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Status quo of Biodiesel Production in Africa: A Review on Technological Options, Policies and Aboriginal Feedstock Potential

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Abstract

Growing industrialization, modernization along with better living standards in Africa, are expected to rise in the coming years with energy demand, increasing eventually. This expansion is occurring at a time when oil prices have reached new heights. Unstable oil prices do indeed, increase the vulnerability of importers. However, it also presents an opportunity to explore promising technical options to help reduce the over-reliance on imported petroleum fuels. Biofuels including biodiesel, offer new opportunities for African countries. They can contribute to economic growth, and rural incomes for some countries and provide low cost fuel for others. In this paper: the importance, properties, vegetable feed-stocks and enhancement in technology for production of biodiesel are described, including; characterization, engine performance, energy actual state, current situation of biodiesel and bioenergy policies in Africa. From the exploration, it is inferred that; there are auspicious oil resources in the plan for biodiesel industrialization in Africa.

Keywords: Africa; energy; biodiesel; transesterification; feedstocks; policies.

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1. Introduction

Energy, climate change and biofuels have recently become among the hot 'buzzwords' and with good reason. Meeting future energy requirements with continued use of limited fossil fuels is now widely recognized as unsustainable because of depleting supplies and environmental degradation. Ideally, energy demands should be reduced since, the world's propensity for energy is expected to rise by another 60% in the next 25 years [1]. The world can no longer afford to rely solely on fossil oil and oil-derived products [2]. There is an urgent need, to find solutions to address the mankind's oil (and carbon) addiction. This requires energy efficiency awareness as well as changes in consumer behavior. The best way to maintain energy reliability is through diversity in sources of energy, suppliers and supply routes. Energy availability is a key element for modernization, as it enable fundamental provisions that magnify the quality of living [3,4]. However, securing adequate, economical high quality energy provision with merest detrimental impacts on the environment has been not only crucial for Africa, but also vital for this continent in which many nations are still striving to accommodate their current energy needs [5,6,7]. Energy resources in African countries are irregularly distributed [5,8]: the supply of 12% global oil is concentrated in Nigeria, Algeria, Egypt and Libya [9]. Only these four countries with 9.5% oil reserves are said to be self-reliant in energy as exporters. Most of the African countries are net energy importers. They import petroleum fuel at a cost that places heavy economic burden on the country [9]. As evidence for urgent need of substantial investment, in domestic energy for social-economic development [10,11]. Expanding the domestic energy facilities would increase the efficiency of how the continent uses its energy resources, while enabling African countries to escalate their reliability of supply and dwindle the dependence on petroleum imports. This would also help upgrade energy security alongside, increasing access to energy services [3,12]. With current research on energy focusing on modern energy as promising, beneficial and guarantee to countries, biodiesel from vegetable oils and animal fats are the most obvious promising choices [2,13,14]. Growth projections of biodiesel, are laying emphasis on vegetable oils, especially the edible ones though, feasibility studies indicate that using all the edible oil resources will still not be sustainable [4, 9,15]. An example, is the World Bank and Muller and his colleagues [16,17] 2008 reports. These reports clearly indicate that by 2030, biodiesel will represent about 60–80% transport fuel in Africa. And since the edible oil resources would not be sustainable, attention has been drawn to inedible oil resources, which can serve as guarantee resources for sustainable biodiesel in order to augment energy and yet maintain food security. Inedible plants have the advantage of being used for afforestation to reclaim wastelands. At present, the main inedible resource for biodiesel in Africa is jatropha. But jatropha cannot single-handedly sustain biodiesel for Africa's energy security [4]. The term ''biodiesel' widely refers to an oxygenated diesel fuel made from various feedstock by conversion of the triglyceride fats to methyl or ethyl esters via transesterification. Increasing interest in biodiesel in many African countries can be attributed to factors such as high prices of crude oil, fluctuations in their prices, local and global environmental impacts of petroleum fuels such as climate change, movement of developed countries (Germany aims to convert up to 50-75% renewable energy by 2020, Japan, etc.) from voluntary legislation to obligatory legislation and imposition of market share of biodiesel into the transport sector. For instance, to meet the target of about 8-20% by 2020, EU countries would need to import feedstock (and/or biofuel) from elsewhere, due to lack of sufficient arable land for energy crops and the well-established regulations safeguarding forests and governing land use. [3]. Others factors such as Development of policies and projects related to agriculture mechanization, job opportunities, new research and technological advances, economic development, and the need to increased access to energy services to meet the Millennium Development Goals [18,19] also contribute. Africa can be seen as the single largest potential for the global production of bioenergy crops [18]. This study was therefore undertaken with the aim of exploring the potential vegetable oil resources for biodiesel in Africa. The study draws attention to areas such as current energy situation in Africa, techniques involved in biodiesel production as well as some aspects related to engine performances for biodiesel, trendy state of biodiesel in Africa, driving forces for increased biodiesel production, problems of biodiesel commercialization in Africa, vision for biodiesel in Africa, potential biodiesel resources and fuel properties of selected oil resources for biodiesel. Including, the implications of biodiesel on environment, the African continent as well as the outlook.

2. Energy trendy state in Africa

Africa is one of the fastest growing continents in the world, with all countries growing at annual rates of over 3% and it has a landmass of over 30.3 million km2. The continent is huge in scale– around the size of the United States, China, India and Europe combined – [20]. 16% of the global population lives in Africa (1.2 billion) [21], with a population density of 42 peoples per Km2 in 53 countries of diverse socio-cultural entities [22]. This continent is graced with resources including fossil and renewable; about 9.5%, 5.6%, and 8% of the world's global economic recoverable reserves of oil, coal and natural gas, respectively, are in Africa [20,23]. While it has energy resources more than sufficient to meet domestic needs, more than two-thirds of its population does not have access to modern energy [3,20] The distribution of energy resources in Africa indicates that every sub-region of the continent except East Africa is a net exporter of energy, at the same time importing petroleum products at a cost that is burdening and crippling the economy [5, 20]. North Africa is by far the largest exporter of oil and gas to Europe and other markets. Nigeria and Ghana are leading exporter of oil in West Africa whereas, Southern Africa's net energy export (oil) is from Angola; who also suppliers 99% of Africa's coal output. Gabon, Cameroon and Congo are leaders of Central Africa's oil-exporters to other regions. Five major countries (South Africa, Egypt, Algeria, Nigeria and Libya) had contributed to 84% of all energy produced in Africa as at 2012, (Table 1) [10,24].

Africa's energy sector is vital to its development and yet is one of the most poorly understood parts of the global energy system. Since 2000, much of sub-Saharan Africa has experienced more rapid economic growth than in the past, raising expectations of a new phase of development. Policies are being put in place in many countries aimed at securing a much-needed expansion in domestic energy provision [20, 25]. However, the current state of the energy system represents a major threat to the realization of the region's economic hopes. Energy demand in sub-Saharan Africa grew by around 45% from 2000 to 2012, but accounts for only 4% of the world total, despite being home to 13% of the global population. Access to modern energy services, remains limited: more than 620 million people in sub-Saharan Africa remain without access to modern energy and nearly 730 million rely on the traditional use of solid biomass for cooking. Sub-Saharan Africa produced 5.7 million barrels per day (mb/d) of oil in 2013, primarily in Nigeria and Angola.

Table 1: Major African countries which import and export energy [20,24-26]

Major energy exporters *	Net energy exporters	Importers **
Algeria	Angola	Benin
Congo	Cameroon	Eritrea
	Cote d'Ivoire	
Egypt	D. R. Congo	Ethiopia
Gabon	Gabon	Ghana
Libya		Kenya
Nigeria	Sudan	Morocco
South Africa		Mozambique
		Namibia
		Senegal
		Tanzania
		Togo
		Zambia
		Zimbabwe

* Major energy exports are in excess of 0.5 quads.

** Most of the African countries' imports are very small (less than 0.3 quads).

While 5.2 mb/d of crude oil were exported, around 1.0 mb/d of oil products were imported. Natural gas use of 27 billion cubique meter in 2012 is similar both to the volume that was exported and to the volume that was flared. In the last five years, nearly 30% of world oil and gas discoveries were made in sub-Saharan Africa [28, 33]. Nevertheless, Africa is the lowest consumer of energy: an African consumes only 1/11, 1/6, and ½ of energy consumed by a North American, a European, and a Latin American, respectively [22, 25]. Africa is, yet, an unexploiter of biofuels, especially biodiesel, despite the fact that the majority of its nations rely so much on biomass as the main energy resource [5, 20, 26]. Low incomes, coupled with inefficient and costly forms of energy supply, make energy affordability a critical issue. This really indicates the need for energy diversification in which biodiesel can play a vital role. Biodiesel feedstock can be categorized into four groups [2,27]: oilseeds (edible or inedible oil), animal fats, waste materials and algae as shown in Table 2.

Table 2: Feedstocks categories of biodiesel production

Category	Classification		Feedstocks	References
1. Oilseeds	edible	C	Soybean, rapeseed/canola, sunflower, palm, coconut, olive	[6,8]
		A	False fax, safflower, sesame, marula, pumpkin, African peer seed, Sclerocarya birrea, Terminalia catappa L., yellow nut-sedge tuber, rice bran	[5,7,10,15]
	inedible	A	Jatropha, karanja, mahua, linseed, ruber seed, cottonseed, neem, camelina, putranjiva, tobacco, polanga, cardoon, deccan hemp, castor, jojoba, moringa, pon, koroch seed, desert date, eruca sativa gars, see mango, pilu, crambe, syringa, milkweed, field pennycress, stillingia, radish Ethiopian mustard, tomato seed, kusum, cuphea, camellia, paradise, cuphea, treminalia, michelia champaca, garcinia indica, zanthoxylum bungeanum	[7,16,5-28]
2. animal fats		C	Beef tallow, pork lard	[5,29]
3. waste materials		C	Cooking oil, frying oil	[30,31] [5,32,33]
		A	[illegible] (DDG)	
4. algae			*Botryococcus braunii, Chlorella sp., Chrolella vulgaris, Crypthecodinium chonii, Cylindrotheca sp., Dunaliella primolecta, Dunaliella salina, Isochrysis sp., Haematococcus pluvialis, Monallanthus salina, Muriellopsis sp. Nannochloris sp., Neochloris oleoabundans, Nitzschia sp., Phaeodactylum tricornutum, Porphyridium cruentum Schizochytrium sp., Spirulina, Arthrospira platensis, Tetraselmis suecica*	[34-36]

C: conventional; A: alternative.

3. Biodiesel

Biodiesel is a biomass-derived fuel that is considered to be one of the most promising petroleum diesel fuel substitutes [37, 38]. It is a biodegradable, non-toxic, almost sulphur-free and non-aromatic fuel derived from vegetable oils or animal fats. Chemically, biodiesel is a mixture of monoalkyl (usually methyl-) esters of long chain fatty acids (i.e. fatty acid methyl esters (FAME)) derived by alcoholysis of triacylglycerols (triglycerides) from a renewable lipid feedstock [39-41]. Biodiesel is better than diesel fuel in terms of sulfur content, flash point, aromatic content, and biodegradability [42].

3.1. Biodiesel production technologies

There are four processes to produce a high quality of biodiesel, suitable to be used in conventional diesel engines without modifications: direct use and blending (dilution), pyrolysis, micro emulsion and transesterification [43, 44-47].

3.1.1. Blending

Crude oils can be mixed directly or diluted with diesel fuel. Having blended, the resulting product is well fused so that all parts of the solution are identical. A blending of 20–40% of vegetable oil with diesel fuel for diesel engine has yielded good results [46,48]. In South Africa, researchers studied sunflower oil (during the 1970s fuel crisis and during an oil embargo against apartheid South Africa, adopted by the United Nation General Assembly) [49,50]. Regarding this period, South Africa has a rich history as technology developers in the larger lignocellulosic conversion technologies. In the 1970s, the Council for Scientific and Industrial Research (CSIR) began funding a comprehensive research programme focused on utilization of lignocellulose through the Cooperative Scientific Programmes (CSP) involving research institutes and universities. Valuable outcomes were (i) the discovery and characterization of new yeasts, such as Candida shehatae able to convert the pentose sugars derived from the hemicellulose fraction of bagasse to ethanol, and (ii) the development of the consolidated bioprocessing (CBP) concept that offers the largest potential cost reduction of any potential research-driven improvement in biomass to bioethanol processes. In a similar manner, South Africans ingenuity made significant contributions in the development and establishment of biodiesel technologies. The fuel crisis was so acute that South African farmers were unable to buy the fuel required to plant as much as they intended to; this left South Africa vulnerable not merely on the transport-fuel front, but also to a food crisis, if the situation persisted. So an alternative-fuel project was established, with the “dream” of creating a fuel from agriculture for food production. A research team of the division of Agricultural Engineering developed the sunflower-to-biodiesel technology in South Africa. Initially, to test the viability of sunflower oil as a fuel, the team took a tractor, filled it with sunflower oil and started it; after the engine worked for between 70 – 100 hours, it seized. The injector sprayed the fuel into a cylinder, but the sunflower oil started cooking up the injector with a sticky carbon substance, which eventually; broke the engine because, the bio oil was thicker than the diesel and thus unable to spray fine enough drops. The breakthrough came when a researcher, Louwrens du Plessis at the CSIR suggested a chemical process (trans- esterification with methanol and alkali) for the sunflower oil diesel, which proved successful. The engine ran perfectly as long as the crude bio oil was further extensively refined to fuel standards. The power output achieved using sunflower biodiesel was marginally inferior while the fuel's thermal efficiency, which establishes how well fuel is transformed into mechanical energy, was 10% higher than that of fossil diesel. The sunflower biodiesel, reduces visible emission particles (exhaust smoke) by 36%, carbon monoxide by 44%, aromatic hydrocarbons by 80%, and monocyclic aromatic hydrocarbons by 90%. Pre-combustion chamber engines were run with a mixture of 10% vegetable oil to maintain total power without any alterations or adjustments to the engine in Caterpillar, Brazil, in 1980. At that point, substituting 100% vegetable oil for diesel fuel was not practical, but a blend of 20% vegetable oil and 80% diesel fuel was practical and worked [39,48]. Some advantages of the use of vegetable oils as diesel fuel are: (1) liquid nature-portability, (2) heat content (80% of diesel fuel), (3) ready availability and (4) renewability. The disadvantages of the use of vegetable oils as diesel fuel are: (1) higher viscosity, (2) lower volatility and (3) unsaturated hydrocarbon chains reactivity. For both direct and indirect diesel engines, pure vegetable oils and/or blends have generally been unsatisfactory, impractical and difficult [48].

3.1.2. Micro-emulsification

Micro-emulsion formation is a potential solution for the problem of viscosity of vegetable oil. Micro-emulsion is defined as transparent thermodynamically stable colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the 1–150 nm range formed spontaneously from two normally immiscible liquids and one or more ionic or nonionic amphiphiles [48]. Micro-emulsions are clear, stable isotropic fluids with three components, namely an oil phase, an aqueous phase and a surfactant. Micro-emulsion-based fuels are frequently called "hybrid fuels", although blends of pure diesel fuel with vegetable oils have also been called hybrid fuels [51].The common solvents used are ethanol and methanol. All micro-emulsions with butanol, hexanol and octanol can meet the maximum viscosity limitation for diesel engines [52]. A micro-emulsion prepared by blending soybean oil, methanol, 2-octanol and cetane improver in the ratio of 52.7:13.3:33.3:1.0 has passed the 200h EMA test [53].

3.1.3. Pyrolysis

Pyrolysis is also known as thermal cracking. Pyrolysis refers to a chemical change due to the application of thermal energy in the presence of a catalyst and in the absence of air or nitrogen. The substrates for the pyrolysis method for production of biodiesel can be vegetable oils, animal fats, natural fatty acids or methyl esters of fatty acids. Since the liquid fractions of the temperature based conversion of vegetable oils are likely to approach diesel fuels properties. It has been observed that the biodiesel obtained from pyrolysis of triglycerides is suitable for direct use in diesel engines. This type of decomposition of triglycerides produces alkanes, alkenes, alkadienes, aromatics and carboxylic acids [44-48, 52, 54, 55]. It has been observed that the pyrolyzate had lower viscosity, flash point and pour point than petroleum diesel fuel and equivalent calorific values [3]. Singh and Singh [39] reported that the pyrolysis process is effective, simple, zero wastage and pollution free. The cetane number (CN) of the pyrolyzate vegetative oil or fat was lower compared to fosil diesel. Pyrolyzed vegetable oils have an acceptable quantity of sulphur, water and sediments and give acceptable copper corrosion values but unacceptable ash, carbon residual and pour point [56]. The pyrolysis process can be divided into three subclasses based on the operating conditions: conventional pyrolysis, fast pyrolysis and flash pyrolysis. The mechanism of pyrolysis of triglycerides is illustrated in Figure 1. The scheme of the thermal cracking process is outlined in Figure 2. The yielding of biodiesel starts at a temperature of 250°C and continues up to 300°C with some percent of residue remaining in the reactor. Catalytic cracking plant consists of a reactor with oil inlet to pour raw oil mixed with the catalyst, safety valve to safeguard the reactor, a pressure gauge to indicate the pressure inside the reactor and drain hole to eradicate the residue and waste.

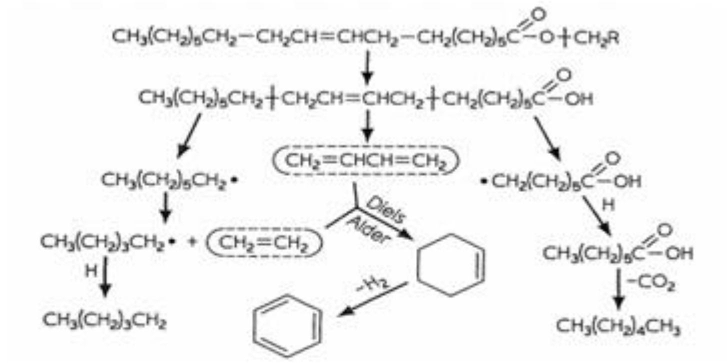

Figure 1: Triglycerides pyrolysis mechanism [57]

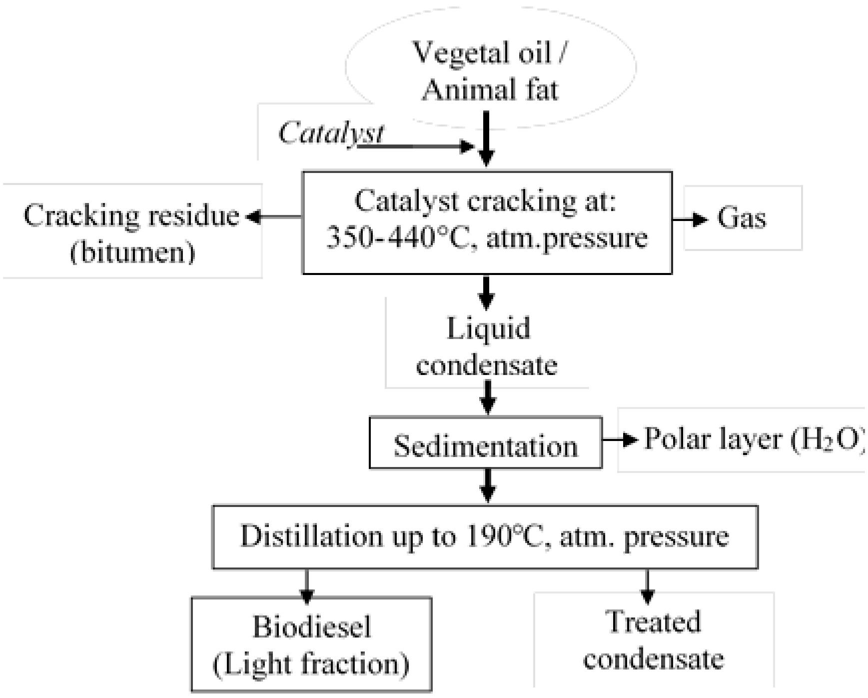

Figure 2: Thermal cracking scheme and procedure for biodiesel production [55,57]

3.1.4. Transesterification

Transesterification is a chemical reaction between triglycerides and alcohol to produce an ester and a by-product glycerol. The process reduces the viscosity to a value comparable to that of diesel and hence improves combustion. Depending on the fatty acid composition of the oil, saponification number, iodine value and cetane number; it can be determined at the initial stage, whether the oil is suitable for transesterification reaction or not. The ratio of raw material to alcohol is quite important to increase yield of Fatty acid methyl esters (FAME) significantly. The molar ratio of alcohol, reaction temperature, catalyst amount, reaction time, water content, and free fatty acids (FFAs) are the process variables that effect catalyzed transesterification. The transesterification reaction undertakes three steps. First step is triglycerides convert to diglycerides, second step is diglycerides convert to monoglycerides, and third step is monoglycerides finally convert to glycerol (Figure 3) [58]. This process requires 3 mole of alcohol for 1 mole of triglyceride to produce 1 mole of glycerol and 3 mole of fatty acid esters, i.e. biodiesel. The reaction is equilibrium. Industrial processes use 6 mole of methanol for each mole of triglyceride [59]. This surplus amount of methanol confirms that the reaction is driven in the direction of methyl esters, i.e. towards biodiesel. Yield of methyl esters can exceeds 98% on a weight basis [59]. There are two types of transesterification processes: catalytic and non-catalytic transesterification. Transesterification reaction can be catalyzed by both homogeneous (alkalis and acids) and heterogeneous catalysts. Acid-catalyzed reactions (i.e.H_2SO_4, H_3PO_4) are used to convert FFAs to esters, and are characterized by slow reaction rate and high ratio of alcohol. Base-catalyzed (i.e. NaOH, KOH, and NaMeO, CH3ONa) process is considered to be better than the acid catalysis, since the reaction is faster (barely 30 min. compared to 1–8 hr) and have roughly the same yield. However, base catalysed reaction is affected by water content and FFAs of oils or fats. FFAs can react with base catalysts to form soap and water. Moreover, acidic catalyst is corrosive and destructive to the reactor and other supporting equipment involved in the process. Homogeneous catalysts show greater performance toward transesterification to obtain biodiesel when the FFA content is less than 1% [60]. Homogeneous catalysts have certain disadvantages such as expensive separation of the homogeneous catalyst from the reaction mixture, generation of large amount of waste water during separation and cleaning of catalyst and the products, formation of unwanted by-product (soap) by reaction of the FFA [61]. Nevertheless, uses of heterogeneous catalysts overcome problems when free fatty acid content is more than 1% and catalyst can be separated more easily from reaction products. Use of heterogeneous catalysts avoid the undesired saponification reactions, and also facilitate the transesterification of plant oils. The use of heterogeneous catalysts considered more environmental friendly and therefore researchers focus on that more as compared to homogeneous. Heterogeneous catalyzed production of biodiesel has emerged as a preferred route as it is environmentally benign, needs no water washing and product separation is much easier. Some of the commonly used heterogeneous base catalyst are: $K/\gamma\text{-}Al_2O_3$ catalyst, $HTiO_2$ hydrotalcite catalyst, Ca and Zn mixed oxide, Al_2O_3 supported CaO and MgO catalysts, alkaline earth metal oxides, KF/Ca–Al, basic zeolites, alkali metal loaded alumina. Still, both types of catalyst transesterification methods have been found to be relevant for biodiesel production [48,62]. Ordinarily, the catalyst increases the reaction rate of the transesterification and also enhances the solubility of alcohol as well. Acid-catalyzed reaction is used to reduce the higher acid value of the feedstocks, as a pretreatment step known as esterification. A higher conversion could be achieved by increasing the reaction temperature and the reaction time [63,64]. Base-catalyzed reaction is faster than the acid-catalyzed reaction but the yield of biodiesel is lowered due to the formation of soap [65]. In addition to this, the separation of biodiesel from glycerol is quite difficult. However, it is observed that methoxide catalysts give higher yields than hydroxide catalysts [66,67].

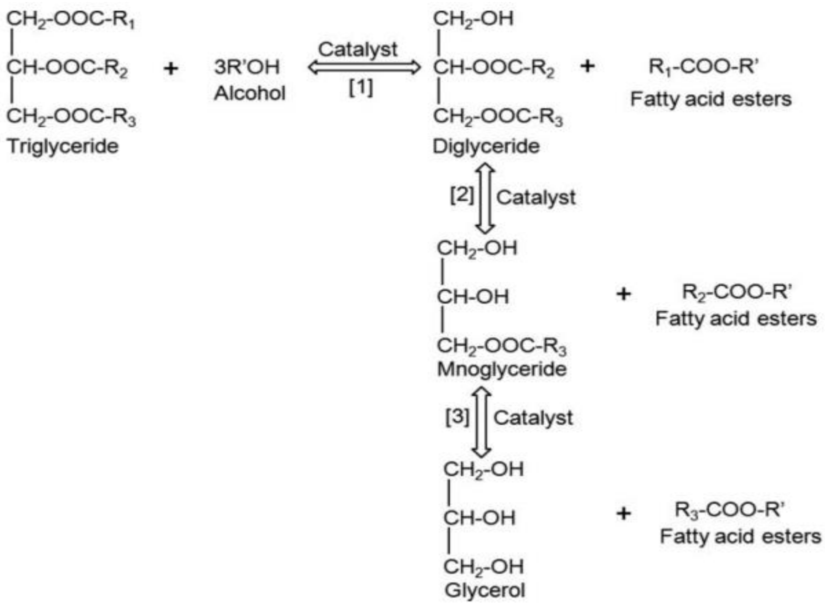

Figure 3: Steps involved in the transesterification process

In view of the fact that both homogeneous acid and base catalysts have certain limitations, a combination of both the catalysts (sequentially) called transesterification double step process (TDSP) are used that have high yield of FAME especially in the feed-stocks having high FFAs content like Neem oil. In the first step, the acid catalyst is used to transesterify the FFAs to ester which drops FFAs to less than 0.5 wt%. In the second step transesterification of low FFAs oil is carried out with needs the base catalyst. Therefore, TDSP helps to eliminate the limitations of the basic or acid catalytic methods and resulting in an efficient and easier quality biodiesel production [67]. Both ethanol and methanol can be used to alcoholize the transesterification reaction of biodiesel production. The low cost, chemical (shortest chain of alcohol) and physical (polar) properties of methanol make it the first preference in chemical reactions. Catalytic transesterification of vegetable oils/animal fats with methanol is also known as methanolysis: this reaction is well studied and established using acids or alkalis, such as sulfuric acid or sodium hydroxide, as catalysts. Usually, industries use sodium or potassium hydroxide or sodium or potassium methoxide as catalyst, since they are relatively less expensive and quite active for this reaction [46,68]. Transesterification can also be catalysed by enzymes. The most commonly used enzyme for transesterification is lipase. Lipase of different organisms are reported such as *Candida antarctica* [69,70], *Candida rugasa* [71], *Pseudomonas cepacia* [72,73], immobilized lipase (Lipozyme RMIM) [74,75], *Pseudomonas* sp. [76] and *Rhizomucor miehei* [77,76]. Most of the studies on lipases for biodiesel production have principally focused on screening of lipases and on investigating the factors that influence the reaction [78]. As for the enzyme-catalysed system, the transesterification reaction is more time consuming than the other two catalytic methods of transesterification [79]. The lipase of both extracellular and intracellular will catalyse the transesterification of triglycerides in either aqueous or non-aqueous systems effectively. Enzymatic catalysed transesterification methods can overcome the problems mentioned above either by alkalior acid-catalysed transesterification [59]. The disadvantage of the lipase-catalysed process is the high cost of the lipases used as catalyst [69]. The enzyme reactions are very specific and chemically clean. Due to the alcohol acting as inhibitory to the enzyme, a specific strategy is to feed the alcohol into the reactor in three steps of 1:1 mole ratio each. The reaction rate is very slow, with a three-step sequence requiring 4–40 h, or more. The reaction conditions are modest, from 35–45°C [80]. Non-catalyzed production of biodiesel includes two processes: supercritical and Biox processes. Supercritical alcohol transesterification reaction takes place under extremely high temperature and pressure. A supercritical fluid (SCF) is a compound, mixture, or element above its critical pressure and critical temperature, but below the pressure required to condense into a solid [81]. Under such conditions, the densities of both liquid and gas phases become identical, and the distinction between them become difficult The properties of supercritical alcohol are lie in-between those of a gas and a liquid [82]. Supercritical method is expected not to be affected by FFAs and no soap generation is involved and therefore, the quality of biodiesel and glycerin is better than catalyzed reaction with significantly low reaction time. Goembira and Saka [81], reported highest yields of FAME (96.7 wt. %) and triacetin (8.8 wt. %) with supercritical methyl acetate method. The main limitations of this method are that it depends on critical conditions of alcohol which demands high pressure (4.9–8.1MPa) and temperature (239–290°C). Modification of supercritical process involve two-step for high yield of FAME consisting of hydrolysis of oils in sub-critical water and subsequent supercritical dimethyl carbonate esterification. Sawangkeaw and his colleagues [83], reported enhancement in fuel up to 4.7% and 12.9% using supercritical methanol and supercritical ethanol process, respectively. Ionic liquids (ILs) uses as both solvents and catalysts have attracted significant attention for their use in biofuel production. ILs are organic salts with melting points around or below the ambient temperature. ILs are composed of organic cations and either organic or inorganic anions. The most common ILs are divided into four groups according to their cations: quaternary ammonium ILs, N-alkyl-pyridinium ILs, N-alkyl-isoquinolinium ILs, and 1-alkyl-3-methyl-imidazolium ILs. In Biox processes, co-solvent is primarily used to overcome low solubility of methanol in oil. The process takes place at a low temperature of 30°C and convert oil with high percentage of FFA (more than10%) into biodiesel. The process involves two steps where in the first step, the conversion of FFA was achieved and in the second step conversion of triglyceride take place. The addition of the co-solvent is required in each step. The most commonly used co-solvent is tetrahydrofuran due to its close boiling point to that of methanol. Figure 4 shows the procedure where the reactor stage refers to individual stage involved while the separation of methanol and co-solvent is achieved in the lower separation process. The co-solvent is recycled and reused through the continuous process. In the separation process, both excess methanol and the co-solvent are recovered from the products. The main advantages to use this process is its ability to handle feeds with high FFA, the reaction time is short and it can be carried out under ambient temperature and pressure. The limitation of this method include complete removal of co-solvent is required due to its hazardous and toxicity natures and further the separation of methanol and the co-solvent is difficult due to their very closed boiling points. Several enhancing methods for biodiesel production viz., ultrasound-irradiation, hydrodynamic cavitation and microwave-irradiation process have been developed that needs lesser catalyst, time and has lesser energy consumption than just transesterification [84-88]. Ultrasound wave generates cavitation bubbles as it passes through the liquid. The use of ultrasonic energy in biodiesel production process is a new, attractive and effective procedure to solve problems that are faced by conventional methods. Ultrasonic irradiation is cost effective biodiesel production method and leads to the creation of cavitation bubbles near the phase boundary of alcohol and oil and therefore enhance the yield. Transesterification using low frequency ultrasound (28-40 kHz) results in higher yields using lower amount of catalyst in short period of time [89, 90].

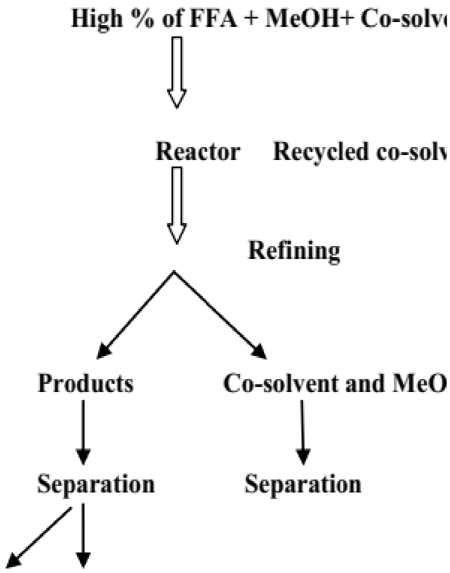

Figure 4: Flow diagram of the Biox process

Hydrodynamic cavitation involves the formation and collapse of bubbles. The bubbles are generated around the vapour pressure of the liquid and after collapsing, raise the temperature up to 103-104 K and thus increasing the rate of reaction. Ghayal and his colleagues [91], reported that more than 95% of triglycerides were converted to methyl esters in 10 minutes of reaction time with cavitational yield of 1.28 × 10−3 (grams of methyl esters produced per joule of energy supplied). Microwave-assisted transesterification of different feedstocks such as rapeseed oil, cotton seed oil and waste cooking oils has been reported by several researchers [92, 93]. Microwave applications in biodiesel production has settle the ability of the technology to achieve superior results over conventional techniques. Short reaction time, cleaner reaction products, and reduced separation-purification times are the key observations reported by many researchers. The required wavelength and frequency range of microwave irradiation for transesterification of oil is 0.01 to 1 m and frequency range of 0.3 to 300 GHz, respectively. In the range of methods adopted for the production of biodiesel fuel, the pros and cons of the four primary ways; with yield, reaction conditions and effects on fueled engine have been illustrated in Table 3.

Table 3: Pros and Cons of different methods of biodiesel production; yield, reaction condition and impact on fueled engine

Methods	Advantage	Disadvantage	Biodiesel yield (%), running time and temperature	Problems of using in engines	References
Direct use and blending	Liquid nature-portability Heat content (80% of diesel fuel) Readily available	Higher viscosity, Lower volatility Reactivity of unsaturated hydrocarbon chains	----	Coking and trumpet formation. Carbon deposits. Oil ring sticking; thickening and gelling of the lubricating oil	[94-96]
Micro-emulsions	Better spray patterns during combustion. Lower fuel viscosities	Lower cetane number Lower energy content	90-98% (4min-20min; 60°C – 80°C)	Irregular injector, needle sticking; incomplete combustion, Heavy carbon deposits; increase lubrication oil viscosity	[97,98]
Thermal cracking (pyrolysis)	Chemically similar to petroleum derived gasoline and diesel fuel	Energy intensive and hence higher cost	84-94% (4min-20min; 60°C – 80°C)	----	[94,99]
Transesterification	Higher cetane number; lower emissions; higher combustion efficiency	Disposal of byproduct (glycerol and waste water)			
Alkali Homogeneous	High catalytic activity, low cost, favorable kinetics, modest operation conditions	Low FFA requirement, anhydrous conditions, saponification, emulsion formation, more wastewater from purification, disposable	80-95% (1-6hrs; 50°C – 70°C)	----	[100-102]
Acid Homogeneous	Catalyze esterification and Transesterification simultaneously, avoid soap formation	Equipment corrosion, more waste from neutralization, difficult to recycle, higher reaction temperature, long reaction times, weak catalytic activity			
Alkali Heterogeneous	Noncorrosive, environmentally benign, recyclable, fewer disposal problems, easily separation, higher selectivity, longer catalyst lifetimes	Low FFA requirement, anhydrous conditions, more wastewater from purification, high molar ratio of alcohol to oil requirement, high reaction temperature and pressure, diffusion limitations, high cost	84-99% (1.5-4hrs; 50°C – 150°C)	----	[102-104]
Acid Heterogeneous	Catalyze esterification and Transesterification simultaneously, recyclable, eco-friendly	Low acid site concentrations, low microporosity, diffusion limitations, high cost			
Enzymes	Avoid soap formation, nonpolluting, easier purification	Expensive, denaturation	90.93-99% (24-72hrs; 35°C – 37°C)	----	[105-107]

3.2. Biodiesel emerging technologies

The most common problems associated with crude vegetable oils are high viscosity, low volatility and polyunsaturated characters. Due to their ability to bypass limitations encountered by conventional methods; some processes, appear reliable for biodiesel production in the future. For instance: Catalytic hydrodeoxygenation (HDO) and Membrane biodiesel production processes. In the HDO process, the main concern is to upgrade the biomass-derived oil by removing the oxygen contents present in the feedstock as water. In addition to this, it also removes sulfur and nitrogen present in the fuel eliminating the chances of the formation of oxides of sulfur and nitrogen [108]. The process includes the treatment of oil at high pressures and moderate temperatures over a heterogeneous catalyst. The use of vegetable oils, as feedstocks is highly favorable for this process because their hydrocarbon content is in the same range as that of fossil fuels such as kerosene and diesel. A study by Prasad and his colleagues [109] tried to explain the catalytic hydrodeoxygenation reaction along with the formation of byproducts. The chemistry of the reaction and the formation of products purely depend on the catalyst being used in the reaction [110, 95]. The reaction takes place with simple hydrodeoxygenation via an adsorbed enol intermediate and the product is a hydrocarbon fuel with water and propane as the by-products. The hydrocarbon fuel produced by this hydrodeoxygenation method is characterized by its improved properties compared to conventional petroleum-based fuels. This biofuel exhibits a higher cetane number. Notwithstanding, the n-paraffinic fuel has poor cold flow properties. To improve these low-temperature properties, the nparaffin is isomerized to isoparaffin. During the isomerization, the normal paraffin with its high freezing point and outstanding cetane number can be converted to isoparaffin, which has a far lower freezing point but retains a high cetane number [111-113]. Membrane processes for the production and refining of biodiesel are being increasingly reported. Membrane technology has attracted the interest of researchers for its ability to provide high-quality biodiesel and its remarkable yield as well [114-116]. Membrane reactors are suitable for biodiesel production due to their ability to restrict the passage of impurities into final biodiesel product [117]. This restriction of impurities helps in obtaining quality biodiesel from the feedstocks. The impurities, mainly the unreacted triglycerides should be removed after the completion of transesterification reaction [118,119]. This issue could be solved by employing organic/inorganic separative membranes for cleaning the crude biodiesel. Furthermore, organic/inorganic separative membranes have many advantages as they consume low energy, are safer and simple in operation, eliminate wastewater treatment, have easy change of scale, higher mechanical, thermal and chemical stability, and resistance to corrosion [120]. Atadashi and his colleagues [121] concluded that membrane technology could produce a high-quality biodiesel. Furthermore, they reported that properties of biodiesel from the membrane technology process were in agreement with the ASTM standard specification.

3.3. Performance evaluation of engine using biodiesel as fuel

3.3.1. Specific fuel consumption (SFC)

It is defined as the mass fuel flow rate per unit power output. The interest to estimate specific fuel consumption is to determine how well an engine will use a fuel supplied to the work produce. It is observed that, while using mustard oil as raw material, as the load increased specific fuel consumption decreased to the minimum [122].

The fuel mass flow can be computed using the following equation:

$$F = [(Mt + Mi) - (Mt + Mf)]/t \qquad (1)$$

Where, F: fuel mass flow (kg/s), Mt: storage tank mass (kg), MI: initial fuel mass (kg), Mf: final fuel mass (kg), t: test time (sec).

3.3.2. Brake horsepower

It is the amount of power generated by a motor without taking into consideration any of the various auxiliary components like gear, friction, transmission etc. that may slowdown the real speed of the motor. It is also known as "crank horsepower". It is given by:

$$\mathrm{BHP} = (2\pi \mathrm{NT})/60 \qquad (2)$$

Where, T: torque (Nm), N: Rotational speed (revolutions/minute)

3.3.3. Thermal efficiency

Brake thermal efficiency is the percentage of energy taken from the combustion which is actually converted into mechanical work. The following equation represents thermal efficiency of the engine:

$$\eta = [3600/(LHV)(SFC)]100 \qquad (3)$$

Where, η: set efficiency (%), SFC: specific fuel consumption (g/kW/h), LHV: lower heating value (MJ/kg) – It is the effective energy released per unit of fuel mass and also the work generated.

3.3.4. Effect of biodiesel on engine power

From the cited literature, engine power will drop due to the loss of heating value of biodiesel. However some researcher reported that there was no significant difference in engine power between pure biodiesel and petroleum diesel (PD) [123,124]. Utlu and Koçak [125] found that the respective average decrease of torque and power values of WFOME (waste frying oil methyl ester) was 4.3% and 4.5% due to higher viscosity and density and lower heating value (8.8%). Hansen and his colleagues [126] observed that the brake torque loss was 9.1% for B100 biodiesel relative to D2 diesel at 1900 rpm as the results of variation in heating value (13.3%), density and viscosity. And Murillo and his colleagues [127] found that the loss of power was 7.14% for biodiesel compared to diesel on a 3-cylinder, naturally aspirated (NA), submarine diesel engine at full load, but the loss of heating value of biodiesel was about 13.5% compared to diesel.

3.3.5. Effect of content of biodiesel on engine power

Content of biodiesel blended with diesel results in variations of engine power performance. Carraretto and his colleagues [128] observed that, the increase of biodiesel percentage in the blends resulted in a slight decrease of both power and torque over the entire speed range for different blends (B20, B30, B50, B70, B80, B100) of biodiesel and diesel on a 6-cylinder DI diesel engine. Aydin and his colleagues [4] reported that the torque was decreased with the increase in CSOME (cottonseed oil methyl ester) in the blends (B5, B20, B50, B75, B100) due to higher viscosity and lower heating value of CSOME. Pal and his colleagues [84], showed the variation of brake power was almost negligible for all types of Thumba oil biodiesel blends (B10, B20, B30) within a whole engine speed range on a 4-cylinder, DI, water-cooled (WC) diesel engine. [84]. Gumus and Kasifoglu [129] found the power increased with the addition of biodiesel content in the blends until the B20 blend and reached a maximum value, when the biodiesel content continued to increase in the blends, the power would decrease below that of the diesel fuel and reached minimum value for B100, which was obtained on a single cylinder, 4-stroke, DI, air-cooled (AC) diesel engine. Likewise, Usta and his colleagues [130] showed that the power initially increased with the addition of biodiesel, reached a maximum value, and then decreased with further increase of the biodiesel content. Lapuerta and his colleagues [124] and Ghobadian and his colleagues [131] obtained very small variations in effective torque with respect to waste cooking oil methyl ester and ethyl ester (WCOM and WCOE) and their blends (WCOM30, WCOM70, WCOE30, WCOE70) on a 4-cylinder, 4-stroke, turbocharged (TU), intercooled, DI, 2.2 L Nissan diesel engine. And with respect to waste cooking biodiesel blends (B10, B20, B30, B40, B50) at full load on a 2-cylinder, 4-stroke diesel engine. Mejia and his colleagues [132], reported the use of castor oil biodiesel in the blends could lower the cloud point value but simultaneously, increase the viscosity of the diesel–biodiesel blends.

3.3.6. Effect of Properties of biodiesel and its feedstock on engine power

Biodiesel properties, especially heating value, viscosity and lubricity, have an important effect on engine power. The lower heating value of biodiesel is attributed to the decrease in engine power. Higher viscosity of biodiesel generally results in the power losses, because the higher viscosity decreases combustion efficiency due to bad fuel injection atomization [123, 125,133-135]. High lubricity of biodiesel leads to the reduced friction loss and thus improves the brake effective power [136]. Biodiesel feedstocks have little or no effects on engine power. The maximum and minimum differences in engine power and torque at full load between the PD and VOMEs were only 1.49% and −0.64%, 1.39% and −1.25%, respectively, which indicates that using VOME (vegetable oil methyl ester) yields the same engine power as PD at full load conditions as well as at average load conditions for various engine speeds [123,134].

4. Effect of Engine type and its operating conditions on biodiesel engine power

Engine type and its operating conditions, such as engine load, engine speed, injection timing and injection pressure, have significant effects on biodiesel engine power.

The engine power and torque can be increased by the application of the low heat rejection engine, due to the increased exhaust gas temperatures before the turbine inlet in LHR engine. Comparison on naturally aspirated (NA) conditions to the turbocharged (TU) conditions on a 4-stroke, DI diesel engine showed mean increase in torque for biodiesel with the TU conditions.

5. Current state of biodiesel in Africa

In Africa, biodiesel is one of the emergent biofuels. Currently, the biodiesel market is mainly characterized by several small- and medium-scale producers. Meanwhile, plans for large-scale investment projects, are far advanced for the commencement of its commercial productions in various countries including: Ghana, Zambia, Liberia, Tanzania, Ethiopia, Nigeria, Senegal, Kenya, Angola, Mozambique, Zimbabwe and South Africa. [137-139]. Small-scale biodiesel production using Jatropha curcas is presently, disseminated in the continent. In Ghana for example, Anuanom Industrial Bio-Products and Biodiesel**1** Ltd have two biodiesel production plants in place with an annual capacity of 70,000 metric tonnes of jatropha oil per plant (combined annual capacity of 140,000 metric tonnes). The company (Anuanom) had a partnership with a German-Austrian private company to invest 12-million-dollar, for a biodiesel production factory of a capacity of about 360,000 t/a. With the assistance of the Bulk Oil Storage and Transportation (BOST) Company Limited (in Ghana), this is expected to be the first commercial biodiesel production plant in Africa on condition that; raw materials will be available to sustain the production. Other African countries have measures in place to push the biodiesel agenda in various strategic proposals. Typically, Energy Commission of Ghana has proposed that a national biodiesel target of 20% should be met as from 2015. Plans are in place to waive off duties and levies in support of this process [140]. Countries including Mali, Cameroon as well as Eastern and Southern African countries have targets in place with programmes initiated to enable smooth take-off and sustenance of the industry. The Mali Folke Center, a local NGO supports Jatropha for biodiesel and power generation in Mali [141]. Projects are being developed in Cameroon as from 2008, where about 30000 - 250000 ha of jatropha and palm oil cultivar, are destined for the production of biodiesel [142]. Since 2013, Zimbabwe's National Biodiesel Feedstock's Production Program, has aimed for substituting at least 10% of its daily consumption of imported fossil fuel through biodiesel. South Africa has already started selling petroleum fuels blended with 10% biodiesel at its petrol and filling stations since 2007 [143] and the targeted crops for biodiesel production include canola, soybeans and sunflower. In Zambia, a US$8 million biodiesel plant is in place, by kind courtesy of Marli Investment where jatropha oil will be the source of feedstock. Also located in Kabwe, about 140 km north of the capital, Lusaka, is a biodiesel plant which was expected to produce 60 million liters of fuel per year. This plant has already been in operation since August 2007 [143]. Angola already has over 80 million hectares of agricultural land reserved purposely for the cultivation of biodiesel crops and could, with effective strategies and coordination, become an African ‘biofuels superpower’ [144]. Other investments in Africa include: D1 oils in Swaziland, Madagascar, South Africa and Zambia, International Biofuels Crops in Liberia, Nigerian National Petroleum Corporation and the Dutch biodiesel equipment manufacturer in Senegal (BioKing).The first biodiesel plant in Mozambique was erected in Matola, in 2007 by Ecomoz as a result of the mandate from the Mozambique government. To address the erratic supply of raw materials (mainly Jatropha curcas and coconut copra), this programme focuses on utilizing available community resources, by stimulating economic and social activities in previously forsaken rural communities through the establishment of rural Trading Points [145]. Biofuels in Africa are being developed in a very complex, dynamic and diverse context. This has resulted in many differing and contrasting frameworks and policies. To date, only a few African countries have implemented effective support policies for renewable (biofuels) energy. Table 4, indicates the biofuel potential of different resources in selected African countries for modern energy, the fact that biodiesel is an emergent one in Africa and the current policy state on biofuels [43, 146-148].The South African national standard (SANS 1935) specifies requirements and test methods for marketed and delivered biodiesel to be used either as automotive fuel for diesel engines at 100% concentration, or as an extender for automotive fuel for diesel engines. At 100% concentration, it is applicable to fuel use in diesel engine vehicles or subsequently adapted to run on 100% biodiesel.

6. Challenges for biodiesel production and commercialization in Africa

In spite of the trend supporting the growing interest in biodiesel in Africa, some factors, practices, perceptions and policies, may also hinder or delay biodiesel commercialization in the continent. Some of these issues are as follows:

6.1. Land use and tenure system

Land is central to biodiesel development. In order to gain maximum benefits from biodiesel, large tracks of lands are required for production of energy crops. However, in Africa most lands are family property and do not belong to an individual. Others are also community lands and are only rented to investors for a short while. In cases where the land is taken away from the socially and economically vulnerable communities or families, it negatively affects them. In Tanzania for instance, most of the land belongs to about 11,000 villages where smallholder production is the mainstay of rural livelihood [3]. Any attempt to secure such lands for commercial energy crops will not only prove difficult but also worsen the poor farmers' plight. Other African nations with community and customary oriented lands include Ethiopia and Mozambique [150,151].

6.2. Financial problems

The high initial cost of biodiesel production with respect to acquisition of resources and infrastructure as well as inadequate financial arrangements for biodiesel technology could be an important barrier to biodiesel commercialization in most African countries. Existing capital markets do not favor small-scale investments as required for some biomass energy. This even though might not be peculiar only to African countries [151], developing countries face the worse. Some factors contributing to this include lack of available credit facility with low interest rate.

6.3. Technical issues

Biodiesel production process presents distinct barriers related to technical issues [152]. The supply of feedstock is crucial to the success of biodiesel process. As such, securing resources to produce biodiesel in Africa could be problematic. By way of example, to supply 30% volume of the petrol used in South Africa would require the order of 5 million tons of soya bean. This is a reasonably large amount as it is only half the maximum available capacity [5]. Another factor could be the perception by the poor African that only the developed world can afford biodiesel. This is because only industrialized countries such as Brazil, Russia, Germany, USA, China, etc. currently have the technological base, the capital and infrastructure to push large-scale biodiesel production.

6.4. Information hurdles and paucity of expertise

Due to lack of awareness and limited information on biodiesel, the benefits (both economical and environmental) are potential hindrances to the market penetration of biodiesel in most African countries. The public do not have much education on the development, application, dissemination and diffusion of biodiesel's resources and technologies in the national energy market. The fact that stakeholders and the consumers are not sensitized to the potentials of biodiesel is another issue. This could even probably affect the view of investors as risky [3]. The development of biofuels in Africa occurs in the rural areas. Since these are areas where many subsistence farmers reside with limited means of communication, poor telecommunication infrastructure and high cost of services could also be a source of barrier to biodiesel commercialization in Africa. The limited availability of experts and skilled manpower for biodiesel development could hinder the development and market penetration of the industry. This is largely due to the exodus of highly trained manpower from developing countries, most especially Africa to industrialized nations. For example, between 1980 and 2000, Africa as a whole counts only 3.6% of the world total scientists and its share in the world's scientific output has fallen from 0.5% to 0.3% as it continues to suffer the brain drain of scientists, engineers and technologists. Though the number of scientific papers produced by Africans has tripled in the past decade, to over 55,400 in 2013, according to Reed Elsevier, an Anglo-Dutch information company. That still only accounts for 2.4% of the world's total For example, Africa as a whole counts only 20,000 scientists (3.6% of the world total) and its share in the world's scientific output has fallen from 0.5% to 0.3% as it continues to suffer the brain drain of scientists, engineers and technologists [153]. The increase in number of this exodus could be attributed to the deterioration in political, economic, and social conditions in the continent and these reduce the availability of skilled manpower (human resources) which African countries need for self-reliant and sustainable development [3].

6.5. Policy, institutional and legal hurdles

Commercialization of biodiesel requires adequate institutional support and deliberation. Shortfall of coordination among institutions involved in biodiesel development and commercialization such as government, ministries of energy/science and technology, research and financial institutions hinders efforts for the speedy adoption of biodiesel process. African countries are characterized by a weak legal system, with problems ranging from paucity of appropriate legislation, little respect for the judicial system to weak legal enforcement.

Table 4: Biofuels Key Feedstocks, regional bodies and policies in some selected African countries [43,146-149]

Country	**Regional representation**	**Regional body**	**Feedstocks**	**Biodiesel** Megalitres (ML)	**Bioethanol** Megalitres (ML)	**Presence of Policies**
Ghana	West Africa	ECOWAS	Jatropha, Palm oil, Rubber	50	--	Energy Policy, renewable energy
Nigeria	West Africa	ECOWAS	Jatropha, Palm oil, Rubber, Sesame , Neem, Molasses	--	70	Energy policy, Biofuels strategy
D.R.Gongo	Central Africa	not establish	Palm oil, Rubber, Melon, Sesame	--	--	Draft energy policy
Angola	Southern Africa	SADC	African palm oil	--	--	Biofuel law
Mozambique	Southern Africa	SADC	Jatropha, sugarcane	--	--	Renewable energy policy, biofuels strategy
South Africa	Southern Africa	SADC	Sunflower, canola, soya, rapeseed sugarcane	--	--	Energy policy (SANS 1935), renewable energy white paper, anddraft biofuel industrial strategy
Cameroon	Central Africa	not establish	Jatropha, Palm oil, Rubber, Sesame, Melon	--	--	No biofuels policy
Congo	Central Africa	not establish	Palm oil, Rubber, Melon	--	--	Policy under development
C.A.Republic	Central Africa	not establish	Rubber, Melon, Sesame			No biofuels policy
Ivory Coast	West Africa	ECOWAS	Rubber, Sesame, Tobacco, Molasses	--	20	Policy under development
Liberia	West Africa	ECOWAS	Rubber, *Pongamia pinnata*, Palm oil	--	--	Draft biofuel policy
Guinea Bissau	West Africa	ECOWAS	Rubber, Palm oil, Cashew	--	10	Policy under development
Uganda	East Africa	EAC	Molasses	--	119	--
Gabon	Central Africa	not establish	Rubber, Palm oil, *Pongamia pinnata*	--	--	No biofuel policy
Guinea	West Africa	ECOWAS	Rubber, Palm oil, Sesame	--	--	No biofuel policy
Benin	West Africa	ECOWAS	Palm oil, Jatropha	30	20	--
Mali	West Africa	ECOWAS	Jatropha	--	--	Renewable energy, energy and biofuel industrial strategy
Malawi	Southern Africa	SADC	Molasses	--	146	Malawi's national energy policy
Kenya			Jatropha, Molasses	40	413	--
Swaziland	Southern Africa	SADC	Molasses	--	480	National energy policy – Renewable Energy Action Plan
Tanzania	East Africa	EAC	Molasses, Jatropha	--	254	Energy policy-process of developing a strategy
Zambia	Southern Africa	SADC	Jatropha, sugarcane, sorghum	--	--	Renewable energy, energy and biofuel industrial strategy
Zimbabwe	Southern Africa	SADC	Jatropha, sugarcane and OIL seeds	--	--	Draft energy policy
Sudan	Northern Africa	not establish	Molasses	--	408	--
Uganda	East Africa	EAC	Jatropha, Molasses	--	119	Energy policy
Burkina Faso	West Africa	ECOWAS	Neem, *Balanites aegyptiaca*, Jatropha, Sugarcane,	--	20	Draft biofuel policy

7. Potential benefits of biodiesel processes

7.1. Poverty alleviation

The expansion of biodiesel occurs in the rural areas where there are land opportunities for agriculture as well as the feedstocks. These areas include the poorest Africans where many small-scale and subsistence farmers reside. Biodiesel activities are seen to contribute to poverty alleviation through provision of income per capita by cultivating and selling of crops (energy) produce [19]. Countries such as South Africa and Mozambique are committed to promoting biodiesel mainly in response to national poverty alleviation agenda. Whether biodiesel development enables the achievement of this goal is an issue that needs comprehensive investigation.

7.2. Increase job creation with improved standard of living

Women in developing countries are responsible for securing energy and water for their households and also doing the majority of farm work. There is therefore the potential that biodiesel commercialization can assist in liberating women from these toilsome burdens [154], thereby empowering them and making fuel more accessible and affordable and at the same time freeing them for other activities. Biodiesel commercialization can also rapidly increase developing countries' agricultural productivity. The environmental and socio-economic transformations prompted by the growing global demand for biodiesel will have positive impacts on men and women in developing countries.

8. Vision for biodiesel in Africa

Most African countries suffer from the huge burden of petroleum importation. Biodiesel as an emergent technology in Africa has been envisaged in the following ways [137]:

(i) The process will lessen foreign exchange drain on the national coffers.

(ii) Help provide power for places without access to the national/ regional grid.

(iii) To enhance job creation right from farm level to the marketing/exportation of products.

(iv) To attract funding of projects through international funding agencies. Such schemes could aid in exploring access to climate change projects and markets.

(v) To make available unexploited land resources to enhance food and energy security in Africa.

(vi) For Africa to become raw material exporter to other regions instead of importer.

9. Potential oil resources for biodiesel in Africa

Subramanian and his colleagues [155] reported that, there are over 300 tree species which can produce oil seeds. Azam and his colleagues [156] observed that different oil-bearing plants are unutilized and have the potential to be used as raw materials for biodiesel. Their study revealed that 37 out of the total [157] species of plants found could be suitable for biodiesel. Table 5 illustrated the phisico-chemical properties of biodiesel from potential feedstocks in Africa.

10. Implication of biodiesel on environment and the African Continent

The long-term impact of biodiesel production on the environment is very essential. Biodiesel is considered carbon neutral as the CO_2 released during consumption is trapped from the atmosphere for the growth of plants. Comparing pollutants emission of biodiesel to conventional diesel, biodiesel emits lesser pollutants [158,159]. Sarantopoulos and his colleagues [160], evaluating a small-scale biodiesel production technology, with a case study of Mango'o village in Cameroon, observed that: biodiesel against fossil fuel, reduces the greenhouse gas emissions. This presupposes that the engine exhaust contains little or no SO_2, with less or reduced emissions of PAH, CO, HC and NOx. The growing of energy crops on marginal lands can also help reclaim wastelands to reduce competition of growing food crops on fertile lands. Growing of non-edible oil plants for biodiesel will also ensure infinite supply of renewable energy as the sun will continue to hit the earth to fuel all the activities for all year round [161,162]. Biodiesel will also strengthen the economy since more jobs can be created in the agriculture sector and the taxpayers' money would no more be used to import fossil fuel. Martin and his colleagues [163] study on biofuel development initiatives in Tanzania attests to the fact that there is a great deal of optimism that biodiesel will reduce the burden of importing fossil fuels and improve livelihoods as well as alleviate poverty in Africa. It will also help strengthen international trade between Africa and the rest of the world. However, biodiesel can contribute to greenhouse gas emissions. A related study by Stephenson and his colleagues [164] on global warming potential and fossil-energy requirements of biodiesel production scenarios in South Africa concluded that biodiesel activities contribute significantly to greenhouse gas emission. Biodiesel activities could also contribute to forest depletion and biodiversity threat, instigation of land ownership and usage conflicts, food security, pollution, trade and its impact on national and global economies [24]. All the cultivation practices starting from land clearing and the consequent loss of forests and grasslands could aggravate the current threat of global warming and climate change. Using productive lands for energy crops can also result in increased competition for land for other industrial and urban purposes.

Table 5: African biodiesel physico-chemical properties and feedstocks

Feedstocks	Seed Oil content (wt%)	Kinematic viscosity (40°C mm²/s)	Density (kg/m³)	Cetane number	Flash point (°C)	Cloud point (°C)	Oxidation stability (110°C)	Reference
Jatropha	40- 60	4.80	880	55.84	135	2.7	2.3	[39,156,165]
Jojoba (15°C)	45- 55	5.2	920	55	186	16	–	[156,166,167]
Mahua	35- 50	3.98	850	56.61	208	5	7.1	[56,168, 169]
Moringa	33- 41	4.91	877.5	62.12	206	10	–	[168,170,171]
Tung oil (15°C)	40.37	7.84	903	39	–	–	0.3	[168,172,173]
Rice bran	14.83 - 15.20	4.81-5.6	872-877	51.6	153	–	–	[173,174,17]
Camelina	43	4.15-4.3	884-888	42.76	151-152	0 (3)	1.3-2.5	[39,47,168]
Castor oil	45- 50	15.25	899	52.31	–	13.4	1.1	[39,165, 168]
Derris indica (15°C)	13.4- 26.97	4.85	890	58	180	–	6	[60,172,176]
Baobab	20.8- 33	–	–	–	–	–	–	[177]
Citrullus	14.8- 57.26	–	–	–	–	–	–	[178,179]
Croton oil	26.73 -50	4.6	889.9	46.6	189	4	–	[60,180,181]
Milk bush	20- 25	4.33	875	61.5	75	12	–	[60,172,182]
Algae	20- 50	9.8	–	71.67	149	16	–	[176, 183,184]
Parkia	16.86	–	–	–	–	–	–	[185,186]
Rubber	40 - 60	3.12	–	43-66.2	128	5	–	[60,187,188]
Tomato seed	32- 37	–	–	–	–	–	–	[2]
Tobacco	36- 41	4.23	888	51.6	165.4	–	–	[2, 165,176]
Neem	20 - 30	5.21	884	57.83	–	–	0.8	[39,173, 182]
Ethiopian mustard	42	–	–	–	–	–	–	[2]
Cotton seed	17- 25	50	0.912	41.2-59.5	–	–	–	[2,189]
Sesame	45-63	1.23	0.860	51.41	180	-9	>6 h	[41,190,191]
Sunflower seed	32-50	4.5	0.88	49	–	–	–	[41,192]
Desert date	45-50	–	–	–	–	–	–	[2,165]
Shea nut	32- 55	4.42- 4.77	877	58	171	6	–	[193,194]
Palm kernel	43.9-48.2	4.839	0.883	66.5	6	167	–	[195,196,197]
Palm oil	63.8-74.9	5.14	0.89	63.6	185	21	–	[197,198]
Groundnut oil	45.3	5.16	088	50.51	202	–	–	[199,200]
Coconut oil	45.5	2.7	800	51	100	–	–	[201]
Soybean oil	19 - 27	4.66	0.86	–	150	-5.56	–	[202,203]
Yellow Oleander	61.7	4.2	0.874	75	175	12	–	[204,205]
Waste vegetable oil	–	4.5	865	48	438	–	4	[206,207]
EN14214 Standard		3.5-5.0	860-900	>51	101	0.3 max	>3	
ASTM Standard		1.9-6.0	0.86-0.89	48-65	93min	2.85-11.85		

11. Prospect for the future

It is no doubt that using the available fertile lands meant for growing edible plants to cultivate non-edible plants will worsen the current food versus fuel competition. On the other hand, growing non-edible oil plants on waste and abandoned lands means that these resources will profitably be used for biomass generation. Organic farming is gaining ground since, farm practices that depend on fertilizers, biocides and pesticides pose threats to the ecology; due to pollution to fauna and flora. Using the farm lands to grow energy crops will be the favorable route. It is known that certain energy crops like jatropha thrive well on marginal and semi-arid lands which can be used for sustainable development of mining communities in most African countries. Introducing and promoting biodiesel as another marketing channel for agricultural crops such as jatropha and neem, can help reduce the high rate of youth migration through job creation. Non-edible for biodiesel will also increase income level of rural populace through job creation by locating biorefineries in such areas which will consequently improve the local economy as a whole. There is also a possibility of high job diversification through integrated biodiesel practices which will offer competition for labor with other traditional employment avenues. This has the tendency to increase the income levels of employees as they would be offered more than a choice. In sub-Saharan Africa, women and children are mostly responsible for collecting traditional biomass for cooking. Replacement of these traditional fuels with biodiesel and other gel fuels has enormous potential for Africa by freeing time for the women and children to engage in other businesses and thereby promoting education. It is obvious that the strategic nature of fuels places many countries' and regional economies out of gear with distortions in crude oil prices. Hence weaning such economies from oil import dependency could be an economic achievement. This could be done through developing and patronizing biodiesel.

12. Conclusion

Energy is a primary requirement to preserve economic growth and maintain standards of human growth index in Africa. The transportation sector is the second largest energy demanding sector after the industrial sector world-wide and accounts for 30% of total delivered energy. Nearly all fossil fuel energy consumption in the transportation sector is from oil (97.6%). However, the expected decrease of fossil fuels and the environmental problems associated with burning them has encouraged many researchers to investigate the possibility of using alternative fuels. Biodiesel is a very promising resource. The two key reactions in biodiesel production are esterification and transesterification. These reactions are influenced mainly by the type of feedstock oil, reaction conditions, catalyst used, and alcohol to oil molar ratio. The wide range of available feedstocks for biodiesel production represents one of the most important advantages of the production of biodiesel. Selecting the best feedstock is vital to ensure the low production cost of biodiesel. Most of the biodiesel fuels are produced from edible oils, whose large-scale consumption is leading to price rise and shortage of food supplies. Hence, the focus is on looking into different non-edible feedstocks for biodiesel production. Nonedible feedstocks could be potential resources due to their favorable fuel properties, performance and emission characteristics while emerging technologies can make the energy resources more efficient and eco-friendly. Several studies have been conducted on biodiesel production in Africa using single oil. Conversely, a few number of researches were carried out on the mixture of different feedstocks for biodiesel production. Hence, it is worth recommending that; the prospect of using hybrid feedstock for biodiesel production from an African perspective; due to the availability of feedstock and possible production cost reduction, should be further investigated to improve fuel properties and availability of biodiesel. Moreover, the aim of Africa is to foster development and prosperity through gains in energy efficiency rather than increase consumption through transition towards environmentally friendly use of renewable resources. Biodiesel can offer African countries some prospect of self-reliance in energy at both the national and local levels which will enhance economic, ecological, and social development.

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