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REVIEWS

The potential of biodiesel in mitigating the energy crisis in Sub-Saharan Africa energy sectors

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Abstract. Because of their destructive effects on the climate, recent campaigns have continuously emphasized the need to eliminate fossil fuels. Thus, there is a pressing need for other sources of energy that can reduce greenhouse gas emissions to the atmosphere. These alternatives must be easily accessible and should contribute to the industrial development in developing regions, especially Sub-Saharan Africa. Poor access to electricity is a major challenge that hampers the development of some countries in Sub-Saharan Africa. Renewable energy such as biofuels can perfectly solve this. Biofuels possess unique attributes that can help the world attain energy security and energy balance. The depletion of fossil fuels and other factors such as technological advancement and industrial development in most countries in Sub-Saharan Africa threatens the availability of energy. It is a major setback to the achievement of the United Nation's Sustainable Development Goal 7. Narrowing down to the use of biodiesels, implementing their use can save the continent from a lot of damage and build up a more sustainable energy sector. Massive deployment of Biodiesels into the energy sector of Sub-Saharan Africa will not only ease the access to energy but also boost the agricultural sector and the country's economy in the region. This paper reviews the current state of biodiesel in Sub-Saharan African. The paper employed a systematic review to provide an elaborated overview on the current trend of biodiesel production in Sub-Saharan Africa and the challenges for full deployment of this alternative fuel as well as a thorough discussion on the possible impacts of biodiesel in the regions.

Keywords: Biofuels; Sustainable Energy; Fossil Fuel; Climate

1. Introduction

Undergoing combustion, fossil fuels emit carbon dioxide to the environment. This has drastic long-term negative effects on the environment, leading to climate change, and global warming (Mensah et al. 2021; Ojo et al., 2020). In addition to the aforementioned environmental impact of fossil fuels on the environment, they have been depleted in a natural reserve and will dry out completely (Kehinde et al., 2018). These concerns have jolted concerned institutions to find renewable alternative sources of energy. The United Nations, for instance, has made the

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program of combating climate change one of its top priorities and has invested heavily in pursuing a net-zero carbon economy (Hansen et al., 2019; Hansen et al., 2019). At the present rate of consumption, petroleum reserves would be completely depleted in the nearest future (Patel et al., 2013). Hence, the need for alternative sources of energy cannot be neglected (Esan et al., 2019; Huang et al., 2010). In the search for clean energy sources, researchers have successfully found several ways of generating clean and renewable energy that cannot be depleted and have zero negative impact on the environment. Sources of clean energy that have so far been researched are bioenergy (Cai et al., 2016; Orangun et al., 2021), solar energy (Agrawal, 2019), geothermal energy (Abraham & Nkitnam, 2017), wind energy (Oyedepo et al., 2019), and hydro energy (Chisti 2007; Okedu et al., 2020).

Bioenergy as renewable energy involves energy generated from biological matter (Olugasa et al., 2014). This excludes the conventional burning of wood and coal to generate energy. There are various types of biofuels such as biogas (Hagos et al., 2017), biodiesel (Amenaghawon et al., 2021; Efavi et al. 2018), biobutanol (Abedini, et al., 2020; Jiang et al. 2019; Kallarakkal et al. 2021; Szulczyk and Cheema 2021), bioethanol (Adewuyi, 2020), etc. Biogas is derived from the anaerobic digestion of organic matter to produce methane (Orangun et al., 2021; Raja and Wazir 2017). This clean gas has great potential especially in rural communities since it can be used to convert organic waste to methane that can be used as cooking fuel. Biodiesel, on the other hand, is produced by the transesterification of vegetable oils and animal fats (Helmi et al. 2021; Yusuff et al., 2019). The high cost of biodiesel, however, puts it at a disadvantage in its competition with fossil fuels. Realistically, biodiesel from vegetable oil and animal fat cannot satisfy the existing energy demand for transport fuels (Agrawal, 2019). However, advanced technology of newer biodiesel production methods, such as biodiesel production from microalgae (Azad, 2019; Nagarajan et al., 2013; Yusuff and Ewere, 2020) that do not require the use of plant oils and animal fats are springing up. New technologies in biodiesel production could see the production of commercial quantities at relatively lower costs compared to conventional diesel fuel. This explored the present state of biodiesel in Sub-Saharan Africa. It examined setbacks to its full implementation and provided recommendations for complete utilization. It seeks to provide a comprehensive view on the state of the art of biodiesel production and commercialization in sub-Saharan Africa as well as its potency to solve the energy and carbon emission problems scourging the region.

2. Methodology

Works of literature have extensively discussed ways to improve the performance of biodiesel in compression ignition engines by varying the primary feedstock used for its production. Siva et al. (2019) improved the performance of waste orange peel biodiesel in a diesel engine by blending it with water and Span 80. Liangliang et al. conducted a study that provides a thorough discussion on the advances in enzymatic biodiesel commercialization as well as sub-topics like lessening the cost of enzymes, the expansion of low-quality materials, and comparison of the merits and demerits of several enzymatic processes (Liangliang et al., 2021). In a study conducted by Ayoub et al., factors like availability, and the ability of biodiesels to cover a tangible percentage of fossil fuel were used in assessing feedstocks for sustainable biodiesel synthesis (Ayoub et al., 2021).

However, there is a dearth of research focusing on the socio-economic aspect of biodiesel as an alternative fuel. This paper reviews the current state of biodiesel in sub-Saharan Africa and its relevance to the region's energy sector. It gives an extensive discussion on small and medium-scale biodiesel projects initiated in some countries in Sub-Saharan Africa as well as efforts made by the government of these countries and foreign investors coupled. In addition, potential impacts of the execution of these projects are discussed.

For data collection, specific keywords were searched on Google Scholar, Scopus, AJOL, and DOAJ databases. The keywords include "Biodiesel and Sub-Saharan Africa", "Biodiesel in Africa" conjoined with combining the word biodiesel with the name of some countries. The results were sorted by their relevance. Relevant studies on the topic were extracted. The data search was complemented by results from a simple search of the keywords on Google. Necessary information and data resulting from the search were extrapolated and used for this study.

This paper is structured into four sections. Section 2 and 4 discuss the technologies used in biodiesel production and the generation of power from biodiesel respectively. Section 3, 5, and 6 provide a comprehensive view of the current state of biodiesel in sub-Saharan Africa, the possible impact of its full deployment in the regions as well as the challenges in the use of biodiesel and the way forward.

3. Result

3.1. Biodiesel Production Technologies

There are four basic ways to produce biodiesel namely thermal cracking, direct use and blending, micro-emulsions, and transesterification of vegetable oils and animal fats. In thermal cracking, oxygen is removed during the process that erases the benefits of the use of oxygenated fuel (Gebremariam & Marchetti, 2017). The biodiesel produced from micro-emulsion is characterized by a decrease in viscosity, rise in cetane number conjoined with excellent spray characters and its continuous use in diesel engines leads to injector needle sticking, incomplete combustion, and formation of carbon deposits (Gebremariam & Marchetti, 2017). The direct usage of biodiesel in a direct or indirect fuel injection diesel engine is considered impractical and not satisfactory due to the thickening of lubricating oil, gum formation due to oxidation and polymerization, and the free fatty acid (Gebremariam & Marchetti, 2017). Of all these technologies, the transesterification method is the most commonly used Biodiesel production (Patrick & Bello, 2015). The advantages of using transesterification include higher cetane number, lower emission, and higher combustion efficiency (Serge et al., 2019). In transesterification reaction, the vegetable oil or animal fat is reacted in the catalyst with an alcohol (usually methanol) to give the corresponding alkyl esters (Giwa & Akanbi, 2020). There are two basic types of catalysts used for transesterification reactions. The first involves the use of alkaline catalysts while the second involves the use of an acid catalyst. The alkaline-based catalyst is the most preferred since it is cost-effective (Serge et al., 2019). However, the alkaline catalysis conversion of low-cost feedstock such as used frying oils would be complicated if the oils contain large amounts of free fatty acids, this high FFA forms soaps with alkaline catalysts (Serge et al., 2019). The soap formed disrupts the separation of the biodiesel from the glycerin fraction. Alternative processes using an acid catalyst are available (Helmi et al., 2021).

3.2. Transesterification

The major component of vegetable oils and animal fats is triglycerides. These are esters of fatty acids with glycerol (Knothe & Gerpen, 2005). The transesterification for biodiesel production involves the exchange of the organic group 'R" of triglycerols with the organic group of R' of alcohol, usually methanol. Figure 1 provides a diagrammatic explanation of the transesterification. reaction.

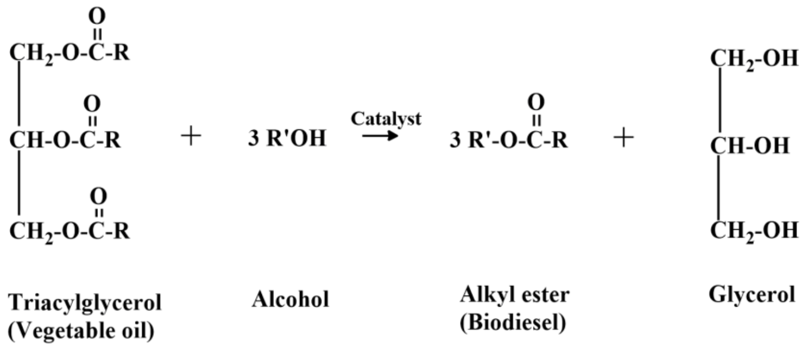

Figure 1. The transesterification reaction. R is a mixture of various fatty acid chains. The alcohol used for producing biodiesel is usually methanol (R' = CH3) (Knothe & Gerpen, 2005)

3.3. The Current State of Biodiesel and its Production Rate in some Countries of Sub Saharan Africa

Unlike Brazil, China, India, the USA, and Europe that are core members of the international biofuel forum as well as big players in the biofuel industry, South Africa is the only country in Africa that performs fairly in the biofuel world. South Africa has about 200 small-scale entrepreneurs that produce biodiesel majorly from feedstock like waste vegetable oil that contributes to advancing global biodiesel production (Thaba et al., 2015). Globally, about 130 billion liters of biofuel were consumed in 2016. It is expected to increase to almost 650 billion liters in 2050 (IRENA, 2019). Even though most Sub-Saharan African countries have enough agricultural resources as well as favorable climates to cultivate feedstock such as Jatropha and other crops, the development of biodiesels is still at its infancy stage. The biodiesel market in Africa is mainly dominated by small and medium enterprises, although countries like Ghana, Zambia, Liberia, Tanzania, Ethiopia, Nigeria, Senegal, Kenya, Angola, Zimbabwe, Mozambique, and South Africa have some laid out plans to embark on large scale biodiesel projects for commencing commercial productions (Sekoai and Yoro, 2016). In 2010, the number of biogas plants in Africa was appreciable with Tanzania possessing about 4000 digester units (Dahunsi et al., 2019). However, it Is saddening to note that a rough estimate of 40% of these plants failed or performed poorly largely due to planning and construction errors, poor community awareness, lack of adequate maintenance culture, the misconception of the technology's benefits, and lack of technical know-how by end-users (Dahunsi et al., 2019). However, most countries in Sub-Saharan Africa have initiated several programs related to Biodiesel to strengthen their energy sector. In a bid to reinforce the rate of biodiesels production in Burkina Faso, its government planted 70000 trees of Jatropha Oilseeds in 2009 (Sekoai and Yoro, 2016). In response to the 2003 European Union Biofuel directives, several biofuel development projects were initiated by the government of Burkina Faso in collaboration with some other partners. This includes the Foundation Fasobiocarburant (FFB) project which was financed by Dutch investors (Sekoai and Yoro, 2016). The Government of Ghana introduced a bioenergy policy targeted at supplementing the country's petroleum oil with 10% biofuel by 2020 as well as 20% by 2030 by leveraging on the country's vast biomass potential. Anuanom Industrial Bio-products and Biodiesel 1 Ltd, which are major biodiesel firms in Ghana, have two major biodiesel production plants, which boast a production capacity of 70,000 metric tonnes of Jatropha Oil per plant (Sekoai and Yoro, 2016; Nouadjep et al.

2019). These two companies form a part of the major Biofuel firms that are working towards achieving this goal. Anuanom Industrial Bio Product also partnered with a German-Austrian private company and Bulk Oil Storage and Transportation (BOST) Limited to commence the establishment of a commercial biodiesel production plant in Ghana. The factory is expected to have a production capacity of about 360,000 tons per annum with a worth of about 12 million US dollars (Sekoai and Yoro, 2016; Nouadjep et al. 2019).

A Japanese company named Biwako Bio-laboratories Limited pledged to embark on a 20 million dollars Jatropha plantation project in Kenya and is expected to produce 200,000 tons of Jatropha Oil seeds per year. The Mali-Folkecenter Nyetta, a non-governmental organization in Mali assists local farmers to cultivate Jatropha Oil seeds and they also generate power from the biodiesels produced to meet the energy demands of the immediate communities around the center (Sekoai and Yoro, 2016; Nouadjep et al. 2019). In Nigeria, the use of biodiesels for power generation is still at the beginning, although some network services providers across the country use biodiesels in their base stations. Lagos represents the hub of biodiesels production in Nigeria as it hosts firms like Biodiesel Nigeria Limited, Avatar Energy Limited, and Canrex Biofuel Limited. Other biodiesel firms in the country include Aura Bio-Corporation in Cross River state and Shashwat Jatropha in Kebbi State (Popoola et al., 2015). Senegal also collaborated with leading Biofuel countries like India and Brazil to initiate several biofuel projects in the country. This includes 4000 hectares Jatropha Oil seeds plantation in Touba and the cultivation of other feedstocks such as sunflower as well as castor oil in Kolda. Matola hosts the first Biodiesel plant in Mozambique. This structure was instituted in 2007 by Ecomoz. Apart from this achievement, Mozambique now has other biodiesel production factories which are courtesy of companies like Petromoc and Sunbiofuel (Popoola et al., 2015; Sekoai and Yoro, 2016; Nouadjep et al. 2019). Other African countries such as Angola, Benin, South Africa, Zambia Liberia, Niger, Zimbabwe, Togo, and Uganda have also embarked on different Biodiesel projects (Sekoai and Yoro, 2016). Uganda has enacted some energy policies managing biofuel production in the country and it currently boasts of a production capacity of 119 mega liters of biofuel (Serge et al., 2019). The feedstocks commonly used in the country include jatropha and molasses. Tangible deposits of animal wastes, municipal wastes, and water hyacinths that are useful for biofuel production could be sourced in local communities in Niamey, Niger (Popoola et al., 2015). Zambia possesses a forest of about 42.5 million Hectares as a huge resource in increasing the availability of bio-related feedstocks needed for biodiesel production (Babajide et al., 2015). The country has a great potential for next-generation biofuel (Babajide et al., 2015). Lilongwe, the capital city of Malawi, houses biodiesel-based production that is worth eight million US dollars (Sekoai and Yoro, 2016). This project was initiated by Dutch Investors and it can produce 250 tons of Jatropha Oil seeds per day, which amounts to 5000 liters of biodiesels (Sekoai and Yoro, 2016). In Zimbabwe, a large biodiesel refinery was launched in 2007. This project is located in Mount Hampden, which is about 15 kilometers from Harare, the nation's capital. Figure 2 depicts the map of Sub-Saharan Africa and the countries discussed in this study.

Figure 2. The map of Sub-Saharan indicating some countries where biodiesel is produced.

3.4. Generating Power from Biodiesels

Once biodiesels are produced, they are usually used in the combustion ignition engine which was typically designed for use with fossil fuel-generated diesel. The engine operates on the diesel cycle that includes isentropic compression, constant-pressure heat addition, isentropic expansion, and constant-volume heat rejection. The fuel starts igniting at the latter part of the compression stroke and continues to be injected till the piston gets to the top dead center. This combustion is what is used to produce mechanical power in the engine. The higher the calorific value of the fuel, the more efficient the engine will be.

The calorific value differs among different biodiesels. Linseed oil methyl esters, for example, have a calorific density of 40.2MJ/kg while Corn oil methyl esters have a calorific value of 41.35MJ/kg (Rao et al., 2010). However, they all have a value of around 40-42 MJ/kg. The kinematic viscosity differs more though. The major properties used in measuring the performance of diesel engines when biodiesel is used or blended include the viscosity and lubricity of the diesel (Nouadjep et al., 2019). Biodiesels have a higher viscosity than that of regular diesel and it generally results in power losses. This is because the higher viscosity decreases combustion efficiency due to bad fuel injection atomization (Nouadjep et al., 2019). Asides from poor atomization (reduction in particle size of the fuel for easy spraying and effective dispensing by the fuel injector), a too high viscosity causes an increase in carbon deposits and incomplete combustion (Rao et al., 2010). The higher viscosity the fuel needs, the higher the pumping power needed. Fuels with lower viscosity leaks past the plunger through the clearance between plunger and barrel during fuel compression.

For every type of fuel, some properties are associated with it. These are classified as the physical (viscosity, cloud point, pour point, flash point), chemical (chemical structure, acid value, saponification value, Sulphur content, copper corrosion, oxidation resistance, and thermal degradation), and thermal properties (distillation temperature, thermal conductivity, carbon residue, and calorific value) (Rao et al., 2010). The structure of the systems built to be used with biodiesel is greatly affected by these qualities. The neat biodiesel or biodiesel blends have to meet the best amount of viscosity to avoid damage to fuel injectors and fuel pumps (Rao et al., 2010). This is because the transesterification process they undergo reduces the viscosity and most of the needed properties of the biodiesel are left to be determined by the processes they undergo.

Sub-Saharan Africa is a place where diesel engines are used in many cases to complete transportation, power generation, and manufacturing processes. Most times if not all, the diesel gotten from fossil fuels are the ones being used to run them. There are many opportunities for large-scale biodiesel production that can be blended or used neatly in these engines. When these properties are located correctly and the environment is rescued from many hazards in the climate, they will perform well. More jobs will be created and clean energy will be utilized in power generation.

3.5. Possible Impact of Biodiesels on Africa's Energy Sector and Other Relevant Areas

Meeting households and industrial energy demands is a major challenge in Sub-Saharan Africa. This leads to an energy access predicament in which one in seven people living in the region lacks access to basic electricity. Biodiesel as an alternative fuel has the potential to put an end to this menace and to substitute conventional fuels without fuss. Although there is much emphasis on electric cars, the fossil fuel consumption rate of the transportation sector is still very high. In 2019, the transportation sector in the USA accounts for approximately 30% and 70% of its energy need and petroleum consumption (Chauhan and Shukla 2011). Biodiesel has the potency of lessening the energy crisis in the transport sector as it is readily available, environmentally friendly, can be used in its unrefined state, and have the ability to increase the performance of vehicle due to its lubricity. In comparison with petroleum-based diesel, the Fossil Energy Ratio (FER) of biodiesels is much higher which gives it more advantage.

Most countries in the sub-Saharan region are developing countries that hope to improve their technological and industrial capabilities in the next few years. The main action accompanying these types of decisions is to increase energy demand. Importing fossil fuels with the country's revenue may not be able to sustain the energy needs of the countries in Sub-Saharan Africa in the future and this may lead to a paucity of energy. The use of biodiesels is a potential escape route to solve the intense energy scarcity that will emerge from the high energy consumption rate that may strike developing countries in Sub-Saharan Africa in the future.

In its blended and pure form, biodiesels have a considerable carbon emission rate, unlike conventional petroleum diesel. Biodiesel also emits carbon dioxide but it does not contribute to the overall environmental increase in the greenhouse gases emission rate. This is since the carbon dioxide released during combustion is absorbed by the atmosphere for the growth of the plants. The carbon dioxide emission rate of B20, major biodiesel blends commonly used in the USA which contain 20% biodiesel and 80% petroleum diesel, is 15% less than the carbon emission from conventional petroleum diesel, while B100 has the potential of reducing carbon emission by 74%. These unique traits of biodiesels make it a perfect fuel for attaining a carbon-neutral environment and a solution to climate-related challenges such as global warming. Using Biodiesel, the oxides of Sulphur and nitrogen will be diminished (Hassan & Ayodeji, 2019). About 23% of Sub-Saharan Africa's GDP comes from agriculture and farming that remains a treasure in this region due to the favorable climate of the regions. Incorporating a massive Jatropha planting scheme in the agricultural plans of Sub-Saharan Africa could make the countries constituting the region become big sellers of biodiesels in the international market (Babajide et al., 2015). This will boost the country's economy and further spur an increase in the development rate of these countries. Youth unemployment and poverty alleviation can be tackled by the cultivation of Jatropha and by enacting biodiesel production plants (Babajide et al., 2015; Hassan & Ayodeji, 2019; Patrick & Bello, 2015).

3.6. Challenges Associated with Biodiesel Production in Sub-Saharan Africa and the Way Forward

Despite the advantages of the use of biodiesels in Sub-Saharan Africa, it has not been put to use. There are several challenges that the production and use of biofuels generally have been facing, making it limited in Sub-Saharan Africa and leaving us to the use of fossil fuels which constantly damage our climate and cause various hazards. These inhibiting factors constantly come to play and affect investments into the production and utilization of biodiesels. Some of these challenges and the way forward in each case include:

Food versus Fuel Debate

Biofuels generally face the challenge of balancing the use of biomass for food purposes and energy purposes. Many researchers have argued in favor of food as it is seen as a more essential need of every human being (Patrick & Bello, 2015). This is however handled currently as more non-edible crops are being integrated into the energy production process. The use of Jatropha and algae is one of the ways to combat this, rather than using soybean oil and palm oil (Nagarajan et al., 2013). These two are very useful as they contain the needed oils for the production of biodiesels. More research is underway to discover new crop varieties that will be discovered and used in biodiesel production but not yet eaten, so as to avoid unfair competition with food security.

Inadequate Man-power and Expertise in Biodiesel Development

Most biodiesel production in sub-Saharan Africa is conducted at the research level, rather than large-scale production, which can be utilized to a large extent. This is a result of a lack of expertise of people in Africa as pertains to biodiesel production and use (Patrick & Bello, 2015). While many think that the continent should maximize its resources, not many are skilled enough. The interest is not in this line that it is not surprising that bioenergy training and education have not reached the required level. To get over this challenge, more Africans should be trained and sent to be equipped with all the necessary technical know-how and expertise required from places where it has been adequately utilized.

Lack of Adequate Policies

The government of many countries in Sub-Saharan Africa has not taken the step to put in place policies that will ensure a perfect environment for biodiesel production and biofuels in general. The Nigerian government, for instance, has never put a policy that involves biodiesel use in particular (Adewuyi, 2020). Despite many countries in Sub-Saharan Africa have the potential for sustainable energy production from seed oils, not many governments have invested in the production of biodiesels. Some have set policies which were never met because it was not taken as a priority. The matter is a simple issue of will and decision-making. The government should look into making favorable policies to support more research and eventual large-scale production of biodiesels.

Environmental Impact

The way that biodiesel production has an impact on the environment is through different activities used to grow biomass (Sekoai and Yoro, 2016). Before the biodiesel production process, many agricultural processes were carried out. In this process, eutrophication occurred and life in the surrounding oceans and rivers died. This is a result of the use of fertilizers. Land depletion happens when constant use of the lands for crop production is required. However, this can be tackled by the proper systems that allow for the cultivation of crops like algae in artificial ponds and controlled use of land.

4. Conclusion

Biodiesel is a better alternative to fossil fuels. They are environmentally friendly as they reduce the greenhouse gases emitted into the atmosphere. At the same time, the raw materials required for their production can be largely cultivated in Sub-Saharan Africa. The arguments on its relevance have all been cleared mostly based on it being reliable and sustainable. Outlining the great benefits, challenges, and predictions, biodiesel has proven to flourish in the energy sector in sub-Saharan Africa.

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