EVALUATING SUCCESS OF ENERGY FROM ALGAL BIOMASS

by

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ABSTRACT

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Key words: microalgae, sustainability, environment friendliness, cost-effectiveness, fossil fuels

This thesis explores the effectiveness of algal biomass as a possible alternative to fossil fuels. The thesis examines the cost-effectiveness, sustainability and environmental friendliness factors of algal biomass and checks if algal biomass is a viable alternative that can bring down the disadvantages caused by fossil fuels in the energy sector. The research was conducted by reviewing existing studies on the subject. Algal biomass was found to be better than fossil fuels in terms of sustainability and environmental friendliness factors. With improving technology, the cost-effectiveness could also be improved. Thus, indicating that Algal biomass could be considered a great alternative to fossil fuels.

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ACKNOWLEDGEMENTS

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INTRODUCTION

Life today is at a point where energy is the main force required for society to function. Humans have travelled a long way from just sun energy to fossil fuels. The use of fossil fuels for energy is at its peak today, and the main disadvantage is the emissions from the processing of fossil fuels leading to pollution. Large amounts of carbon are being emitted into the atmosphere, affecting the total balance of nature.

Global warming remains the primary problem caused by carbon emissions from fossil fuels. It leads to climate change and many other issues associated with climate change. Petroleum use alone accounts for about a third of the global total carbon emissions (Nunez, 2019). Also, the demand for fossil fuels keeps rising as it is a significant source of energy in many countries around the world (Nunez, 2019). Transportation and power production are the two major sectors that use fossil fuels, where the former contributes 21% of carbon emissions into the atmosphere (Kheshgi et al., 2004). With the increasing economic growth of global countries, fossil fuel transportation demand is expected to go up by 2.1% by the end of the year 2030 (Kheshgi et al., 2004). This has already caused environmental problems and will affect the environment more seriously in the coming years if the trend continues. Therefore, it is not an option but a necessity to switch to a new energy source, one with better efficiency, so the environment is not compromised for energy. In this scenario, algal biomass is one of those resources that could be considered a switch. However, more analysis is required to see if it is the right option.

OBJECTIVE

The objective of the thesis is to evaluate the existing scenario of energy from algal biomass and analyze if it is a possible alternative for fossil fuels in terms of economic and environmental factors.

HYPOTHESIS

Hypothesis: Algal biomass could be a feasible substitute for fossil fuels in terms of economic viability and environmental friendliness.

LITERATURE REVIEW

Energy is among the basic requirements needed for civilization; therefore, its supply must be abundant and secure. Electrical energy is commonly used, and the most important source of energy with greenhouse gas emissions commonly used, accounting for 60% of energy consumption (Poudyal et al., 2019). Also, fuel-based power generation and a drastic increase in population and human activities globally have contributed to a significant challenge associated with gas emissions. Kumar et al. (2019) explained that conventional fuel-based energy generation had posed significant threats due to carbon emissions, above the alarming levels. This gives rise to environmental challenges to humanity and climate change. Biomass is commonly used for energy generation. Kumar et al. (2019) discussed that biomass is a non-conventional fuel-based energy source or renewable energy source where power generation is from plants. The biomass from plants uses solar energy to grow and develop, and after combustion, other plants convert the surrounding carbon dioxide released during combustion into sugars during photosynthesis. The energy procured from this source is exploited and makes biomass an essential and sustainable power source. Algal biomass is one of the current energy sources used due to increasing public interest in its sustainability and reduced environmental impacts. Konur (2021) pointed out that crude oils have been named the major fuel and energy sources, however, public concerns regarding the adverse effects on the environment, price fluctuations, and sustainability of crude oils have resulted in a shift from crude oils to bio-oils as alternatives. Despite that petrodiesel is still widely used, and biodiesel fuels are increasingly being used in the power and transport sectors (Konur, 2021). This has resulted in the public interest in developing algal biodiesel fuels as alternatives to crude oils and crude oil-based petrodiesel fuels (Konur, 2021). This

chapter thus seeks to address the use of algal biomass. The chapter discusses algal biomass for energy production as an alternative to the current energy sources. This chapter is organized by sub-themed sections of an overview of algal biomass, energy production from algal biomass, and economic, environmental, and efficiency of algal biomass compared with other sources of energy.

OVERVIEW OF ALGAL BIOMASS

Algae are one of the most studied sources for energy production currently. They are acknowledged as the primary biomass source for bioenergy production (Choudhary et al., 2020). Algae are simple aquatic microscopic organisms that play a crucial role in converting water, sunlight, and carbon dioxide into sugar or starch, further converted to algal biomass through photosynthesis (Aravind et al., 2020). They serve as potential sources for producing various biofuels, including bio-oil, biomethane, biodiesel, bioethanol, and biohydrogen (Choudhary et al., 2020). For energy production, microalga biomass is converted into fuel through chemical, biochemical, or thermochemical routes based on the availability and possibility of using bio-products (Choudhary et al., 2020). While using algae as the primary source to produce energy has been considered for some time, the use of lipids in the algae as the primary source of producing liquid fuels has been seriously considered as an alternative energy source more recently. This is because of the availability of the algae. It is well established that algal biomass for energy production is well-thought-of because algal growth is everywhere, including open ponds and oceans (Aravind et al., 2020). The algae from these water sources are used for pyrolysis during energy production. During this process algae like *Rhodophyceae, Chlorophyceae* and *Phaeophyceae* are used. Also, green algae are used to produce high amounts of bio-oil (Aravind et al., 2020). With the use of such algae products,

significant amounts of bio-oils are produced. Research by Araújo et al. (2021) showed that microalgae from ponds and oceans are mainly used in energy production because of significant amounts of oil they produce. These products contribute to about 70% of oils during energy production. Similarly, Bošnjaković and Sinaga (2020) showed a large-scale production of algal biodiesel from algae species, including *chizochytrium, Nitzschia*, and *Botyococcus braunii* species. The researchers showed that more than 50% of algal biodiesel are produced from these species that yields about 77 g/m2/day and an estimated 280,000 kg/ha/year of biomass (Bošnjaković & Sinaga, 2020). Therefore, this has made using algal biomass as a potential source of biofuel more viable (Aravind et al., 2020).

ENERGY PRODUCTION FROM ALGAL BIOMASS

The concept to use natural resources from living organisms as biofuel feedstock existed previously, and currently, it has been considered the most appropriate alternatives to other sources of energy. Sim et al. (2021) explained that the decision to use algal biomass as an alternative energy source to other commonly used sources, such as lignocellulose, is attributed to the higher fixation rate of carbon dioxide algal biomass displays. This attracts attention as the potential substrate for biofuel production. Similarly, the existing body of knowledge demonstrates that algal biomass is currently the preferred source of energy production because of the high content of carbohydrates and its abundance (Sivaramakrishnan & Incharoensakdi, 2018). Previous studies demonstrated that algal biomass is a suitable substrate for biofuel production compared to other energy sources because it is highly likely to be used as a feedstock for continuous production of biohydrogen (Anburajan et al., 2019; Kumar et al., 2018). Energy production from algal biomass occurs through biochemical and thermochemical

conversion routes. According to Aravind et al. (2020), algal biomass is the preferred alternative energy source to produce biodiesel from biochemical conversion through conversion methods of transesterification and anaerobic digestion. These two methods are mostly preferred and are used for energy production, mainly for the production of algal biodiesel because of the availability of algae products (Aravind et al., 2020).

In comparison to other energy sources like solar, algal biomass does not require the use of oxygen. For instance, in anaerobic digestion, the biomass is broken down into small and simple molecules to yield essential bio-products without oxygen. Upon digestion, algal species release methane with reduced thermal and electrical losses (Aravind et al., 2020). Regarding transesterification, algal biomass is the upcoming source of biodiesel production, where algal bio-oil is used for energy production through liquefaction and pyrolysis processes. When compared to other energy sources, this transesterification is economically feasible for energy production on a commercial scale (Aravind et al., 2020). During the transesterification process, the glycerides from algae are combined with the alkyl alcohol that have low molecular mass (Pourkarimi et al., 2019). This combination results in the production of fatty acid methyl esters and glycerol, which undergo pyrolysis or liquefaction to produce biodiesel from the algal bio-oils (Pourkarimi et al. 2019).

ECONOMIC, ENVIRONMENTAL, AND EFFICIENCY FACTORS

Following the growing economic activities worldwide, especially in the emerging markets, rising oil prices have enabled major consumers to focus on the use of green biofuel because it is cost-effective. Based on the economic factors, algal biomass is cheaper than, and provides a renewable fuel source other energy sources like fossil fuels are unable to being they are not renewable. Since microalgae are grown

everywhere, including marginal farmland using brackish water and saltwater, algal biomass, the cost of land and water supply is lower, which helps minimize competition between the two (Yadala et al., 2020). Further, algal biomass is economically sustainable compared to other energy sources because of the available nutrients needed for energy production. Research by Lian et al. (2018) demonstrated that algae mainly require inorganic sources of phosphate and nitrogen, carbon dioxide for growth, and cofactor micronutrients. Since fertilizers account for the primary percentage of algal cultivation costs, the nutrients can be recycled, making the large-scale production of algal biomass and energy production more economically viable (Bošnjaković and Sinaga, 2020). Bošnjaković and Sinaga (2020) compared to the cost of algal cultivation for energy production with the price of crude oil showing an increased price for crude oil and biodiesel production compared to algae biomass, with the production cost ranging from $0.43 to $24.60 (Bošnjaković & Sinaga, 2020). Also, the production cost of biofuels from algal biomass is related to the supply cost of biomass. It is well documented that with water and land availability, biofuel production costs are lower than those of other sources (Bošnjaković & Sinaga, 2020).

Algal biomass is environmentally friendly compared to other energy sources in terms of greenhouse gas emissions and land and water use (Ullah et al., 2014). Given that the global oil production is at a peak and the increasing carbon emissions into the environment, causing increased global warming and climate change, it is essential to give more attention to environment-friendly renewable energy resources (Ullah et al., 2014). Following global economic growth and the demand for renewable energy, bioenergy is recognized as an essential component for future energy requirements. Substituting fossil fuels with biofuels is an effective strategy for energy production to

meet global energy demands and reduce carbon emissions from fossil fuels (Ullah et al., 2014). Research by Bošnjaković & Sinaga (2020) showed that algal biomass for biofuel production complies with the international regulations by significantly minimizing greenhouse gas emissions. Based on the life cycle analysis conducted for biofuel production with algal biomass, research showed relatively low greenhouse gas emissions compared to the emissions from fossil fuels. The reduced greenhouse gas emissions from algal biomass thus make it an appropriate alternative and efficient energy source in the current world of energy production (Bošnjaković & Sinaga, 2020). The algae for biofuel production requires soil for cultivation and does not compete for land where food is grown. As such, algal biomass as the source of energy is economically sustainable, making it more efficient for energy production than other sources (Ge et al., 2018).

According to Rossi et al. (2020), algal biomass is currently the most preferred alternative energy source because microalgae used during energy production can quickly respond to environmental changes. Rossi et al. (2020) also established that given the growing gas emissions to the environment, algal biomass as a substitute for fossil fuels reduces greenhouse gas emissions. Biodiesel produced from algal biomass has reduced carbon emissions to the surrounding atmosphere, making it an alternative energy source for fossil fuels, which account for approximately 25% of greenhouse gas emissions (Rossi et al., 2020). Algal biomass is cost-effective because it requires a low cost of water supply and availability of resources. Regarding environmental factors concerning land water resources, Slade and Bauen (2013) found algal biomass requires a low-cost water supply for efficiency and successful production of biofuels. This is because of water availability from various sources ranging from open ponds to oceans. Thus, algae cultivation needs water with very few competing uses, including seawater. Slade and

Bauen (2013) asserted that algal biomass can use re-circulating water, therefore decreasing the possibility of nutrient losses and water consumption.

METHODOLOGY

The study was based on pre-existing research on algal biomass in recent years. The data used in this thesis is from research relating algal biomass with factors that define cost of production and environmental friendliness. Most of the relevant resources related to biomass production were closely examined to get an in-depth view of the "still-developing" energy source. Most of the information from articles is based around small-scale laboratory experiments and hypothetical situations based on currently available data on algal biomass.

The research papers and articles were obtained online via different article databases. Search for articles was aided by search engines such as Google Scholar, Web of Science, and Microsoft Academic. Search terms were developed to help during the search process. The search terms used were algae, microalgae, energy production, algal biodiesel, algal biomass, energy from algae, the efficiency of algal biomass, algal biomass and sustainability, biochemical conversion of algae and energy production, anaerobic digestion, and transesterification of algae.

RESULTS

The research aimed to evaluate the existing scenario of energy from algal biomass and analyze if it is a possible alternative for fossil fuels in terms of economic and environmental factors. Secondary data were used to address the research aim. Qualitative analysis with the utilization of a thematic method was conducted to determine appropriate themes to achieve the research objective. Based on this thematic analysis, the emergent themes found to suit the research are grouped based on economic and environmental factors. The themes are cost-effectiveness, sustainability, and environmentally friendly resources. This chapter is structured by the identified themes in relation to the research objective.

COST-EFFECTIVENESS

The theme of cost-effectiveness describes the economic impact of algal biomass compared to fossil fuels as the alternative energy source. The theme describes the cost of energy production from biomass compared to other energy sources. Based on the review conducted, existing scientific literature shows that algal biomass is cheaper for energy production than any other source of energy, such as fossil fuels (Bošnjaković & Sinaga, 2020). For example, a study by Slade and Bauen (2013) conducted a cost analysis on the use of algal biomass to produce energy and found that the cost of production is very low due to the availability of raw materials and a lower cost of labour. As such, it was found that the cost of biomass production has reduced from ~9 € kg^{-1} to ~3.8 € kg^{-1} (Slade & Bauen, 2013). Also, Slade and Bauen (2013) found that the cost of biomass production with the use of algae products from pond systems ranges from ~1.6 € kg^{-1} to 1.8 € kg^{-1}. The cost analysis for biomass production is presented in Figure 1.

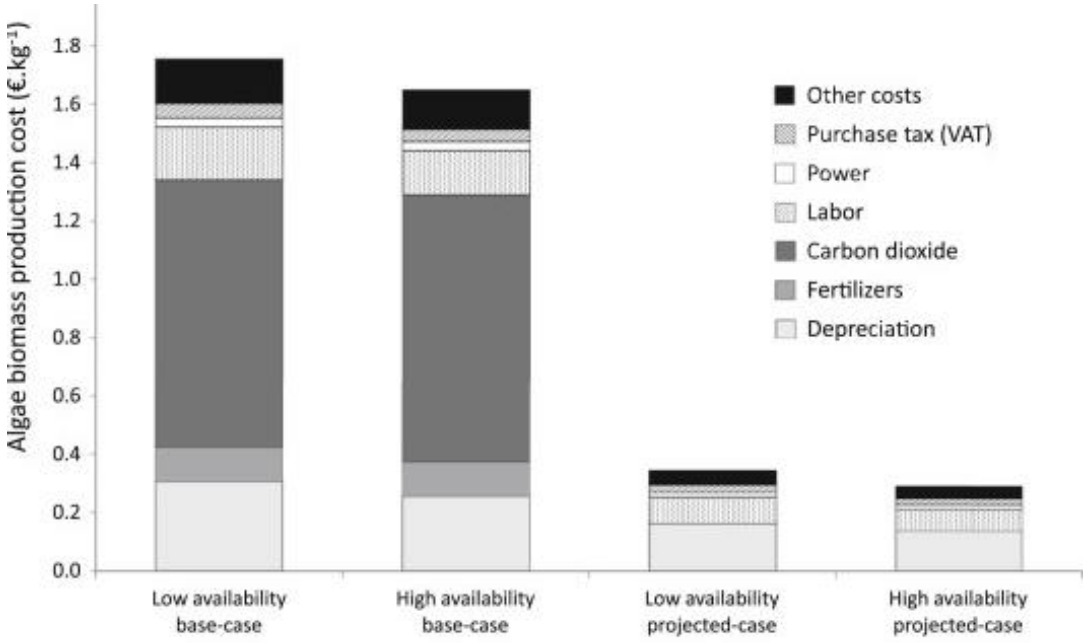

Figure 1. Algal biomass production cost from pond system. Source: Slade and Bauen (2013)

Bošnjaković and Sinaga (2020) established that the use of algal biodiesel for energy production had been acknowledged to lower prices associated with using more economical sources of energy. The reduced cost of algal biomass production has been witnessed with the use of an open-pond farming system, which has been acknowledged as the most economical option for energy production from algae. While using these systems, mass production requires less water consumption with high water speed in the channels, resulting in reduced cost of operations (Davis et al., 2011). Similarly, existing evidence demonstrates that the cost effectiveness of algal biomass production is attributed to the use of biomass feedstocks with faster harvesting processes, reduced carbon dioxide generation and usage, lesser requirement of large lipid content and land for energy production, making algal biomass production more viable commercially (Barnejee et al., 2022). Further, it is well established that with the introduction of algal-

based green fuel technologies, the production cost has reduced because of low energy demand with the high production of commercial scale energy (Khan et al., 2017). Moreover, the by-product from algal biodiesel production has a greater value and is commercially viable, leading to improved production economics (Bošnjaković & Sinaga, 2020). For example, by-products from algae, including halobenzoquinone disinfectants, cosmetics and food supplements are high-value products that show the economic value of algae during biodiesel production (Bošnjaković & Sinaga, 2020). These by-products from algal biodiesel production have made companies to focus on using algae because the products are commercially viable and of high economic value (Trivedi et al., 2015). Also, it was evident that valorization of by-products during algal biodiesel production improves the cost of production because of the high value of algae needed for energy production, such as food supplements (Bošnjaković & Sinaga, 2020).

The review also found that algae consists of lipids, proteins, and carbohydrates as the essential compounds, which are proven to be high-value biomaterials necessary for energy production (Ge et al., 2018; Mirkouei et al., 2017). For example, proteins and carbohydrates have been found to be high-value biomaterials for biomass production because they represent the largest percentage of organic composition for different algal species, especially for green algae and cyanobacteria with percentage of proteins ranging from 36% to 70% (Ge et al., 2018). Thus, the production of algae from lipids, proteins, and carbohydrates is cost-effective because it entails the use of water from lakes, which are readily available (Ge et al., 2018). Also, from the existing studies, it was found that biodiesel production is more economically viable than other energy sources such as fossils because of the modern technology that is used that helps lower production costs (Mirkouei et al., 2017). For instance, Mirkouei et al. (2017) presented cost-effectiveness

of algal biomass production due to the locality of raw materials. Mirkouei et al. (2017) found that the greatest benefit of algal biomass production is the use of mobile bio-refineries that enables the production of high energy density products due to the close proximity to raw materials, including farm and forests compared to fossil fuels like gasoline and diesel that require the use of biochar and syngas, which are costly (Mirkouei et al., 2017). This enhances the feasibility of algal biomass, which is also attributed to the use of a biorefinery system that produces multi-products. This process is cost-effective because it increases the feasibility of using available resources or algae that serves as biodiesel fuel (Chew et al., 2017). Algae require nitrogen and phosphorus as the main nutrients for their growth, which are found in wastewater (Suparmaniam et al., 2019). Thus, using this wastewater for algae farming gives algal nutrients. Also, wastewater treatment is necessary for algae, which is cost-effective, and the combination of algae farming, and wastewater treatment makes it possible to lower production costs, thereby making algal biodiesel production more competitive (Suparmaniam et al., 2019).

Despite the economic viability and feasibility of algal biodiesel production, some studies showed that algal biomass production could be costly, especially during algae's harvesting and drying processes (Show et al., 2018). For example, Kargbo et al. (2021) studied the technological and economical feasibilities of algal biomass and established that the use of local waste biomass and use of lignocellulosic sources during gasification for fuel production is economically viable because of the availability of materials.

According to the work of Show et al. (2018), it was found that when using algae for large-scale production, harvesting through the chemical process via coagulation-flocculation method can be too costly, as it requires an extensive process to separate

algae from other excess chemicals in order to get the needed raw material for biomass production. Further, it was found that the collection, concentrating, and drying for algae biodiesel production leads to a high cost of energy because microalgae processing requires energy-intensive methods and photobioreactors to get the needed algal biofuel (Saad et al., 2019).

SUSTAINABILITY

The theme of sustainability defines that biomass is more economically sustainable than other energy sources. The theme describes that during energy production with algal biomass, the process is more efficient for energy production, making algal an alternative source of energy than any other sources, including fossil fuel energy. This was found across three studies that supported the economic sustainability of algal biomass compared to crude oils or fossil fuels (Bibi et al., 2021; Kargbo et al., 2021; Konur, 2021).

A study by Bibi et al. (2021) investigated the causality of biomass energy consumption in the United States and the environmental sustainability of using biomass for energy production. Bibi et al. (2021) and other researchers established that algal biomass is associated with less carbon dioxide emissions (17%) than fossil fuel energy sources that are associated with increased gas emissions of carbon dioxide. Thus, biomass is more efficient to achieve economic sustainability than fossil fuels because the economic and environmental sustainability of biomass is significant as it reduces the production cost and environmental stress caused by gas emissions (Bibi et al., 2021). The information presented by Bibi et al. (2021) validates the findings found in another previous study by Ullah et al. (2014), which showed that following the global demand for renewable energy sources, it could not be possible to meet economic and

environmental sustainability by other fuel sources like fossil fuels. Consequently, adopting renewable sources like biofuels as the alternative and supplementary to fossil fuel sources could be essential to achieve economic and environmental sustainability (Ullah et al., 2014). Similarly, a study by Kargbo et al. (2021) showed that the second-generation feedstocks of algal biomass are sustainable and feasible for fuel production because of higher yields of liquid fuel and other economically viable products, including heat and electricity. Kargbo et al. (2021) and colleagues demonstrated in their study that biomass is economically sustainable with the use of second-generation feedstocks in terms of production cost based on plant sizes, as presented in Figure 2.

Plant Size	Feedstock	End product	Production cost (US$/GGE)
2000 MT/ day	corn Stover	Diesel	HT = 4.27 LT = 4.83
550 MT/ day	Pyrolysis Bio-oil	FT-liquid	Distributed process = 1.43 Centralised process = 1.56
80 MT/h	Wood	Diesel	[c] 5.0
	Syngas from biomass gasification	Diesel & Gasoline	[c] 4.0
1923.7 MT/ day	Woody Biomass	Diesel	Cobalt-based FT = 4.3 Iron-based FT = 5.0
2000 MT/ day	Corn Strover	Liquid fuel	Biochemical scenarios = 5.0–5.50 Gasification scenarios = 4.50–5.0 Pyrolysis scenarios = 2.0–3.0

Figure 2. Production cost with algal biomass. Source: Kargbo et al. (2021).

From Figure 2, Kargbo et al. (2021) showed that for larger plants (2000 MT/day), focusing on the use of second-generation feedstock, the production cost ranges between $4.27 to $5.0/GGE and from $ 2.0 to $3.09/GGE for gasification-FTS and pyrolysis, respectively (Kargbo et al., 2021). This economic sustainability for energy

production through second-generation feedstock was found to be more effective and efficient for larger plants than smaller plant sizes (below 1000 MT/day)) that accounted for between $1.6 and $5.0/GGE and $2.2 and $9.4/GGE for gasification-FTS and pyrolysis, respectively (Kargbo et al., 2021).

ENVIRONMENTALLY FRIENDLY RESOURCES

The theme of environmentally friendly resources describes the use of biomass as an alternative to other energy sources because of reduced environmental challenges in terms of gas emissions and the use of natural resources, including land and water. From the reviewed studies, it was found that the use of algal biomass for energy production is environmentally friendly because it complies with the environmental regulations set to minimize global warming and gas emissions that cause harm as compared to other energy sources, including fossil fuels (Bibi et al., 2021; Milano et al., 2016). Thus, with no or minimal greenhouse gas emissions, algal biomass has been acknowledged to be an effective alternative to other sources of energy like fossil fuels because of its environmental sustainability in terms of reduced greenhouse gas emission or carbon dioxide emission (Bibi et al., 2021). The comparison of gas emissions between algal biomass and fossil fuels is presented in Figure 3, which shows that biofuels have the least percentage (0.8%) of gas emissions compared to fossil fuels with the largest percentage (78.4%), supporting the use of biomass as the best alternative energy source (Milano et al., 2016).

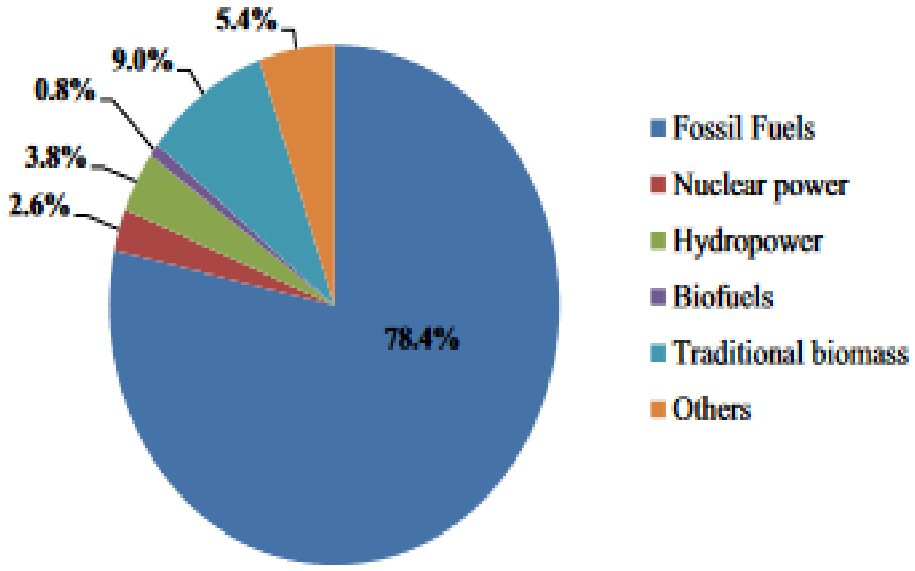

Figure 3. Comparison of Carbon dioxide emission from biofuels and fossil fuels. Source: Milano et al. (2016).

Similarly, research by Arora et al. (2020) demonstrated that algal biomass is the best energy source because it potentially produces sustainable fuels and chemicals with minimal gas emissions. The research illustrated that algal biomass fuels have a low net contribution of carbon dioxide to the environment due to their photosynthetic fixing of carbon dioxide during fuel combustion (Arora et al., 2020). Consequently, algal biofuels have lower emissions of greenhouse gases than conventional fossil fuels, making algal biomass to be the best alternative and are, therefore environmentally friendly (Arora et al., 2020). From the review, it was also found that algal biomass can be used as an alternative for fossil fuels and other energy sources in terms of land and water use. Reviewed studies demonstrated that algal biomass is eco-friendly and helps maintain a sustainable environment because the microalgae used during energy production have a high potential to capture carbon dioxide, therefore aiding in mitigating environmental impacts of greenhouse gas emissions (Bošnjaković & Sinaga, 2020; Mona et al., 2021;

Ullah et al., 2014). Also, one study by Mona et al. (2021) showed that algal biomass is the best alternative source of energy production because algal species have a higher growth rate and photosynthetic efficiency than other sources of energy, making them the best alternative energy sources to achieve a sustainable environment. This information aligns with that of Rossi et al. (2020) that supported algal biomass as the potential and preferred alternative energy source since microalgae used to produce the needed energy production promptly responds to environmental changes.

DISCUSSION

The research investigated the existing energy scenario from algal biomass and analyzed if it is a possible alternative for fossil fuels in terms of economic and environmental factors. The main focus of the research was to determine whether algal biomass could be used as a substitute for fossil fuels for energy generation. Existing studies related to the topic were reviewed to find appropriate themes for this research. Data analysis was completed with the use of the thematic method of analysis, which entailed combining phrases with similar phrases to create new themes (Castleberry & Nolen, 2018). The themes are cost-effectiveness, sustainability, and environmentally friendly resources. This section of the paper discusses the findings based on these themes to show whether algal biomass can or cannot be used as the best alternative to fossil fuel.

The analysis method found that algal biomass can be a great substitute for fossil fuels because it is less expensive or cost-effective than other energy sources. Using algal biomass, energy production can be cheap because of the availability of the needed resources, hence more economical than fossil fuels (Bošnjaković & Sinaga, 2020). Also, the availability of high-value biomaterials in algal biomass makes the algal biomass to be economical. Algae are mainly found in lakes, indicating that the materials are more readily available than those needed in fossil fuels that require modern technology. Consequently, algal biomass is economically viable in minimizing the cost of operation, thereby lowering the cost to produce energy (Ge et al., 2018; Suparmaniam et al., 2019). Figure 1 depicts the cost of production from the pond system which seems to be less expensive. Despite the fact that many reviewed studies supported the cost-effectiveness of algal biomass over fossil fuels during energy production, very few studies (Saad et al.,

2019; Show et al., 2018) showed that biomass is expensive. However, studies supporting its cost-effectiveness outweigh those opposing, showing that algal biomass could be a better alternative to fossil fuels.

As most studies showed, the cost-effectiveness of algal biomass makes it a better alternative to fossil fuels in terms of economic viability. This type of energy source is also environmentally friendly due to its sustainability. Algal biomass is environmentally sustainable due to its feasibility for fuel production and second-generation feedstocks (Kargbo et al., 2021). As depicted in Figure 2, the cost of production is based on the plant size, which makes algal biomass sustainable (Kargbo et al., 2021). Based on the plant sizes, it is evident that algal biomass is more efficient for energy production, making it more sustainable than other sources of energy like fossil fuels.

Besides, algal biomass can be the best alternative for fossil fuels in energy production because it is acknowledged as an environmentally friendly resource based on greenhouse gas emissions. During energy production, carbon emission is limited, which is in compliance with environmental regulations (Bibi et al., 2021). With such low gas emissions, algal biomass is not harmful to the environment and to humans; hence can be used for energy production to replace fossil fuels, which are known to have increased hazardous carbon emissions (Bibi et al., 2021). Additionally, algal biomass is supported as the best alternative energy source to replace fossil fuels because it has been found to have the least percentage of greenhouse gas emissions. From Figure 3, it is well indicated that algal biomass has 0.8% of greenhouse gas emissions compared to fossil fuels that account for 74.8% of greenhouse gas emissions (Milano et al., 2016). The data shows that fossil fuels are more hazardous than algal biomass in affecting the environment and its surroundings due to carbon emissions. Also, Figure 3 shows algal

biomass as an environmentally friendly resource compared to other sources of energy like traditional biomass, nuclear power, and hydropower, which are also shown to have a higher percentage of greenhouse gas emissions (Milano et al., 2016). This reflects the idea that the chemical released into the environment during energy production with algal biomass has no or limited adverse effects on the environment compared to those produced by other energy sources.

Besides, Figure 3 demonstrates that among other sources of energy, algal biomass can substitute all and should be given priority for energy production because of microalgae's potential to respond to environmental changes and capture gas, especially carbon dioxide that is released into the environment, therefore help prevent environmental effects to the ecosystem caused by greenhouse gas emissions (Mona et al., 2021). Thus, algal biomass can be used as an alternative way to produce the needed energy.

Further, algal biomass can be used in place of fossil fuels because it is environmentally friendly based on energy production from natural resources (Bošnjaković & Sinaga, 2020; Mona et al., 2021). The algae needed to produce energy are mainly obtained from water and have a high growth rate and photosynthetic efficiency, hence adjusting well to the environment (Mona et al., 2021). With such feasibility, energy production does not require extensive use of natural resources. Additionally, the microalgae used during energy production are an essential component with minimal gas emissions to the environment (Bošnjaković & Sinaga, 2020). Consequently, with the use of algae, the environment or the ecosystem is well-preserved from any harm caused by other methods. This shows that algal biomass is eco-friendly

compared to other energy sources and plays a crucial role in maintaining a sustainable environment (Arora et al., 2020).

From the review conducted, materials needed for energy production from algal biomass are readily available, which shows the flexibility of producing energy. The energy production from these materials makes it a viable means to shift from fossil fuels to algal biomass.

CONCLUSION

The study determined whether algal biomass can be used as a substitute or alternative to fossil fuel in terms of economic and environmental factors. Algal biomass is cost-effective compared to other energy sources, including fossil fuels. Algal biomass is cost-effective because of the availability of resources like high-value biomaterials. Also, algal biomass is more sustainable in terms of the production cost of energy and environmental stress caused by gas emissions than fossil fuels. Algal biomass is also environmentally friendly in terms of greenhouse gas emissions. Algal biomass does not release harmful gas to the environment, but its microalgae help capture carbon diode; hence greenhouse gas emissions are limited. Thus, with respect to environmental friendliness and economic viability, energy from algal biomass could be considered a success in replacing fossil fuels. As a developing source of energy, better technology with the use of algal biomass, such as in biorefinery systems, makes it an economically viable method that could bring down the cost of production, which is possible in the current technological era. Thus, algal biomass could be considered a feasible sourcesof energy production over fossil fuels because of its economic viability and environmental friendliness factors.

LITERATURE CITED

Anburajan, P., Yoon, J.-J., Kumar, G., Park, J.-H., & Kim, S.-H. (2019). Evaluation of process performance on biohydrogen production in continuous fixed bed reactor (C-FBR) using acid algae hydrolysate (AAH) as feedstock. *International Journal of Hydrogen Energy*, *44*(4), 2164–2169. https://doi.org/10.1016/j.ijhydene.2018.09.098.

Araújo, R., Vázquez Calderón, F., Sánchez López, J., Azevedo, I. C., Bruhn, A., Fluch, S., ... & Ullmann, J. (2021). Current status of the algae production industry in Europe: an emerging sector of the Blue Bioeconomy. *Frontiers in Marine Science*, *7*, 1247. https://doi.org/10.3389/fmars.2020.626389

Aravind, S., Kumar, P. S., Kumar, N. S., & Siddarth, N. (2020). Conversion of green algal biomass into bioenergy by pyrolysis. A review. *Environmental Chemistry Letters*, 1-21. doi:10.1007/s10311-020-00990-2

Arora, P., Chance, R., Hendrix, H., Realff, M. J., Thomas, V. M., & Yuan, Y. (2020). Life cycle greenhouse gas emissions of different CO2 supply options for an algal biorefinery. *Journal of CO2 Utilization*, *40*, 1-23.

Banerjee, N., Sukichandran, P., Chaudhari, P., Thakur, A. K., & Kumar, R. (2021). Energy analysis and feasibility studies for algal biomass and biofuels. *Materials Today: Proceedings*, 57(4), 1448-1454. https://doi.org/10.1016/j.matpr.2021.11.223

Bibi, A., Zhang, X., & Umar, M. (2021). The imperativeness of biomass energy consumption to the environmental sustainability of the United States revisited. *Environmental and Ecological Statistics*, *28*(4), 821-841.

Bošnjaković, M., & Sinaga, N. (2020). The perspective of large-scale production of algae biodiesel. *Applied Sciences, 10*(22), 8181. doi:10.3390/app10228181

Chew, K. W., Yap, J. Y., Show, P. L., Suan, N. H., Juan, J. C., Ling, T. C., ... & Chang, J. S. (2017). Microalgae biorefinery: High value products perspectives. *Bioresource Technology*, *229*, 53-62.

Choudhary, P., Assemany, P. P., Naaz, F., Bhattacharya, A., de Siqueira Castro, J., de Aguiar do Couto, E., … Malik, A. (2020). A review of biochemical and thermochemical energy conversion routes of wastewater grown algal biomass. *Science of The Total Environment*, 1-24. doi:10.1016/j.scitotenv.2020.137

Davis, R., Aden, A., & Pienkos, P. T. (2011). Techno-economic analysis of autotrophic microalgae for fuel production. *Applied Energy*, *88*(10), 3524-3531. https://doi.org/10.1016/j.apenergy.2011.04.018

Ge, F., Xiao, Y., Yang, Y., Wang, W., Moe, B., & Li, X. F. (2018). Formation of water disinfection byproduct 2, 6-dichloro-1, 4-benzoquinone from chlorination of green algae. *Journal of Environmental Sciences, 63*, 1-8. https://doi.org/10.1016/j.jes.2017.10.001 https://www.nationalgeographic.com/environment/article/fossil-fuels?loggedin=true.

Kargbo, H., Harris, J. S., & Phan, A. N. (2021). "Drop-in" fuel production from biomass: critical review on techno-economic feasibility and sustainability. *Renewable and Sustainable Energy Reviews*, *135*, 1-20.

Khan, S., Siddique, R., Sajjad, W., Nabi, G., Hayat, K. M., Duan, P., & Yao, L. (2017). Biodiesel production from algae to overcome the energy crisis. *HAYATI Journal of Biosciences*, *24*(4), 163-167. https://doi.org/10.1016/j.hjb.2017.10.003

Kheshgi, H. S., Prince, R. C., & Marland, G. (2000). The potential of biomass fuels in the context of global climate change: focus on transportation fuels. *Annual review of energy and the environment*, *25*(1), 199-244

Konur, O. (2021). Algal biomass production for biodiesel production: A review of the research. *Biodiesel Fuels Based on Edible and Nonedible Feedstocks, Wastes, and Algae*, 695-717.

Kumar, G., Sivagurunathan, P., Anburajan, P., Pugazhendhi, A., Saratale, G.D., Choi, C.- S., & Kim, S.-H. (2018). Continuous biogenic hydrogen production from dilute acid pretreated algal hydrolysate using hybrid immobilized mixed consortia. *International Journal of Hydrogen Energy, 43*(25), 11452–11459. https://doi.org/10.1016/j.ijhydene.2017.06.050.

Kumar, S., Rawat, M. K., & Gupta, S. (2019). An evaluation of current status of renewable energy sources in India. *International Journal of Innovative Technology and Exploring Engineering*, *8*(10), 1234-1239. DOI: 10.35940/ijitee.G6004.0881019

Lian, J., Wijffels, R. H., Smidt, H., & Sipkema, D. (2018). The effect of the algal microbiome on industrial production of microalgae. *Microbial Biotechnology*, *11*(5), 806–818. https://doi.org/10.1111/1751-7915.13296

Mirkouei, A., Haapala, K. R., Sessions, J., & Murthy, G. S. (2017). A mixed biomass-based energy supply chain for enhancing economic and environmental sustainability benefits: A multi-criteria decision making framework. *Applied Energy*, *206*, 1088-1101.

Nunez, C. (2021, May 3). *Fossil Fuels, explained*. Environment. Retrieved December 1, 2021

Poudyal, R., Loskot, P., Nepal, R., Parajuli, R., & Khadka, S. K. (2019). Mitigating the current energy crisis in Nepal with renewable energy sources. *Renewable and Sustainable Energy Reviews*, *116*, 1-15. https://doi.org/10.1016/j.rser.2019.109388

Pourkarimi S, Hallajisani A, Alizadehdakhel, A., & Nouralishahi, A. (2019). Biofuel production through micro- and macroalgae pyrolysis: a review of pyrolysis methods and process parameters. *Journal of Analytical and Applied Pyrolysis*, 1-19. https://doi.org/10.1016/j.jaap.2019.04.015

Rossi, S., Casagli, F., Mantovani, M., Mezzanotte, V., & Ficara, E. (2020). Selection of photosynthesis and respiration models to assess the effect of environmental conditions on mixed microalgae consortia grown on wastewater. *Bioresource Technology, 305*, 1-12. https://doi.org/10.1016/j.biortech.2020.122995

Saad, M. G., Dosoky, N. S., Zoromba, M. S., & Shafik, H. M. (2019). Algal biofuels: current status and key challenges. *Energies*, *12*(10), 1920.

Show, K. Y., Lee, D. J., & Mujumdar, A. S. (2018). Advances and challenges on algae harvesting and drying. *Drying Technology*, *33*(4), 386-394.

Sim, Y.-B., Jung, J.-H., Baik, J.-H., Park, J.-H., Kumar, G., Rajesh Banu, J., & Kim, S.-H. (2021). Dynamic membrane bioreactor for high rate continuous biohydrogen production from algal biomass. *Bioresource Technology, 340*, 1-8. doi:10.1016/j.biortech.2021.125562

Sivaramakrishnan, R., & Incharoensakdi, A. (2018). Utilization of microalgae feedstock for concomitant production of bioethanol and biodiesel. *Fuel, 217*, 458–466. doi:10.1016/j.fuel.2017.12.119

Slade, R., & Bauen, A. (2013). Micro-algae cultivation for biofuels: Cost, energy balance, environmental impacts and future prospects. *Biomass and Bioenergy, 53*, 29–38. doi:10.1016/j.biombioe.2012.12.

Suparmaniam, U., Lam, M. K., Uemura, Y., Lim, J. W., Lee, K. T., & Shuit, S. H. (2019). Insights into the microalgae cultivation technology and harvesting process for biofuel production: A review. *Renewable and Sustainable Energy Reviews*, *115*, 109361.

Trivedi, J., Aila, M., Bangwal, D. P., Kaul, S., & Garg, M. O. (2015). Algae based biorefinery—how to make sense? *Renewable and Sustainable Energy Reviews*, *47*, 295-307.

Ullah, K., Ahmad, M., Sofia, Sharma, V. K., Lu, P., Harvey, A., … Anyanwu, C. N. (2014). Algal biomass as a global source of transport fuels: Overview and development perspectives. *Progress in Natural Science: Materials International, 2*4(4), 329–339. doi:10.1016/j.pnsc.2014.06.008

Yadala, S., Smith, J. D., Young, D., Crunkleton, D. W., & Cremaschi, S. (2020). Optimization of the algal biomass to biodiesel supply chain: case studies of the state of Oklahoma and the United States. *Processes*, *8*(4), 476. https://doi.org/10.3390/pr8040476