debate. Microalgae have been shown to decrease many of the disadvantages of their ancestors; nonetheless, they still have substantial limits, such as high production and energy costs. Policy intervention was found to have a considerable impact on the development and use of conventional biofuels. Thus, with financially sound government support, the development of microalgae biofuels may be encouraged by the long-term demand for a liquid fuel substitute that does not increase societal socioeconomic and environmental costs.

Suggestion

Research should focus on assessing the environmental benefits and challenges of microalgae-based biofuel production, including water usage, land use, and greenhouse gas emissions.

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