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Review article

Analysis of properties of biodiesel and its development and promotion in Ghana

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A R T I C L E I N F O

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A B S T R A C T

The increasing global population and the challenges associated with fossil fuel has led to a surge in energy demand, necessitating research on renewable and environmentally friendly energy sources. Biodiesel, is produced from biomass materials like vegetable oil and fats, is a promising alternative. Transesterification is a principal method used in biodiesel production, as it is simple, versatile, and efficient. Biodiesel offers several advantages, including emissions, lubricity, and safety, making it a sustainable fuel option and its properties conforms to the international standards. However, it has lower energy content, cold weather performance issues, and slightly reduced engine power compared to petroleum diesel. The choice of biodiesel feedstock depends on its properties, with jatropha oil and other feedstocks being potential in Ghana. Research on biodiesel in Ghana is still in early stages and the Ghanaian government's policy aims to replace 10 % of petroleum fuel with biofuel by 2020 and 20 % by 2030, but these goals have not been achieved due to barriers. Despite these challenges, the government and stakeholders in the biofuel industry are working to optimize the biodiesel sector for sustainability, efficiency, and scalability. Innovative cultivation techniques and low-cost oil extraction methods are required, necessitating interdisciplinary research collaborations. By capitalizing on these opportunities and implementing targeted interventions, Ghana can become a regional leader in sustainable biodiesel production.

1. Introduction

The world economy and specifically the Ghanaian economy is precisely dependant on energy. The world population has been increasing steadily and according to United Nation(UN) estimates there were 7.6 billion people in 2019 and is likely to increase to 8.6 billion by the year 2030 and subsequently to 9.8 billion by the year 2050 [1]. The desire for the bigger growth in economy and improved standard of living have resulted into a continuous rise in the demand for energy globally. Based on these estimates and

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Nomenclature

Triglyceride Is a molecule made up of glycerol and three fatty acids. It reacts with an alcohol (typically methanol or ethanol) in the presence of a catalyst to create biodiesel and glycerol
Degree of Unsaturation The number of double bonds in triglyceride fatty acid chains and significantly influences biodiesel's physical and chemical properties, including oxidative stability, cold flow qualities, and cetane number, indicating combustion quality
Long Chain Saturated Factor is a measure used in biodiesel production to determine the amount of long-chain saturated fatty acids (LCSFAs) in the fuel
Biodiesel is a renewable, biodegradable fuel produced through transesterification from natural sources such as vegetable oils, animal fats, or recycled cooking grease
Transesterification is a chemical process used to convert fats or oils (triglycerides) into biodiesel (fatty acid methyl esters or FAME) and glycerol by reacting them with an alcohol, typically methanol or ethanol, in the presence of a catalyst
Exhaust Gas Recirculation (EGR) is an emissions reduction technology used in internal combustion engines, primarily diesel and gasoline engines, to lower nitrogen oxide (NO_x) emissions, which are harmful pollutants contributing to smog and air quality issues
Multi-Functional Platform (MFP) is a multipurpose, decentralised energy system that promotes rural development by delivering mechanical and electrical power for a variety of productive purposes in off-grid or neglected regions
Prescribed Obligatory Purchases (POPs) Legally controlled purchases which are mandated by laws or regulations, often enforced by governments or regulatory bodies, often relating to public safety, environmental protection, or legal compliance

coupled with the latest trend and demand, 60 % more of energy will be needed globally by 2030 as compared to the current daily energy demand [2].

In the recent years, only some of the areas of research focus such as accessibility to energy and low carbon transition by international development have witnessed huge transformation. The demand for energy in Ghana like other countries in Africa has been increasing faster therefore, surpassing the energy supply with in the last ten years. Incorporating renewable energy to Ghana's energy mix is a vital role to address the energy and replace conventional fossils fuels with fuels that are clean and locally reliable in addition to providing opportunities to the economy [3,4].

According to Gray et al.2021 [5] transportation sector is one of the fastest-growing sectors globally which consumes close to 27 % of the basic energy. Aside from transportation sector, energy is also required for domestic, industrial and other miscellaneous uses. Transport sector relies on the crude oil, whose reserves are limited and not well distributed since some regions of the world are having more than others [6,7]. Almost 80 % of the global energy requirements is currently from the fossil's fuels [8].

Use of fuel from fossil sources presents problems and the main drawbacks which include faster depletion of the fuel stock, increase in the cost of the fuel, emission of huge amounts of CO_2 to the atmosphere which leads to global warming, etc. It is therefore, crucial to explore a substitute energy sources which are sustainable and friendly to the environment apart from the ordinary fossils fuel due to these challenges [9,10].

The development and promotion of biodiesel in Ghana is a representation of the concerted efforts from the government, private sector, and international partners in enhancing energy sufficiency and sustainably fostering mitigation of environmental impacts related to fossils fuels. The Renewable Energy Act, 2011 (Act 832) was enacted as part of the renewable energy policies by the Ghanaian government with the aim of giving incentives to renewable energy which include biodiesel. In addition, the policy on bioenergy, which is under Ministry of Energy aims at supporting biofuel projects in utilizing feedstocks such as jatropha and palm oil. Notwithstanding these efforts, large-scale cultivation of jatropha faced challenges resulting from low yields and high costs, while production of palm oil arouses the concerns relating to food competition and environmental sustainability [3].

Research and development initiatives in Ghana are significant in optimization of biodiesel production processes and evaluation of the feasibility of different feedstocks. Projects that are carried out in collaborations with international partners have instrumentally enhance technological capacities and building of local expertise. Pilot projects and small-scale facilities for production have been put up together with the involvement of the private sector and Non-Governmental Organizations (NGOs), with the focus of community-based initiatives with the aim of promoting the development of rural areas and creation of jobs. However, the economic viability of biodiesel remains a significant hurdle, with high initial investment costs and inconsistent feedstock availability posing major challenges [11–13].

Though policy and regulatory frameworks, exist they are not fully implemented and enforced. Clear guidelines are supposed to be put in place with an aim of supporting mechanism and fostering a conducive environment for the production of biodiesel. Technical barriers, for example the need for advancement in the production technology and limitation in the local capacity for large-scale operations, further adds the complication to the development process. Market development is also hampered by competition due to the presence of cheaper fossil fuels and very little awareness of consumer and public acceptance of the biodiesel [11,12].

Based on the Renewable Energy Act of 2011of Ghana, biomass energies include energies which are obtained directly or indirectly through processing of plant materials, industrial wastes and the common wastes [11–13]. According to American Standard for Testing Material (ASTM), biodiesel is a fuel comprising of mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats, through a transesterification process and is intended for use in diesel engines The term "bio" refers to the organic source of biodiesel, which is contrary with conventional diesel. Biodiesel is a liquid which is clear ranging from light to dark yellow in colour. It is made up of boiling point of more than 200 °C, and a flash point ranging from 145 to 175 °C [13,14].

Biomass is the prevalent renewable resource on the planet. As a result, converting biomass into biodiesel is a viable option to replace diesel from fossil materials without compromising energy demand [14,15]. Qualities of biodiesel are affected more by the type of the feedstock material that are used as well as technology applied in the bio-conversion procedure [16–18].

In Ghana and other developing countries, the production of biodiesel has become a relevant and contemporary research trend because of two major factors: (a) achieving oil sufficiency and (b) lowering carbon footprints [19]. Expanding the research on biodiesel production can solve the energy insecurity in Ghana [20]. Biodiesel is significantly important in Ghana's among various biofuels because of its potentiality of leveraging abundant resources, reduce import dependency, stimulate economic development, promote environmental sustainability, empower rural communities, improve energy access, and align with national development goals. By prioritizing biodiesel development and adoption, Ghana can realize multiple socio-economic and environmental benefits, thus positioning itself as a leader in sustainable energy transitions within the region and globally [18].

Studies indicate that feedstock exclusively constitutes almost 75 % of all the cost of producing biodiesel [20–23]. The major goal of producing biodiesel is the reduction of manufacturing cost hence lowering competition with petroleum-based fuel. Thus, it is critically important to produce biodiesel from feedstocks which are cheap and readily available in order to replace refined oils that are expensive [24–26]. Table 1 indicate some of the feedstocks that are abundantly available in Ghana for biodiesel production [26]. Palm, coconut, soybeans, etc are some of energy crops used as biodiesel feedstocks, but they are also edible oil and their use to produce biodiesel poses threat to food security due to competition for oil for food and for producing fuel. Oil have certain disadvantages, which include greater viscosity and reduced volatility, and this can lead to incomplete combustion in internal combustion engines, resulting in chemical adsorption [24,28].

The aim of the Government of Ghana's policy on development of biofuel and specifically biodiesel is to substitute consumption of petroleum fuel nationally with biofuel by at atleast 10 % by 2020 and 20 % by 2030. Policy on biofuel ensures efficient production technologies of biodiesel which aim at lowering the cost and improving the quality and efficacy of the biodiesel by prioritizing its research and development. Furthermore, it necessitates removal of barriers that exists within the institutions and encourage involvement of private sector in biodiesel industry [29,30].

However, from the analysed references there are research gaps involving the research and development of biodiesel in Ghana which is still in the early stages and little research has been carried out on the current state, barriers, and measures to promote biodiesel in Ghana [18–20,29–31]. The objective of this review therefore is to explore the characteristics and the importance of biodiesel and the present status and the potential of development, and highlights the barriers in adopting the use of biodiesel in Ghana as well as the future research direction for biodiesel in Ghana. And with the huge potentiality of biomass resources in Ghana, this review will be useful in raising awareness of importance of expanding biodiesel development and research to help alleviate the country's energy issues by optimising indigenous feedstocks, establishing cost-effective and environmentally friendly production process, and tackling policy and technical issues associated with biodiesel performance.

1.1. Methodology

1.1.1. Data collection procedures

The data was generated through an online google search from the published materials on Google Scholar and Scopus using key words with a particular interest, which were; 'biodiesel development and promotion in Ghana' and 'biodiesel in Ghana'. In supplementing this database, reference list of dissertations, review and research articles which discusses the selected key words were used. Additionally, the abstracts of the all publications from various articles that were selected, were examined.

The following key words were used; 'biodiesel development and promotion in Ghana' and 'biodiesel in Ghana', 22134 search results were obtained and 114 articles were finally selected using various steps (Fig. 1). The relevance of the materials in selection stage determined the validity of the literature review. Different exclusion criteria were applied which include; the materials that were not in English or not properly written, and not accessible were excluded from the review. Duplicated publications and studies which could not provide useful information relating to the topic of the review article were also omitted. The chosen articles were downloaded and were organised based on its suitability. The researchers then meticulously studied all the articles and select the one meeting the purpose of the study.

Table 1
Primary feedstocks for biodiesel production [26].

Edible oils	Non-edible oils	Animal's fats
Palm oil	Jatropha oil	Beef tallow
Coconut	Rubber seed oil	Chicken fat
Soybeans	Shea butter	Fish oil
Waste cooking oil	Neem seed oil	Pork lard
		Poultry fat

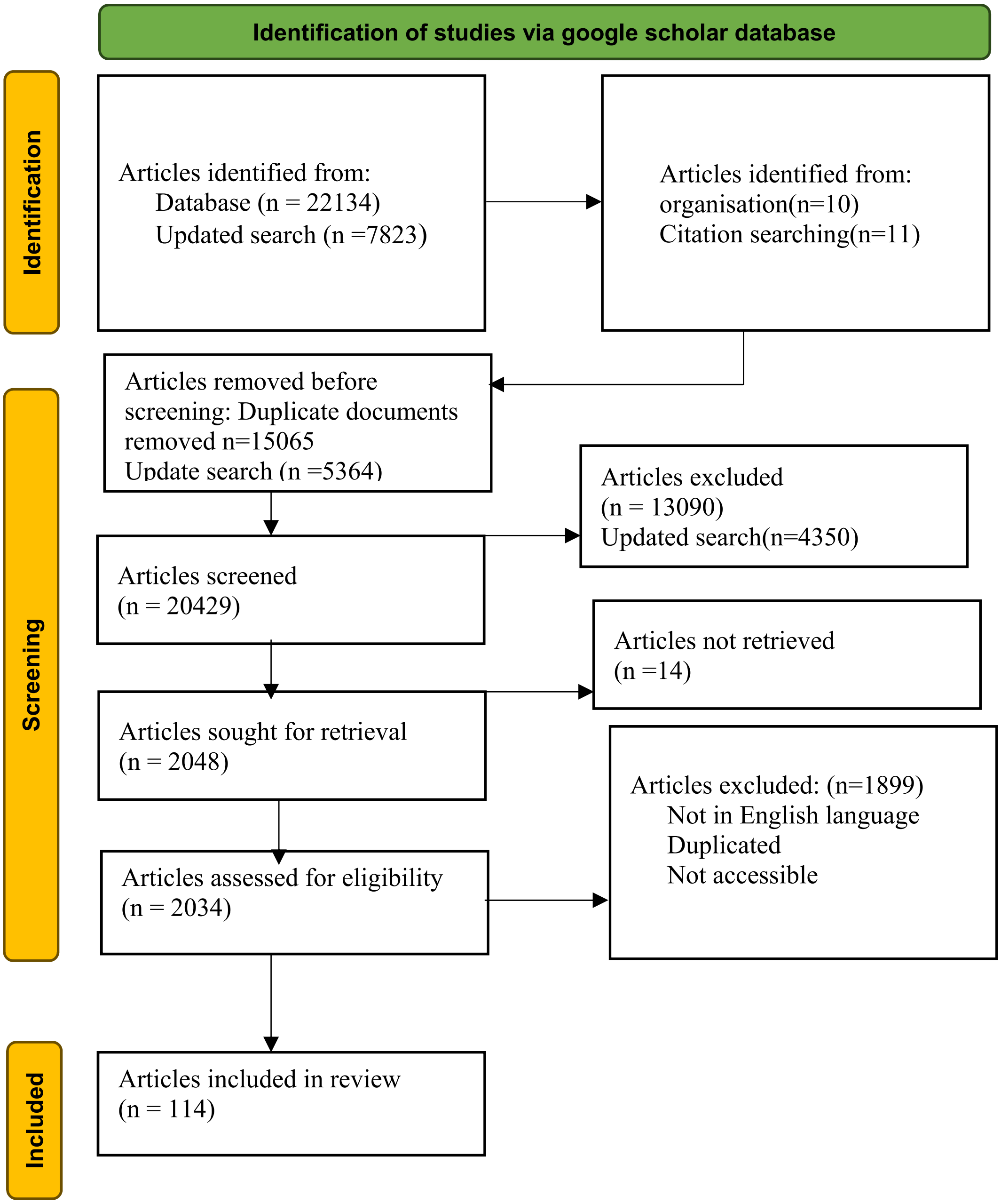

Fig. 1. PRISMA flow diagram [32].

Table 2
Various indigenous oil-bearing and animal fat feedstock in Ghana and their fatty acid profile [27,34].

Feedstock	Palmitic (C16:0)	Stearic (C18:0)	Oleic (C18:1)	Linoleic (C18:2)	Linolenic (C18:3)	DU
Soybean oil	12.13	3.49	23.41	54.18	6.50	0.16
Coconut oil	8.0–11.0	1.0–3.0	5.0–8.0	0–1.0	–	6–11
Palm oil	39.83	5.33	41.90	11.46	0.15	50–55
Shea butter oil	2–10	25–50	36–62	1–11	1	50–70
Rubber seed oil	7.6	10.2	14.9	14.6	24.15	135–160
Waste cooking oil	8.80	4.20	45.15	39.74	0.20	70–120
Neem seed oil	18.1	18.1	44.5	18.3	0.2	65–80
Jatropha oil	13.8	6.6	43.9	33.2	0.5	95 to 112
Animal fats	20.9	47.6	13.7	15.3	1.0	40–70

1.1.2. Data analysis and presentation

The collected data for this review article were critically analysed using content analysis method by quantifying and analysing the relationships and meaning of the key terms. The result of analysis was categorised into distinct themes in order to answer the objective of the study [31].

1.2. Properties and benefits of biodiesel as sustainable energy alternative

1.2.1. Properties of the feedstock oil for biodiesel production

Three main types of fatty acids are in a triglyceride molecule: saturated (Cn:0), monounsaturated with one double bond (Cn:1), and polyunsaturated with two or three double bonds (Cn:2,3). Every biodiesel feedstock possess their own fatty acid structure, and key properties of biodiesel fuel strongly depend on the fatty acid contents of the feedstock from which it is produced [31,32].The fatty acid profiles of different vegetable oils and animal fats are provided in summarized format in Table 2. From the table, vegetable oils are majorly composed of monounsaturated and polyunsaturated fatty acids. According to the fatty acid distribution, two more parameters can also be calculated for biodiesel feedstocks: the degree of unsaturation (DU), and long chain saturated factor (LCSF).

Every vegetable oil sample's total saturation level, total unsaturation level (TUS), mono- and poly-unsaturation level, DU and LCSF values are in Table 2. On examination of fatty acid compositions, it was established that neem seed oil is highly unsaturated fatty acid content. A highly unsaturated fatty acid content in neem oil signifies can improve the cold flow and lubricity properties of biodiesel. Similar studies have been done in determination of fatty acid content of the vegetable oils [33]. The structure of the fatty acid for soybean, cottonseed and jatropha oils were the same as those found in the study by Ahmed et al. 2017a [29].

The degree of unsaturation and the presence of long-chain saturated fatty acids in a feedstock significantly influence the physicochemical properties of the biodiesel produced. A higher degree of unsaturation, indicated by a higher iodine value increases the susceptibility to oxidation, potentially leading to storage stability issues. On the other hand, feedstocks with higher levels of long-chain saturated fatty acids produces biodiesel with better oxidative stability and a higher cetane number, improving ignition quality and combustion efficiency. However, this also raises the cloud point and pour point, making the biodiesel more likely to solidify at lower temperatures, which can pose challenges for use in cold environments. Thus, the balance between unsaturated and saturated fatty acids is crucial in determining the overall performance and suitability of biodiesel [33].

Higher unsaturation levels often result in biodiesel producing lower particulate matter (PM), carbon monoxide (CO), and unburned hydrocarbons (HC) emissions due to more complete combustion. However, it can lead to increased nitrogen oxide (NOx) emissions due to higher combustion temperatures [29]. Soybean oil, palm oil as well as jatropha oil strike a favourable balance in their fatty acid profiles making them ideal choices for biodiesel production. However, soybean and palm oil are edible oils and therefore using it for biodiesel production results into competition for oil for food and oil for biodiesel production. Jatropha oil is non-edible and the best alternative though with some few disadvantages such as containing toxic which makes it challenging and thus requires further processing [35].

1.2.2. Transesterification process

Transesterification is principally a method used in production of biodiesel, because it is simple, versatile, and efficient. Transesterification is a chemical process which entails reaction of oil or fats with an alcohol (usually methanol or ethanol) in the presence of a catalyst, leading to formation of alkyl esters (biodiesel) and glycerol (a byproduct). The organic group R'' of an ester are exchange with the organic group R' of an alcohol in this reaction as shown in Fig. 2. Glycerol of triglyceride is removed and replaced with alkyl radical of the alcohol applied in the transesterification process. Glycerol based triesters are therefore, converted to alkyl-based

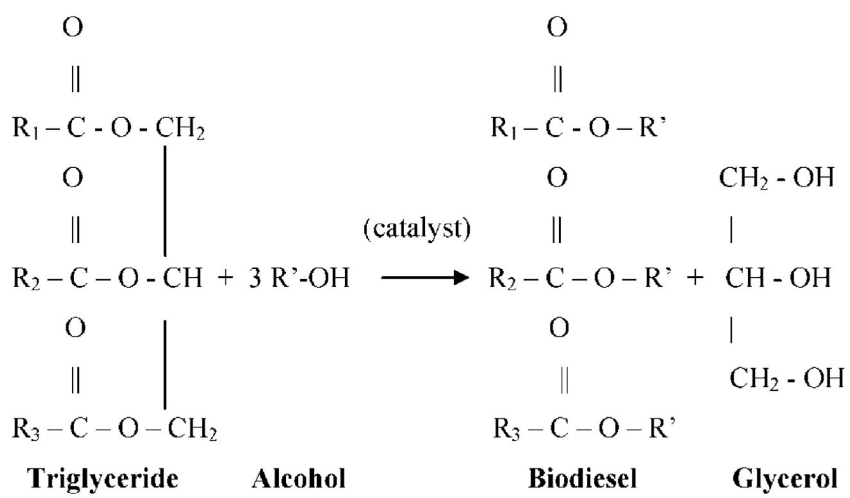

Fig. 2. Stoichiometric transesterification reaction [41].

monoesters and hence transesterification is an ester conversion process. High viscosity is reduced while cetane number and heating value are kept through transesterification. Theoretically, stoichiometric transesterification, is shown in Fig. 2, where 3 molecules of alcohol are used by a mole of triglyceride and results in 3 mol of fatty ester and 1 mol of glycerol.

Methanol is frequently used alcohol in production of biodiesel because it is cheap and has chemical (polar and the shortest chain alcohol) and physical benefits. Methanol reacts faster with triglyceride and catalyst and dissolve easily in comparison with other alcohols. The acidity level of ethanol and mostly branched chained alcohol are low and their reaction with catalyst leads to the production of alkoxide anion. As a result of this, very high molar ratio of alcohol to oil is required. The type of alcohol used in transesterification is vital because it has influence on reaction kinetics and the properties of the fuel. Biodiesel produced is made up of a structure and the bond of the alcohol that was used in transesterification [36–38].

Catalysts and enzymes used in transesterification, are for enhancing the rate of reaction and improvement of features of the fuel produced. The type of catalyst and enzyme used in the transesterification and the concentration are therefore, very crucial. Catalysts are majorly applied in proportion because they are faster in reaction, and is sufficient in reaction at room temperature, and the biodiesel produced from alkaline catalyst are not corrosive to the engine parts [39,40].

Common transesterification methods include base-catalysed, acid-catalysed, supercritical, and lipase-catalysed transesterification. Base-catalysed is the most widely used method due to its efficiency, simplicity, and cost-effectiveness. Alkali catalysts such as sodium hydroxide (NaOH) or potassium hydroxide (KOH) are commonly used. Acid-catalysed is used when oils or fats contain a high percentage of free fatty acids, but requires higher temperatures and longer reaction times. Acid catalysts such as sulphuric acid (H_2SO_4) or hydrochloric acid (HCl) are used to esterify the free fatty acids and prevent soap formation. Supercritical transesterification eliminates the need for a catalyst by using alcohol in its supercritical state under high temperature and pressure. Lipase enzymes can directly catalyse the transesterification of triglycerides without soap formation, making them highly effective for feedstocks with high free fatty acid content. Lipase-catalysed transesterification offers an environmentally friendly and mild alternative to chemical catalysts. However, the high cost and potential for deactivation during the reaction are significant limitations [36,37].

The existing infrastructure is compatible with the process of transesterification thus; it becomes accessible to a variety of producers ranging from small-scale operations to large industrial facilities. The process becomes economically valuable through production of glycerine which is a useful byproduct. Generally, transesterification is practically and environmentally sustainable way to reduce dependence of fossils fuels and promote energy security. Base-catalysed transesterification is the most practical and widely used method for Ghanaian biodiesel production due to its optimal balance of efficiency, cost, and scalability.

1.2.3. Relationship between transesterification and biodiesel properties

The fuel properties of biodiesel produced from various vegetable oils and specified values as per European Biodiesel Fuel Standard (EN-14214) were presented in Table 3. Most of the properties tested were within the required limit. The level of compliance of these parameters (Ester content, flash point, water and sediment, kinematic viscosity, density, sulphur content, copper strip corrosion, cetane number, cold filter plugging point, carbon residue, acid number, free glycerine, total glycerine, phosphorus content, distillation, sodium/potassium, oxidation stability) are dependent on the quality of vegetable oil (i.e. free fatty acid (FFA) content, and water content), completeness of transesterification reaction (conversion) and the suitability of purification steps after reaction (i.e. the number of washing steps, temperature of washing water). Some of the properties although, were not within the acceptable limit for example cetane number for soybean was 49 and this was slightly below the accepted limit of 51. Furthermore, oxidative stability (110 °C) for biodiesel from palm oil, and soybean were below the minimum accepted level of 6.0. Iodine value for soybean was 128 and this was higher than the acceptable limit of 120. The reason why these fuel properties (cetane number, oxidative stability, iodine value, ester content, and cold filter plugging point) are not within the acceptable limit is because the properties of the biodiesel are influenced significantly by the properties of the feedstock oil used [29].

Significant difference exists in properties of biodiesel and fossil fuels. The higher unsaturation of biodiesel results in superior lubricity. Higher cetane number, shows better ignition quality. However, biodiesel has lower energy content per gallon and can gel at low temperatures, which can be problematic in cold climates. In contrast, fossil fuels, derived from crude oil, have a more consistent and higher energy content, are less prone to gelling in cold temperatures, and have established infrastructure for distribution and use, but they contribute more to greenhouse gas emissions and pollution. Determination of the best feedstock for producing biodiesel entails consideration of different factors which include, yield of biodiesel, availability of feedstock, cost, quality of the biodiesel, among others, [42–44].

1.2.4. Advantages of biodiesel

Biodiesel is a compelling alternative to fossil diesel, providing numerous benefits that can potentially reduce significantly the reliance on traditional petroleum-based fuels (Fig. 3). Biodiesel is made from renewable resources like vegetable oils, and animal fats, all of which can be grown or reared and harvested in a sustainable manner. The renewable nature of vegetable oil and animal fats provides a consistent and dependable source of fuel, alleviating concerns about depleting fossil fuel reserves and volatile oil prices [43].

Biodiesel holds great promise for Ghana, providing numerous benefits to the economy, environment, and climate. Economically, producing biodiesel from locally sourced feedstocks can stimulate rural development by creating jobs in agriculture, processing, and distribution. It reduces the country's reliance on imported fossil fuels, thus increasing energy security and lowering foreign exchange costs. Environmentally, biodiesel production in Ghana can reduce deforestation by using non-food feedstocks such as jatropha thereby preserving vital ecosystems. Furthermore, biodiesel has a lower carbon footprint than fossil diesel, which helps Ghana meet its climate goals by lowering greenhouse gas emissions and efforts globally in combating climate change. The production and use of biodiesel help

Table 3
Properties of biodiesel from various potential vegetable oils (EN-14214) [29].

Property	Units	Test method		Limits		Palm	Soybean	Coconut	Jatropha	Rubber	Shea butter	Neem	Waste Cooking Oil
				Min	Max								
Ester content	wt.%	EN	14103	96.5		97.7	96.9	96–98	95.8	96–98	95–98	94–97	96–98
Kinematic viscosity, 40 °C	mm^2/s	EN	ISO 3104	3.5	5.0	4.5	4.2	2.5–4.5	4.4	4–5.5	4.5–6.5	4–6	4–6
Flash point	°C	EN	ISO 3679	120		176	171	170–190	148	170–185	180–190	170–180	170–190
Cetane number	–	–a		51		61	49	60–65	58.5	50–55	55–60	50–55	50–60
Oxidative stability, 110 °C	h	EN	14112	6.0		4.0	1.3	15–20	6.7	5–10	10–15	6–12	5–10
Acid value	mg KOH/g	EN	14104		0.50	0.12	0.14	0.2–0.4	0.27	0.3–0.6	0.2–0.4	0.2–0.5	0.2–0.5
Iodine value	g I_2/100 g	EN	14111		120[b]	57	128	5–15	93.2	80–100	45–55	65–80	60–120
Linolenic acid content	wt.%	EN	14103		12.0	0.2	6.3	0.5	0.4	1–2	0.5	below 1	1–5
CFPP	°C	EN	116		–c	10	−5	10–15	−6	−4 to −1	−5 to −2	−3 to 0	−5 to 5
Methanol content	wt.%	EN	14110		0.20	0	0	0.2	0	0.2	0.2	below 0.2	below 0.2
Monoglycerides content	wt.%	EN	14105		0.80	0.17	0.21	0.8	0.28	0.8	0.8	less than 0.8	less than 0.8
Diglycerides content	wt.%	EN	14105		0.20	0.06	0.10	0.2	0.08	0.24	0.27	0.22	0.18
Triglycerides content	wt.%	EN	14105		0.20	0.04	0.07	0.19	0.03	0.2	below 0.2	below 0.2	0.2
Free glycerol	wt.%	EN	14105		0.02	0.01	0.01	0.02	0.001	0.02	less than 0.02	less than 0.02	less than 0.02
Total glycerol	wt.%	EN	14105		0.25	0.06	0.00	0.21	0.09	0.25	below 0.25	below 0.25	below 0.25

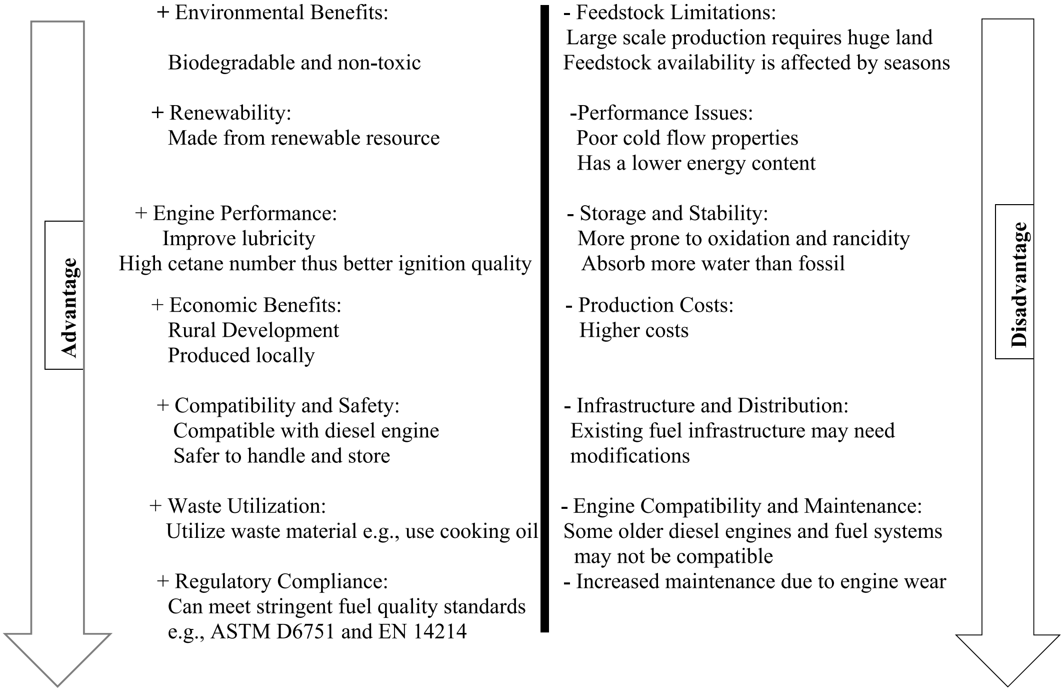

Fig. 3. Advantages and disadvantages of biodiesel from the available feedstocks in Ghana [46].

to reduce harmful air pollutants like particulate matter, carbon monoxide, and sulphur dioxide, ultimately improving air quality and public health. In overall, embracing biodiesel provides Ghana with a sustainable path to economic growth, environmental preservation, and climate resilience [45–49].

Biodiesel is biodegradable and non-toxic, posing little risk to the environment in the event of spills or leaks. A relative assurance of safety on using biodiesel in a diesel engine is guaranteed because it has greater flash point. Its suitability with existing diesel engines and infrastructure furthermore, allows for a smooth transition for current diesel-dependent industries and transportation systems [46,50]. This compatibility also extends to blending with fossil diesel, giving a flexible way to gradually reduce reliance on petroleum-based fuels. Mixing ratio of biodiesel and fossil diesel is not limited [51,52]. To some extent however, mixing ratio has an effect on the power given out by the engine. The commonly use mixture is 20 % of the biodiesel being blended with fossil diesel and this can ensure longevity of the engine life which lowers maintenance requirements [53,54]. According to the estimation, a blend of biodiesel of only 1 % can improve the lubrication of an engine by more than 65 % [55,56]. In overall, the numerous environmental,

Table 4
Average emissions of biodiesel compared to fossil diesel [51].

Emission Type (%)						
Biodiesel from various feedstock oil	Fuel Blends	Total hydrocarbon THC	Carbon monoxide CO	Particulate matter PM	Nitrogen oxide NO_X	Citation
Jatropha	B-20	−20 to −30	−10 to −20	−5 to −15	+2 to +4	[68]
	B-100	−80 to −90	−30 to - 40	−30 to - 50	+4 to +12	[68]
Palm	B-20	−28	34	28.7 %	−19	[69]
	B-100	22.34	0.0152	64.3 %	24.9	[70]
Coconut	B-20	−20	−12	−12	6	[71]
	B-100	−67	−48	−47	31	[71]
Soybean	B-20	−9 to 18	28 to 48	–	–	[72]
	B-100		−33		20	[72]
Waste cooking	B-20	−57	−31	13.9 %	18.33	[73]
Neem seed	B-20	+20	+10	–	+80	[73]
	B-100	−10	−30	–	+56	[73,74]
Shea Butter	B-20	−30 to −70	−20 to-50	−30 to −50	+10 to+15	[75]
	B-100	−50 to −70	−20 to-50	−30 to −50	+10 to+15	[75]
Rubber Seed	B-20	−5 to −10	−5 to −15	−20 to −40	−5 to −10	[76]
	B-100	−10 to −15	−10 to −20	−30 to −50	+10 to+15	[76]

100 % biodiesel blending(B-100) and 20 % biodiesel blending(B-20).
Note: "+'' means the emissions of biodiesel increase compared to fossil diesel; "-'' means the emissions of biodiesel decrease compared to fossil diesel.

economic, and societal benefits of biodiesel highlight its potential to replace fossil diesel and hence more sustainable energy in future [53].

Biodiesel is made of a lot of oxygen molecules which aids in facilitation of the complete combustion in the engine; using biodiesel increases the generation of free carbon [54]. Despite the fact that, biodiesel combustion produces increased specific CO_2 emissions, carbon sequestration during feedstock growth, displacement of fossil fuels, avoided land use change, utilisation of co-products, energy efficiency improvements, and comprehensive life-cycle analysis all contributing to a net reduction in emission of greenhouse gases over the life of biodiesel [55]. These factors add to biodiesel's overall environmental benefits as a renewable and sustainable alternative to petroleum diesel [56–59].

An experimental test was performed using bench consisting of variable compression ratio diesel engine (VCR), eddy current dynamometer, control panel for application of load along with digital display, rotameter-based water-cooling system for engine and dynamometer, fuel storage tanks for biodiesel blend and diesel, data acquisition system, exhaust gas analyser and various sensors for combustion and performance measurement. The research engine was powered using the B100, B20 blends and diesel at a steady speed of 1500 rpm. Twenty experiments were carried out as per design of experiment and emission parameters namely THC, CO, PM, and NO_X were recorded for analysis [55,63].

Values in Table 4 are based on how the fuel blends are used in the vehicle engine.

Pollutants like THC, CO, and PM are remarkably low as compared to NO_X for different feedstocks (table 4). The presence of more oxygen, leads to reactions with the nitrogen which is available in the air and hence formation of additional nitrogen oxides [64,65]. The challenge of additional nitrogen being formed can be overcome through use of delay of angle of ignition and the selective catalytic reduction system (SCR). Among the listed feedstocks, in table 4, the biodiesel from soybean, palm and jatropha oil are the most promising in terms of engine performance and emissions. They produce relatively low emissions of particulates, carbon monoxide, and unburned hydrocarbons. Biodiesel from soybean, palm and jatropha oil, are mix of saturated and monounsaturated fatty acids, which offers excellent oxidative stability and a high cetane number, enhancing ignition quality and reducing emissions of nitrogen oxides. Biodiesel therefore, from the three oils strikes a favourable balance between performance and environmental impact, making them ideal candidates for biodiesel feedstocks.

Ideal ratios for reducing emission exists. According to the analysis by El-Kasaby & Nemit- Allah, 2013 [64] on biodiesel developed within different compression ratio from cooking oil, compression ratio from 14 to 18 resulted in reduction of CO by 37.5 %, THC by 52 %. Another study by Pandhare & Padalkar, 2013 [65] on evaluation of enactment and emission variable using jatropha biodiesel in single cylinder diesel engine reported 13–15 % reduction in CO emission with full loading condition.

Test findings by Gad et al. 2019 [66] showed that addition of biodiesel in 20 %, 35 % and 50 % to pure diesel resulted in brake-specific fuel consumption to rise by 2.6 %, 5.9 % and 7.35 %. A slight increase in brake thermal efficiency with variation in engine load was observed. Moreover, biodiesel has higher cetane number, and good lubrication property, however it has lower calorific value and higher viscosity and flash point which leads to lower brake thermal efficiency and higher brake specific energy [67].

Concisely, biodiesel is an environmentally protective source of energy, and development of biodiesel ensures the realization of targets of renewable energy development and ensuring energy sustainability in Ghana [51].

Biodiesel, on the other hand, has some disadvantages due to its low volatility, high kinematic viscosity and surface tension, high hygroscopic nature, and high unsaturated fatty acid methyl ester content, such as incompatibility with engine components, oxidative instability, effect on engine wear, deposit formation, problems during cold starting, and clogging of fuel filters and injectors [3,42].

Addressing the challenges which confronts the Ghanaian biodiesel industry, requires implementation of targeted strategies [3].The challenge of incompatibility with some diesel engine and fuel systems necessitated the research and development to create biodiesel blends that meet international standards that are compatible with existing engine technologies. Oxidative instability can be reduced by adding antioxidants during production and following proper storage practices. Improving engine lubrication and using corrosion inhibitors can help alleviate concerns about engine wear. Effective filtration systems and fuel additives can help prevent deposits from forming and clogging fuel filters and injectors. Promoting the use of biodiesel heating systems or preheating mechanisms can also help with cold starts. Government, industry, and research institutions must work together to develop and implement these solutions, ensuring the long-term growth of Ghana's biodiesel sector [44].

Biodiesel can be applied directly or indirectly through blending with the fossils fuel. Application of biodiesel in the diesel engine lowers the sulphur oxides emission (SO_x), carbon monoxide (CO) total hydrocarbons (THC), polycyclic aromatic hydrocarbons (PAHs) and particulate matter (PM). Contrastingly nitrogen oxides (NO_x) being emitted is likely to rise because of improve combustion [18].

Excess oxygen in biodiesel than in conventional petroleum diesel raises combustion temperatures, creating ideal conditions for NO_x formation via thermal NO_x mechanisms. Biodiesel's higher cetane number and shorter ignition delay time can result in shorter combustion duration and higher peak temperatures, which promotes NO_x formation. Furthermore, biodiesel's chemical composition, particularly the existence of functional groups containing oxygen such as esters, can hasten fuel oxidation kinetics and increase NO_x emissions when burned. Impurities or contaminants in biodiesel, such as trace metals from feedstock oils or production catalyst residues, can also act as NO_x catalysts. In addition, combustion chamber design and engine operating conditions, such as injection timing, compression ratio, and exhaust gas recirculation rates, can have an impact on NO_x emissions in biodiesel-powered engines [60,61]. Mitigating high NO_x formation in biodiesel combustion necessitates careful optimization of engine parameters, and combustion strategies such as exhaust gas recirculation (EGR), which involves retrofitting engines with exhaust gas recirculation systems, can effectively reduce emission of NO_x through recirculation of a portion of exhaust gases back into the combustion chambers. By implementing these economically feasible strategies, Ghana can effectively reduce high NO_x formation in biodiesel combustion [61,62].

1.3. State of biodiesel development and research in Ghana

Biodiesel is one of the sources of fuel in the energy mix in Ghana but it is in its initial stages. According to the study by Friends of the Earth (Foe), 2010 [77]there is a potential of large-scale acquisition of land, specifically for biodiesel feedstock cultivation in Ghana, and an average of seventeen private commercial development companies for biodiesel in Ghana are involved in biodiesel production. Fifteen out of the seventeen companies were identified to be owned by the foreigners or Ghanaian in diaspora who are financing it and all of them adopted business model that requires a large-scale plantation of the feedstock, greater than 1000 ha. Thirteen foreign companies had their focus basically on the cultivation of jatropha, one on cassava and the other on oil palm as at August 2009. All the companies together had accessibility of 1,075,000 ha of land, 730,000 ha was located in forest savannah transition zone of central Ghana's Brong Ahafo and northern Ashanti regions.

Friends of the Earth (Foe), 2010 [77,78] identified nine companies which are involve in the production of biodiesel in Ghana and these are; Agroils, Galten Global Alternative, Gold Star Farms, Jatropha Africa, Biofuel Africa, ScanFarm and Kimminic Corporation. According to the assertion by FoE, these companies have used an average of 779,000 ha of land, which is equal to almost 37 percent of the Ghana's land under crop farming and are all involved in industrial-scale plantation of jatropha for biodiesel production.

Another study on the socioeconomic implication of industrial biofuel plantation in Ghana by Antwi-Bediako et al. 2019 [79] and Acheampong [80] pointed out a complete list of nine companies in investment of biofuel in Ghana; Jatropha Africa, Anuanom Farms, Smart Oil, Biofuel Africa, Kimminic Corporation, Galten Global Alternative Energy, Savannah Black Farming and Farm Management, ScanFarm and Agroil. The study discovered that the nine companies were involved in industrial plantation of jatropha and as a group they controlled approximately 83,478 ha of land. Table 5 gives a list of the nine biofuel companies that operates in Ghana, place of their investment, land size acquired, variety of crops that are cultivated, and the nine companies were selected for the analysis because it was the current complete list based on the information provided research by Antwi-Bediako et al. [79].

Biodiesel research in Ghana is currently in a growing phase, with several notable research and initiatives aimed at advancing the country's bioenergy sector. For example, ongoing research at Kwame Nkrumah University of Science and Technology (KNUST) is aimed at optimising biodiesel production from locally abundant feedstocks like jatropha and palm oil. Researchers are investigating novel extraction techniques and refining processes to improve biodiesel production efficiency and yield through experimental studies and pilot-scale trials. Furthermore, KNUST and the Council for Scientific and Industrial Research (CSIR) are working together to investigate the viability of using waste cooking oil as a feedstock for biodiesel production, which addresses both environmental and economic concerns. These research projects are critical in laying the groundwork for Ghana's sustainable biodiesel industry, which will help the country achieve its goals of energy independence and environmental stewardship [20,82].

1.4. Development and promotion of biofuel in Ghana

1.4.1. Government promotion and development

Ghana's history of biofuel policies reflects a complex interplay of economic, environmental, and energy security concerns. Ghana's first foray into biofuel production dates back to the early 2000s, when the government implemented policies to encourage the cultivation of crops like jatropha and palm oil for biodiesel production. These policies were motivated primarily by a desire to lower the country's importation of fossil fuels, promote rural development through job creation, and reduction of the environmental pollution caused by traditional fuel sources [81]. Despite initial enthusiasm and investment in biofuel projects, the sector encountered numerous challenges, including land tenure issues, insufficient infrastructure, and fluctuating global commodity prices. As a result, many of the initial biofuel initiatives did not materialise, prompting a review of Ghana's biofuel policies [82].

In recent years, there has been a push for more sustainable and inclusive biofuel policies, with a greater emphasis on small-scale and

Table 5
Biofuel investment in Ghana [74,75].

NO	Company	Country of origin	Location of investment in Ghana	Size of land acquired (ha)	Crop type	Operational mode
1	Jatropha Africa	UK/Ghana	Yeji, Bro Ahafo Region	105,000	Jatropha	Industrial scale
2	Anuanom Farms	Ghana	Old Akrade-Juaopong Eastern Region	405	Jatropha	Industrial scale
3	Smart Oil	Italy	Yeji, Bro Ahafo Region	20	Jatropha	Test or experimental farm
4	Biofuel Africa	Norway	Kpachaa Northern Region and Lolito Volta Region	27,000	Jatropha and crops	Industrial scale
5	Kimminic Corporation	Canada	Brede No. 1 and Krobe Bra -Ahafo Region	13,000	Jatropha	Industrial scale
6	Galten Global Alternative Energy	Israel	Adidome Volta Region	100,000	Jatropha	Industrial scale
7	Savannah Black Farming and Farm Management	United States	Ahenakom, Bra-Ahafo Region	202	Jatropha	Industrial scale
8	ScanFarm	Norway	Agogo Ashanti Region	400,000	Jatropha (food crops, maize and soybeans)	Industrial scale
9	Agroil	Italy	Yeji, Bro Ahafo Region	105,000	Jatropha	Industrial scale

community-driven bioenergy projects. The government has implemented policies to encourage the use of biofuels in transportation and cooking, such as tax breaks, subsidies, and capacity-building programmes [83]. There is also an increasing recognition of the importance of involving local communities and stakeholders in the development and implementation of biofuel policies to ensure social acceptance and equitable distribution of the benefits [84,85].

Currently there is no large operational commercial plant for biodiesel production in Ghana, however, some few medium and small-scale producers exist. Ghanaian government has been keen in promoting the growing of jatropha plant for the production of biodiesel because the plant easily grows in all the places in Ghana due to suitability to the good local climate. Biodiesel from jatropha oil is useful in multi-functional platforms (MFPs) which is driven by the diesel engine, and majority of the women are involved in manual labour in cultivation and harvesting of seeds and they are doing this for their livelihood. Production of biodiesel using jatropha in Ghana cost approximately US $460 for every tonne of oil which equivalent to 8 % less than the cost of the petroleum diesel imported [86,87]. The government has set aside money worth 150 million US$ for developing jatropha plantation within the country. About 15 million US$ is presently at the banks for the organizations that are interested in jatropha cultivation. Jatropha initiatives began to take off successfully in Ghana from 2005 to 2006 and ultimately hit their peak between 2007 and 2008. In 2006, 2500 ha of land was used for growing jatropha and in 2007 the size of land under the cultivation of jatropha increased to 4000 ha. By 2007, Anuanom Industrial Bio Product Ltd (AIBP) had a factory which had a capacity of processing 500-tonne of jatropha seed to form biodiesel in addition to installation of 2000-tonne for production of organic fertilizer which is obtained from seedcake which is the by-product of the biodiesel. A company referred as Biodiesel 1, Ghana limited installed a jatropha processing plant which uses 2000 tonnes of seeds every month and on other hand Biofuel Africa Ltd, established 23,762 ha of plantation of jatropha to produce biodiesel in Central Gonja and Yendi District of Northern Ghana [87].

Moving forward, Ghana's biofuel policies are expected to evolve in response to shifting energy dynamics, technological advancements, and environmental imperatives. Future biofuel policies in Ghana are likely to be driven by the need for energy security, a reduction in greenhouse gas emissions, and the promotion of sustainable rural development. Ghana has the potential to reap the benefits of biofuels while addressing the challenges of the 21st century energy landscape by learning from previous experiences and taking a holistic approach that incorporates social, economic, and environmental considerations [88].

Table 6 shows the cultivated area and production of Ghana's major agricultural crops from 2018 to 2023. Corn, palm oil, and sorghum are potential bioenergy crops that dominate land areas. Other potential crops, such soybean, millet and cotton require less land area. Maize is widely grown non-export crop in Ghana, followed by cassava. Between 2018 and 2022, approximately 2,968,000 tonnes of maize were harvested on average per year from 1217 thousand hectares. Maize is grown in every district of Ghana, thus becoming popular crop for food in the nation. From 2018 to 2022, approximately 281,000 tonnes of palm oil per year and 359,000 tonnes of sorghum were produced across 359 thousand hectares and 301 thousand hectares, respectively for large-scale biofuel projects in Ghana across various ecological zones [85,89–91].

1.4.2. Ghana's bioenergy policy of integrating 20 % biofuel by 2030

Ghana through this policy is seeking the improvement of supply security for oil, saving of foreign exchange, creation of jobs and reduction of emission from the transport sector through the integration of 10 % by 2020 and 20 % of biofuel in the energy mix in transport sector by 2030. The target of biofuel is through the consideration of 20 % of the total demand of gasoline and diesel per year. The target of the composite biofuel was through the consideration as the general target of 20 % is what is important from the perspective of the policy. This is achievable through the use different proportion of biodiesel and ethanol based on relativity on ease of producing each fuel in Ghana. Table 7 shows the variations in demand for liquid biofuel between 915 million litres and 1250 million litres in 2020 and 840 million litres and 2800 million litres in 2030. The reduction in the demand of the biofuel in the base case is possibly due to saturated fuel demand which had occurred earlier [92,93].

It is important to note the likelihood of significance in biofuel demand in Ghana with the consideration of the present status. However, some of the possible obstacles and success, Ghana have encountered in achieving the biofuel target are listed below [84,94].

(i) Obstacles

Technical challenges: Ghana is faced with technical challenges in producing biofuel to achieve the targets and these challenges include; limitation to advanced technology, inefficiency in the process of oil extraction, and difficulty to optimized production from the feedstock which are available locally and many others.

Table 6
Cultivated area and production of major biofuel crops in Ghana from 2018 to 2022, 2022/2023, 2023/2024 [86,87].

Crops	Area harvested (ha) 2018–2022	Area harvested (ha) 2022/23	Area harvested (ha) 2023/24	2018–2022 (1000 Tons)	2022/23 (1000 Tons)	2023/24 (1000 Tons)	% Change 2023/24/ Avg
Maize	1217	1300	1300	2968	3401	3400	15
Rice	305	305	325	664	681	789	19
Sorghum	301	310	310	359	463	350	−2
Palm oil	357	360	360	281	300	300	7
Soybean	114	120	125	201	215	225	12
Millet	176	170	170	198	195	210	6

Table 7
Biofuel demand forecast up to 2030 [92].

Year	Scenario	Total demand(ktoe)	Gasoline (Ml)	Diesel (Ml)	Bio-diesel Target (Ml)
2020	Base	3044	2150	2424	915
	Med	3563	2517	2837	1071
	High	4162	2940	3314	1251
2030	Base	2844	1788	2425	843
	Med	5217	3280	4450	1546
	High	9491	5968	8095	2813

Infrastructure challenges: lack of adequate infrastructure such as transportation network and facilities to process biofuel and these results into producing biofuel inefficiently, distributing and utilizing across the country.

Social and environmental challenges: expanding the production of biofuel in Ghana have resulted in increase in social and environmental issues for example conflicts due to land tenure, communities being displaced, deforestation and competition with food crops. It is important to address these issues properly in order to promote sustainable production of biofuel [92].

(ii) Success

Investment and collaboration: Ghana has witnessed success in mobilizing investment by the public and private sector in addition to partnership and collaboration with international community which has been useful to government plan in accelerating Ghana's biofuel industry.

Diversification of sources of energy: to some extend, reliance of imported fossils fuels has decrease which is important step in contributing to Ghana's effort to achieve biofuel targets [92].

1.4.3. Suggestions to reform the biofuel policy of Ghana

Ghana's biofuel policy should be reformed in a comprehensive manner that considers the economic, environmental, and social elements of biofuel production and use. Here are a few recommendations for a more robust and successful biofuel policy [90,92].

i. Fiscal and tax incentives for the biofuel industry for example government's grant of zero import duty and VAT on processing equipment for biofuel for 10 years and income relief for 10 years for biofuel companies that are in operations should be part of the policy
ii. The policy should allow Energy Commission to utilize section of the Energy Fund in creating awareness and education of the public with active collaboration of energy NGOs which are forefront in Ghana.
iii. The policy should give powers to the National Petroleum Authority (NPA) in promoting and dispensing biofuel blend for government vehicles and transportation of masses.
iv. The policy should enable Energy Commission to partner with Enterprise/Business Development Service (EDS/BDS) companies such as NBSSI and Empretec in training Ghanaian entrepreneurs to start Biofuel SMEs.
v. The policy should allow Environment Protection Agency (EPA) of Ghana to form local carbon market with links to international carbon markets for the purchase of greenhouse gas emissions reductions from biofuel production.

1.5. Barriers and measures in adoption of biodiesel

Biodiesel are typically produced from agricultural products, so there must be a sufficient supply in meeting the demand. Ghana is endowed with numerous oil-producing food crops, some of which are given in Table 8. Until recently, cultivating jatropha was not viewed as an economic venture, most likely due to the oil's low-end use in Ghana. The case was similar for coconut, which, despite

Table 8
Production levels of potential feedstock in Ghana [96].

Feedstock for biodiesel	Current production
Jatropha oil	500 T
Coconut	270 000T
Palm oil	800,000 T
Shea butter	600,000 T
Rubber	15,000 T
Soybean	50 MT
Waste cooking oil	–
Feedstock for ethanol	
Maize	1,100,000 T
Cassava	900,000 T
Cane sugar	900,000 T

being cultivated on a small and medium scale, are not subjected to large-scale industrial use, limiting the amounts produced yearly.

Ghana's location at $\pm 10^{o}$ north or south of the equator makes it perfect for cultivation of palm fruit, with approximately 240,000 ha of land planted in large, medium, and small-scale farms. Levels of production of palm oil are not impressive as depicted in Table 8, yet the country has a significant potential of producing a lot of palm oil to be used domestically as well as industrial use. At the moment, a Presidential Special Initiative (PSI) on palm oil, as expected will result in approximately 300,000 ha of land planted with palm fruits. Approximately 100,000 ha are currently grown. The government's direct participation in the process has resulted in rapid success. Ghana is majorly importing soybean, despite the fact that the country is producing close to 50 Metric Tonnes(MT) and has the capacity of producing about 700,000 Tonnes(T) every year [95].

As shown in Fig. 4, the seed requirements for jatropha and coconut were established to be similar. Shea butter and rubber oil were having the smallest seed requirements in meeting the demand nationally in 2015 and 2020. Another question to consider is the amount of land required to produce these feedstocks, as the yields per hectare vary between oil seeds. This is a genuine concern, particularly since the similar piece of land for growing food crops can also be used for growing energy crops. Published works showing the yield of different feedstocks are extremely scarce in Ghana. Published data on feedstock yields per hectare from other countries are only available. It would be incorrect to use these published data for comparison because food crop yield is heavily influenced by conditions of the soils and practices of farms. Other factors, such as number of times seeds are harvested in a year, influences feedstock selection, along with land availability and cultural practices used.

Currently, the country is lacking the capacity to produce a lot of seeds which are required in production of necessary amounts of biodiesel. Production of palm oil currently stands at more than 1,500,000 T per year while for soyabeans is 1450,000 T. Production of coconut has been stagnant at around 600, 000 T per year in 2015 [95]. Large-scale coconut oil production is nearly non-existent in Ghana. There is almost no data on the production of citronella, castor, and neem seed oils, as well as waste vegetable oils (WVO). In the meantime, palm, jatropha, coconut, soybean, shea butter and rubber oils are viable feedstock options.

The initial assessment indicates that the government projections in the Ghana Government policy on development of biofuel and specifically biodiesel aims at substituting consumption of petrol fuel nationally with biofuel by at atleast 10 % by 2020 and 20 % by 2030, could be achieved. However, the development of biodiesel in Ghana is hindered further by the following additional barriers below [29].

2. Raw material

2.1. Waste vegetable oils (WVO)

Waste vegetable oils are the cooking oil produced as the by-product in the factories that are involve in processing foods, also in restaurants, households and in hotels. The amount of WVO being produced in Ghana cannot be established. It is therefore challenging because of this, for the possible investors in making decision on the size of their biodiesel processing plant using WVO as the feedstock. Moreover, saving carbon dioxide possibly produce from using WVO's biodiesel cannot be accounted due to the lack of data on quantities of feedstock. Studies have proven that using WVO as the feedstock leads to the production of the biodiesel which performs

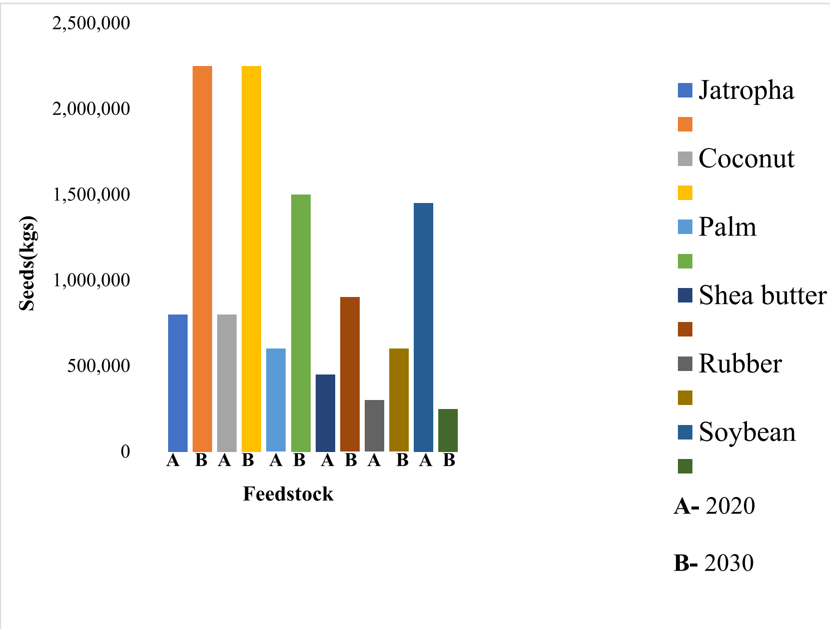

Fig. 4. Feedstock required to meet the demand for substituting 10 % and 20 % of diesel consumed by 2020 and 2030, respectively [95].

best in diesel engines for example in diesel generators and compression ignition in motor vehicles and therefore WVO is an important feedstock for producing biodiesel [29].

The companies that produce biodiesel in Ghana can use WVO by forming alliances with the major producers such as food processing factories and restaurants like Santoku Restaurant, Buka Restaurant and many others. This is to ensure that the amount easily can be quantified and the stability in the supply of raw material as well as improvement of corporate image. There should be efficient recycling platform as well as the specific policies in Ghana in controlling and improving rate of flow and recycle of the WVO. The existing policies on waste management are too general and do not include the recycling of waste edible oil. The specific law on recycling of waste edible oil should be put in place in future and a waste recycling system should be created to increase the rate of recycling waste edible oil [97].

2.2. Energy crops

Scramble for land happened in Ghana between 2004 and 2010 by the multinational and the local companies together with foreigners involved cultivation of energy plants such as jatropha for the production of biodiesel [98]. Many companies from different countries acquired the land and started the cultivation of jatropha plant to produce biodiesel mainly for export. Biodiesel production can be a new source of income to local farmers and also lead to the improvement of the infrastructural facilities and overall development in a broader scope. However, the land grabbing by companies for the large-scale production of biodiesel has caused alarm among the civil society organization, local communities and other parties. In fact, majority of the cases involving the loss of land is associated with commercial biofuel feedstock production in Ghana than any other country in Africa [29].

In Ghana, the land for potential agriculture is 57.6 % and International Fund for Agriculture Development and the Government of Ghana (GoG) through the Ministry of Agriculture, have been supporting small holder's farmers, medium to large-scale plantations who are involved in cultivation of bioenergy crops. Oil yield, techniques of harvesting, pressing of oil and processing of biodiesel from the energy crops which are produced locally, should be improved in order to reduce the cost of production. In addition, food crops should not be used to produce biodiesel unless it is in excess supply as per the recommendation of World Health Organization and Food and Agricultural Organization [99].

2.3. Cost

The cost of biodiesel production is generally a little higher as compared to importation of petroleum fuel obtained from the fossil fuels. And the likely impact of production of biodiesel on the cost of food crops in Ghana is a main concern. The impact of using food crops such as palm oil, coconut oil and others to produce biodiesel is through the loss of land in cultivating food crops hence food insecurity [100]. According to the study by Schoneveld et al. [101], large-scale use of land for feedstock expansion for biofuel in Ghana, led to loss of land, hence households resorted to the reduction of the space under cultivation thus increasing cropping intensity and shortening the period of land to fallow. The trends did not only lower the income of the household levels and food security in a significant way but degraded the land hence lowering it carrying capacity. For example, in the Bia District of the Western Region, large-scale jatropha plantations were established on land previously used for food crops, displacing local farmers and reducing food production [100,101].

Based on research by Brinkman et al., [100] on distribution of food security impacts of biofuel in Ghana, the demand for biofuel will rise significantly as expected in the years to come. Contrastingly, major concerns also arise on impact of rise in production of biofuel on

Table 9
Household food security in Ghana in 2020 and 2030 for the baseline and mandate scenario [100].

Pillar	Indicator	Unit	2020		2030: baseline		2030: mandate	
			Urban	Rural	Urban	Rural	Urban	Rural
Availability	Food energy consumption	(kcal cap^{-1} day^{-1})a	1660	1892	2223	2215	2222	2215
	Protein consumption	(g cap- 1 day^{-1})a	35	37	48	42	48	42
	Fat consumption	(g cap- 1 day^{-1})[a]	26	37	34	40	34	40
	Carbohydrates consumption	(g cap- 1 day $^{-1}$)[a]	321	354	432	424	432	424
	Energy supply from cereals roots and tubers	(kcal cap^{-1} day^{-1})[a]	968	776	1052	1096	1051	1096
	Supply of protein from animal sources (excluding fish)	(g cap^{-1} day^{-1})	4.24	2.44	6.05	2.95	6.04	2.95
	Average value of food production	(USD cap^{-1})	560[b]		834		853	
Access	Household income	(USD cap^{-1} yr^{-1})	2524	1729	7316	4532	7201	4527
	Food price index	(% change, compared to 2010)			−14.2 %		−12.1 %	
	Share of food in total household expenditure	(%)	19 %	22 %	12 %	30 %	12 %	31 %
Utilisation	Share of calories from fruit and vegetables	(%)[a]	16 %	13 %	16 %	15 %	16 %	15 %
	Share of energy supply from roots and tubers	(%)[a]	51 %	42 %	52 %	47 %	52 %	47 %
Stability	Cereal import dependency ratio	(%)[a]	5 %	4 %	5 %	3 %	5 %	3 %
	Food share in total consumption imports	(%)	27 %		14 %		14 %	

[a] Only primary agricultural products are included.
[b] In the MAGNET model, no agricultural production is assumed in the urban areas.

food security. As a result, the impacts were assessed using four pillars of food security; availability, accessibility, utilisation and stability. Using computable general equilibrium (CGE) model MAGNET, 13 food security indicators in combination with household and nutrition model were quantified in urban and rural areas. The results indicated that the country's economic progress is expected to increase food production and consumption, outweighing the impact of a biofuel mandate on food availability and access (Table 9). Implementing a biofuel mandate may slightly reduce food security in 2030, but it still represents significant progress compared to the current situation.

Lack of sufficient financial support is significantly impacting the implementation of bioenergy production projects in Ghana. Even though it is an effective means to use high technology and machinery to generate and save bioenergy, cost deliberations are crucial in commercial activities. Also, it costs a lot to purchase adequate information in addition to high-tech systems. In this modern time, finance is important to meet bioenergy projects' machinery and workforce requirements. Hence, it is unachievable to implement bioenergy project if there is no sufficient financial support from stakeholders and the government [100].

Lack of the distribution channel affects the cost of the biodiesel. Biodiesel is considered to be expensive in Ghana as compared to the vegetable oil used for producing it, such as jatropha oil. From the table the cost of producing biodiesel is between 0.3 and 2.7 USD per litre as compared to 0.18 USD per litre for the production of jatropha oil. As compared to diesel fuel, cost of biodiesel is slightly higher, as shown in Table 10, due to the higher cost of processing jatropha oil and the challenge of lack of adequate channel of distribution such as biodiesel gas station unlike the petroleum fuel [29]. At international level and specifically within the scenario of Sweden the cost of biodiesel from jatropha oil as well as the cost of jatropha oil was low. The higher cost of jatropha oil presently in Ghana resulted in higher cost of biodiesel than petroleum fuel. In Ghana's rural places where jatropha plantation is undertaken for multifunctional platforms (MFP) it more economical to use as compared to jatropha biodiesel. However, the viability of producing jatropha oil and additional processing to jatropha biodiesel in large quantities is higher. As per other studies in countries such as India, Mali and the rest, production of jatropha oil on commercial basis is cheap thus production of biodiesel in MFP is feasible and can keep engine for a long period [102–105] (see Table 11).

The government can assist through the provision of the subsidies to promote production of biodiesel and companies in biodiesel industry should be given exemption from the taxes such as excise tax related to biodiesel production, for the improvement of market competitiveness. Amendment should be carried out on section of the regulation that involves in setting up and management of the gas station. The amendment should consider including biodiesel refilling station within the scope of the business of the gas station.

Various feedstocks oil has different cost for producing biodiesel. In Ghana, jatropha has the lowest cost of 0.66 $ per unit volume among the feedstocks, of while rubber oil has the highest cost of 0.98 per unit volume and this because rubber oil has very high viscosity value as compared to jatropha oil and other feedstocks oils and thus requires more processing(Fig. 5) [105].

2.4. Public acceptance

Majority of the biodiesel project in Ghana do not have adequate community participation in their design and implementation programme. These has resulted in insufficient corporate commitment which cannot really benefit the communities locally and traditional institutions. Due to this, public acceptance of the biodiesel projects is still low and there is a need for improvement in public participation to enhance public acceptance [97,20].

Mass media and use of community awareness campaigns and participations are very crucial in educating the public on the importance of the biodiesel and thus creating awareness in order to enhance the public acceptance. The public should have the knowledge of the biodiesel being environmentally friendly in addition to being a good lubricant to the engine and thus ensuring efficiency and improve life-spun of the engine which will eventually build clients confidence.

2.5. Legislation

Since 2009 the government of Ghana gave approval to the companies such as Scan Fuel Company Limited to start the production of biodiesel using the oil from the jatropha plant, cultivated in an almost 400,000 ha of land. A National Biofuel Policy was enacted by the parliament in 2011 with whose objective include replacement of 5 % of petroleum diesel with biodiesel by the year 2010 and 20 % by the year 2030 [78].

From then up to now, the development of biodiesel in Ghana is still in initial stage because of the failure of initial biodiesel projects using jatropha plant and high cost of raw materials for producing biodiesel rendering it a big challenge without the full financial

Table 10
Comparative prices of jatropha oil, kerosene and biodiesel in Ghana and international market [103,104].

Estimated cost, US dollar/litre					
Product (per litre)	International market (Sweden)				
	2005	**2008**	**2010**	**Case 1**	**Case 2**
Jatropha oil	0.154	0.191	0.085	0.18	0.18
Kerosene ex-refinery	0.92	0.85	0.87	–	–
Kerosene ex-pump	0.83	0.77	1.23	–	–
Jatropha Biodiesel	1.54	1.02	0.99	0.383	0.339
Diesel ex-pump	0.78	1.01	1.21	–	–

Table 11
Summary of the obstacles to adopting biodiesel and their possible solutions.

Barriers	Description of the barrier	Solution
a) Raw materials; Waste edible oil e.g. WVO	The amount of WVO being produced in Ghana cannot be established	Ghanaian biodiesel companies can utilize WVO by forming alliances with major waste producers like food processing factories and restaurants like Santoku and Buka.
b) Energy crops	The large-scale land grabbing by companies for biodiesel production which has raised concerns among civil society organizations, local communities, and other parties	Food crops should not be used to produce biodiesel unless it is in excess supply as per the recommendation of World Health Organization and Food and Agricultural Organization
c) Cost	Impact of producing biodiesel on the cost of food crops such as palm oil, coconut oil and others in Ghana is a main concern	The government can boost biodiesel production through encouraging use of non-edible oil such as jatropha and giving subsidies and exemptions from excise taxes, to firms in biodiesel business thereby improving market competitiveness
d) Lack of distribution channel	Lack of the distribution channel such as biodiesel gas station unlike the petroleum fuel affects the cost of the biodiesel	Amendment should be carried out on section of the regulation that involves in setting up and management of the gas station
e) Public acceptance	Inadequate community participation in biodiesel project design and implementation programmes hence low public acceptance	Mass media and use of community awareness campaigns and participations should be use to educate the public on the importance of the biodiesel
f) Legislation	Lack of proper legislation for the biodiesel firms to easily access loans from the local banks	Legislation on biodiesel industry in Ghana should be amended to include easy accessibility of loan and financial resources by firms in the biodiesel sector

Source: Authors, 2024

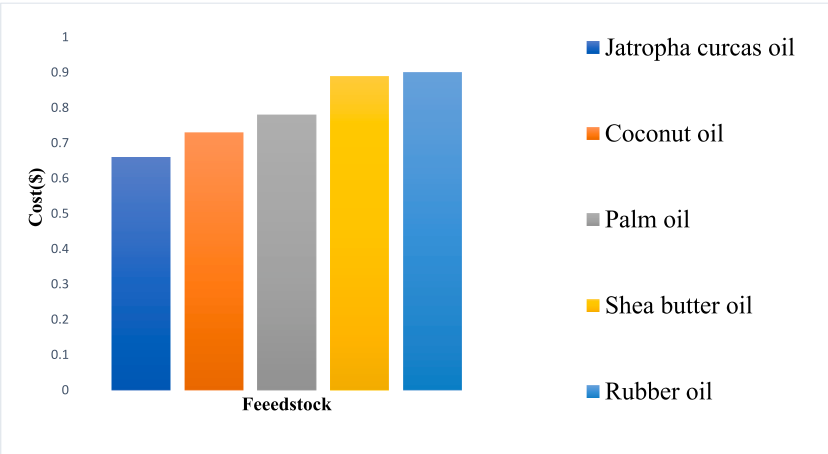

Fig. 5. Biodiesel production costs comparison in 2015 for different feedstocks in Ghana [105].

support of the government through proper legislation for example which can allow the biodiesel firms to easily access loans. Most of the firms in renewable energy in Ghana could not access the loan easily from the local banks, because of lack of appropriate legislations [29].

Biofuel Policy in Ghana aimed at replacing petroleum diesel with biodiesel. And apart from definition of strategic objectives for the development of biodiesel, the policy also recommends the development of the infrastructure, regulatory and institutional framework, product's quality and fiscal incentives in attracting investment. The policy moreover, recommends development and research on biomass and biofuel and specifically biodiesel. The research institutions in Ghana and the universities therefore, should conduct research and development with the aim of improving efficient production of biofuel technologies in order to lower the cost of production, improve the quality and efficacy of the product. Generally, legislation on biodiesel industry in Ghana is expected among other objectives to create a marketing strategy for the agricultural product and a source of income through sell of carbon credit under the Kyoto protocol. The National Standard for Biofuel in addition to permitting framework and National Road Map for the introduction of biofuels into petroleum sub sector were earlier developed [79,97].

2.6. Negative effects of biofuel on rural land tenure and livelihoods

The smallholder livelihoods, customary land tenure system and food security has been endangered by the growing large-scale biofuel investment. If carried out properly the large-scale land investment of biofuel projects can lend itself to smallholder out grower scheme and thus the hostility to smallholder agriculture will not exist. Although, some of the documented biofuel investment in Ghana have not been carried out correctly which has resulted in displacement of the local community or loss of community's access to natural resources which is important to their livelihood. Complains from farmers on lack of consultation on development of biofuel production sites by their chiefs have been witnessed. In an instance, in northern Ghana, the land was bought by the multinational company for developing jatropha plantation thus forcing many farmers out of their land. Poverty coupled with insufficient information as well as the experience with external investors can be misleading to the communities in accepting promises of jobs or new land exchange in order for them to cede their original land. Many times, these promises cannot be actualized or are fulfilled but below the expectations. The research carried out by the ActionAid established that workers in plantation of biofuel are imported from out of the surrounding communities. Moreover, even on hiring local workers, there is no sustainability of the benefits. Large-scale lay off of workers in the plantations are usually carried out by these companies after the reduction in the labour requirements after the stages of clearing and planting [102,106].

Unintended consequences on local livelihood might have been caused as a result of developing plantation on the marginal land. Grazing lands is likely to be converted to the field and this negatively affects traditional herding practices. Marshlands will be drained, which degrades the ground for breeding fish and the rest of the animals such as wildlife. Forest, vegetation cover, and economic trees which include the shea nut trees, which produces fruits used in making of soaps and cosmetics are destroyed by large scale production using machinery. Several Ghanaian women depend on Sheanut harvest for source of income in the raining period. Sheanut tree prefers growing in land that is not suitable for small-scale agriculture and were cleared to pave way for the large-scale jatropha plantation for biofuel production [102,104].

Lastly, the risk of food security is exacerbated by the large-scale cultivation of jatropha for biofuel production. Jatropha seeds produce oil that are toxic and non-edible to human and animals and can be used to produced biodiesel. Marginal lands are used for cultivation of jatropha but fertile lands that are arable have been used instead. Ghana is now importing food to support the local demand and already 1.2 million Ghanaian are affected by lack of adequate food. Food insecurity is likely to increase as a result of converting large portion of land meant for food production to cultivation of biofuel plants [102,107].

Customary authorities, specifically chiefs and earth priest(*tendamba*) who are found in the north as well as the family heads in the south together with Lands Commission plays a critical role in the expansion of the Ghana's biofuel sector. Lands Commission co-ordinates all the relevant public agencies and traditional authorities and prepare policy framework guiding land acquisition for biofuel production. Best practices suggest the policy should include the following [104,108].

1. A community consultation process preceding the acquisition of land that accurately informs communities of what they can be expected to lose and to gain.
2. Clearly defined procedures for transparent and timely consultation between customary authorities and their communities, so that communities have the ability to reject planned investments.
3. Mandatory environmental and social impact assessments to qualify for permits to cultivate biofuel plantations.

2.7. Future outlook

Biodiesel sector in Ghana must be optimized for sustainability, efficiency, and scalability. This involves finding and optimising locally accessible feedstocks with high oil yields and little competition from food crops. Locally available feedstocks such as jatropha oil, palm oil, coconut oil, shea butter oil and rubber oil have significant potential for producing biodiesel. For instance, jatropha thrives in semi-arid regions such as Northern and Upper East regions and through its cultivation farmers in the rural areas can get an extra income at the same time contributing to the production of energy. The government therefore, should provide incentives such as low interest loans or grants to the farmers and business involved in the production of biodiesel. In addition, meeting the targets of Strategic National Energy Policy (SNEP) of boosting the production of biofuel, Ghanian government should, take an initiative of granting subsidy to propel the biofuel production. All forms of taxes on the equipment for the production of biofuel should be significantly waived or removed. Farmers involved in cultivation of biofuel feedstock should have similar incentives as those of cocoa farmers [95,100,102,108].

Technical issues with biodiesel performance and compatibility with existing engine technology should be solved. Advanced engine technologies and aftertreatment systems should be developed to increase efficiency while reducing environmental effect. Interdisciplinary research collaborations between academics, government agencies, industrial partners, and local communities are critical for tackling technical, socioeconomic, environmental, and policy concerns in biodiesel production and utilisation [95,109,110]. The contribution for example of institutions of higher learning specifically like Kwame Nkrumah University of Science and Technology (KNUST) through the research to improves properties of biodiesel such as oxidative stability and cold flow properties will further enhance the quality and efficiency. In addition, carrying out public awareness campaigns can highlight successful projects for example Tamale jatropha biofuel project, which demonstrate ways in which communities can gain economically and environmentally from biodiesel [100–102].

Ghana can partner with other countries which are already producing large amount of harvest for crops used for biofuel production such as Brazil which produces sugarcane, Malaysia and Indonesia which produces palm oil. These countries have passed through the experimental stages of agronomical development which offers good opportunity for Ghana to partner with them for transfer of knowledge [111,113]. Biofuel plant providers can build a plant on a "build-operate transfer" basis in partnership with Ghana from the beginning. This will result into the improvement of local capacity in addressing the issue of technology in the future projects. The success of biofuel technology transfer is dependent on government's active involvement. The support of government for technology transfer entails direct financial incentives which include grants for Research, Development and Demonstration (R, D&D) [96,112].

Biofuel production in Ghana should be carried out with the aim of ensuring social equity. Small-scale biofuel conversion technologies should be established as a result of providing incentives in order for the production of higher-value product and selling of those products from the local industries. The requirement by the Prescribed Obligatory Purchases (POPs) for the private biofuel companies to buy the stipulated percentage of their feedstock oil from local farmers should be enshrined in the Ghana's biofuel policy [99]. POPs in Ghana can be used as a powerful policy tool in accelerating the growth of the biofuel sector through ensuring private companies incorporate biofuels into their energy use. A vivid example of POPs is a mandate which requires oil marketing companies (OMCs) in Ghana like GOIL, Shell, and Total to purchase a particular specified percentage of biodiesel from local producers to be use for blending with conventional diesel. Moreover, specific sectors such as the mining industry, which are significantly present in Ghana through companies such as Newmont and AngloGold Ashanti, and are heavily relying on diesel for machinery and transportation can be mandated to buy a percentage of biodiesel to be used in their operations [99,102,114].

2.8. Conclusion

Biodiesel is a fuel which is renewable, not toxic and it is biodegradable. It can be applied directly to the conventional diesel with a little or no modification at all. Substitution of fossils fuels with biodiesel leads to reduction of air emission, increases the generation of domestic energy and creation of market for farmers through sell of feedstock for producing biodiesel. Biodiesel research and development in Ghana is still in its early stages. In order to develop and promote biofuel, Ghanaian government has implemented some of the programs, for example production of biodiesel using jatropha whereby the government set aside money worth millions of US dollars for developing jatropha plantation within the country. The government programme of producing biodiesel using jatropha oil led to the establishment of several private companies. Biodiesel from jatropha oil is a renewable, and sustainable alternative to conventional diesel. It reduces greenhouse gas emissions, particulate matter, and sulphur content, improves engine performance, and reduces dependency on fossil fuels. Other vegetable oil from edible source such as palm oil, coconut and non-edible sources such as shea butter, and rubber oil are also a potential feedstock for producing biodiesel in Ghana. However, there are barriers to adoption of biodiesel in Ghana which include; high cost of production, the effect of biodiesel production on food security and loss of land, lack of the distribution channel, low public acceptance and lack of proper legislations in biodiesel industry. To overcome these challenges, amendments to regulations, and use of mass media, community awareness campaigns and others which can help promote biodiesel adoption. Furthermore, based on suggestions of this review, Ghana's biofuel policy should be comprehensively reformed to take into account the economic, environmental, and social aspects of biofuel production and usage. The outlook on Ghana's biodiesel sector shows the needs for optimization for sustainability, efficiency, and scalability. This involves finding local feedstocks with high oil yields, developing innovative cultivation techniques, and developing low-cost extraction and refining methods. Interdisciplinary research collaborations and partnerships with countries like Brazil, Malaysia, and Indonesia are crucial for addressing socioeconomic, environmental, and policy concerns.

CRediT authorship contribution statement

Rogers Kipkoech: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Mohammed Takase:** Writing – review & editing, Visualization, Validation, Supervision. **Arcadius Martinien Agassin Ahogle:** Writing – review & editing. **Gordon Ocholla:** Writing – review & editing.

Data availability

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