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Review

Biofuel Development Initiatives in Sub-Saharan Africa: Opportunities and Challenges

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Abstract: In recent years, biofuels have emerged as a suitable alternative to hydrocarbon fuel due to their foreseen potential of being a future energy resource. Biofuel development initiatives have been successfully implemented in countries like Brazil, United States of America, European Union, Canada, Australia, and Japan. However, such programmes have been stagnant in Africa due to various constraints, such as financial barriers, technical expertise, land availability, and government policies. Nonetheless, some countries within the continent have realized the potential of biofuels and have started to introduce similar programmes and initiatives for their development. These include the bioethanol production initiatives and the plantation of jatropha oil seeds in most Sub-Saharan African countries for biodiesel production. Therefore, this paper examines the biofuel development initiatives that have been implemented in several countries across Sub-Saharan Africa over the past few years. It also discusses the opportunities and challenges of having biofuel industries in the continent. Finally, it proposes some recommendations that could be applied to accelerate their development in these Sub-Saharan African countries.

Keywords: biofuels; feedstocks; Sub-Saharan Africa

1. Introduction

Africa is experiencing unprecedented and sustained growth. Currently, the continent has an estimated population of about 1.2 billion people. It is envisaged to have a population of about 2.5 billion people in 2050, which is double the current population [1]. According to a study conducted by the International Energy Agency in 2010, Africa had an estimated population of one billion and about 470 million people, representing 47% (Figure 1), had no access to electricity and were living without clean water facilities. Industrialization and population growth have been highlighted as major drivers affecting energy demands in most developing countries. However in African countries, energy demands will continue to intensify, mainly because of population growth. As a consequence, the population is projected to be 1.6 billion in 2030. This implies that the percentage of rural inhabitants without access to electricity is expected to reach 37%, corresponding to 592 million people, whereas 44% (704 million people) of urban dwellers will have access to electricity, as shown in Figure 1 [2].

Africa's economy is also growing at an average rate of 4% per year. A report from the International Renewable Energy Agency showed that six of the world's ten fastest growing economies over the past decade were in Africa. Thus, in order to maintain this growth as a continent, it was highlighted that the continent's gross domestic product (GDP) needs to increase three-fold by 2030 and seven-fold by 2050 [2]. However, sustaining such economic growth will only be possible if the continent has a thriving energy sector. The major drawback is that many countries within the continent are net oil

importers and have unstable economy *i.e.*, forty-two countries are net oil importers with the exceptions of Libya, Nigeria, Algeria, Egypt, and Angola [2].

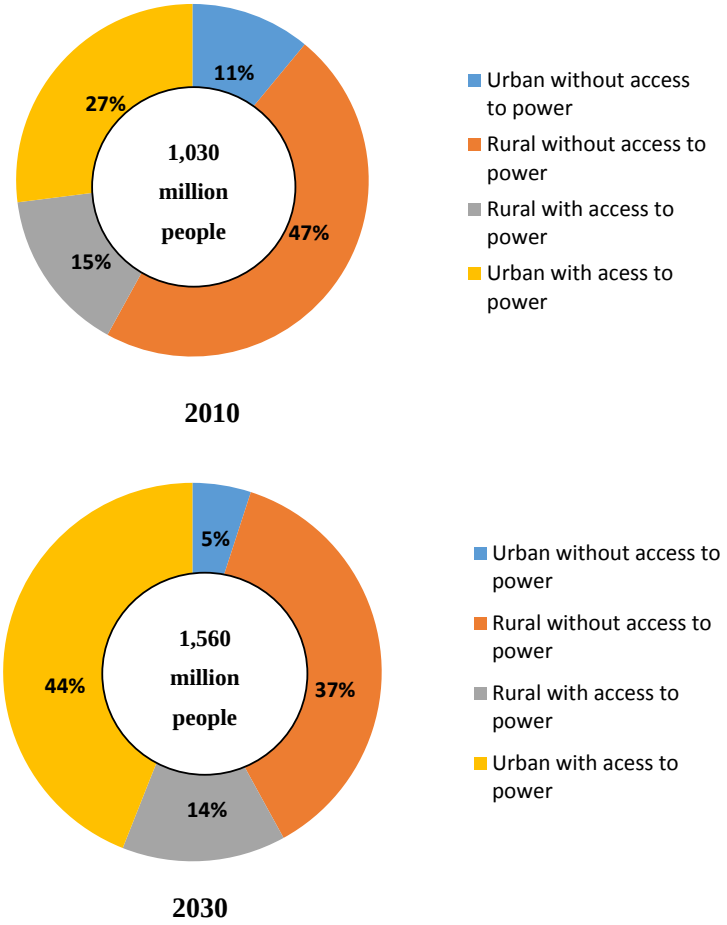

Figure 1. Shows the rural and urban electricity access for people living in Africa for the year 2010 and 2030 [1].

The unstable oil prices have also caused a huge financial burden on Sub-Saharan African oil importing countries, such as Benin, Burkina Faso, Cape Verde, Chad, Comoros, Eritrea, Gambia, Guinea, Liberia, Mauritania, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, and Togo [3]. The price of oil is predicted to be nearly double in these countries than in oil producing markets. Furthermore, the demand for transport fuels is expected to grow by more than 5% year in these Sub-Saharan African countries during the period of 2005–2020 [4]. Other social challenges, such as political unrest, have resulted in severe damage to power facilities in Liberia, Somalia, Sierra Leone, the Central African Republic, and the Democratic Republic of Congo. Similarly, political conflict and economic downturn have negatively affected the power infrastructure in Zimbabwe [4]. Other countries, such as South Africa, are experiencing power outage due to rapid industrial growth. Another drawback is that they are relying on old power facilities that regularly require maintenance [5].

Therefore, these findings present a sense of urgency for the development of alternative energy fuels that will offer these Sub-Saharan African countries the prospect of self-sustainability with potential socio-economical benefits. Moreover, development of alternative energy fuels will have several advantages, such as alleviating the region's dependence on fossil-based fuels, cost-effective energy resources could be selected, more people can have access to electricity, and it could be cheaper to expand these technologies [6]. Biofuels are seen as a potential energy contributor in the next few decades and, thus, many countries are advocating policies that encourage their production and

consumption. Biofuels are considered a favourable alternative source of energy because (i) they are produced from sustainable energy crops; (ii) they can play a pivotal role in strengthening Africa's energy security; and (iii) improve infrastructural development programmes within the continent. This paper examines the biofuels development initiatives that have been carried out in some Sub-Saharan African countries. It discusses the opportunities and challenges of biofuel sector in Sub-Saharan African countries. Finally, it proposes some solutions that can be applied to boost their production.

2. Driving Forces behind the Intensification of Biofuels

The dwindling fossil fuels coupled with environmental degradation have triggered a worldwide interest in the establishment of an environmentally benign, carbon neutral and sustainable form of energy. Biofuels are considered a favourable alternative source of energy because they are produced from sustainable energy crops [7]. In industrialized countries, where greenhouse gas emission is a major challenge, the biofuel sector has been intensified to mitigate this problem. Thus, the worldwide production of biofuels has been increasing significantly over the past few years, from 20 billion litres in 2001 to more than 110 billion litres in 2011 [8]. During this period, the production of bioethanol and biodiesel increased exponentially. According to the US Environmental Protection Agency in 2010, it is expected that the production of biofuels will reach 222 billion litres by 2021 with bioethanol and biodiesel consisting of 81% and 19%, respectively, of this value [9]. It is important to note that a huge percentage of biofuels produced globally are generated from highly industrialized nations, such as the United States of America, Brazil, European Union, Australia, and Japan, in efforts to reduce their carbon footprints. However, in impoverished and underdeveloped regions, like Africa, biofuels are seen as a catalyst for infrastructural development projects, reducing high international oil prices, boosting the continent's energy sector, and the creation of employment opportunities. These are explained in Section 3.

3. Opportunities for Biofuels in Sub-Saharan Africa

The growing global interest in biofuels has prompted many African countries to start harnessing this form of energy. In the next two decades, it is envisaged that the biofuel sector will be a thriving one in most African countries, and will significantly contribute to the continent's infrastructural development programmes and economies. During this period, most countries are expected to formulate biofuel development policies that will regulate this sector [10].

In addition, the development of the biofuel sector presents many opportunities for poverty stricken nations in Africa. It has the long-term potential of boosting the energy sector of oil-importing countries. It can also boost the agricultural sector and could improve local infrastructures and rural development. For instance, farmers can grow specific crops that are used for biofuel production, and then receive incentives from local biofuel industries. Organic residues are also well suited for biofuels because they are easily available, inexpensive, and are considered as waste materials. Thus, the establishment of a biofuel sector will benefit the continent enormously, and this is elaborated below:

- Establishment of biofuel industries will assist rural communities to use the fuel for household electrification, powering farming machinery, and transportation.
- Development of biofuel initiatives will stabilise the continent's energy supply and diversify its fuel options and reduce the burden on oil importing countries.
- Some industrialised countries do not occupy enough land for cultivation of biofuel feedstocks, therefore African farmers can benefit by supplying raw materials to these nations.
- Construction of biofuel industries will provide many employment opportunities to African people and boost the continent's economy.
- Industrialised countries, such as Egypt, Nigeria, and South Africa, are amongst the leading carbon emitters in the continent. Therefore, commercialisation of biofuels technologies will assist in the mitigation of carbon emissions.

4. Biofuels Initiatives in Sub-Saharan African Countries

4.1. Burkina Faso

Burkina Faso is amongst the countries that are deeply affected by the energy crisis [11]. In efforts to curb this problem, biofuel development projects have been booming over the past few years. For example, 70,000 trees of jatropha oil seeds were planted in 2009 and government of Burkina Faso has been collaborating with the European Union Biofuel Directive since 2003 to boost this sector in their country [12]. Thus, biofuel development projects such as the Fondation Fasobiocarburant (FFB) were established, and are financed by Dutch investors [13].

4.2. Ghana

In 2010, Ghana introduced a bioenergy policy, which was created to substitute the country's petroleum oil with 10% biofuels by 2020 and 20% by 2030, respectively [14]. The country introduced this policy with the intention to utilise the vast majority of biomass resources that are abundant in Ghana for the generation of transport fuels and electricity. Biomass resources, such as cassava, sugarcane, maize, and jatropha oil seeds, were identified as potential feedstocks for bioethanol and biodiesel production in Ghana [14].

4.3. Mali

There are a number of biofuel projects that are currently underway in Mali, one of which includes a local non-governmental organization (NGO) referred to as the Mali-Folke Center Nyetaa, which offers assistance to local farmers to grow jatropha oil seeds [10]. Communities living near the Mali-Folke Center are provided with electricity generated from power plants that uses jatropha oil seeds. The project has embarked on a 15-year electrification programme, which aims to generate 300 KW of electricity to more than 10,000 rural residents. It is expected that more than 100 hectares of jatropha plantation will be established and used as feedstock for the production plant [10]. This will boost the livelihood of these communities.

4.4. Malawi

In 2006, an eight million US dollar biodiesel-based production plant was launched in Malawi's capital city, Lilongwe [15]. The project was led by Dutch investors, and currently processes up to 250 tons of jatropha oil seeds per day to produce 5000 litres of biodiesel. Thousands of local farmers have benefited from this initiative and they have been contracted to plant ten million jatropha trees over a period of five years; these trees will serve as raw materials for the production plant [15]. Other biofuel initiatives include the bioethanol production plants in Dwangwa Estate, which produce 15–20 million litres of bioethanol from sugarcane molasses, and the Nchalo Plant, which has a production capacity of 12 million litres per annum [16]. These plants jointly blend 10% (v/v) of bioethanol with petrol [16].

4.5. Mozambique

Various biofuel production initiatives have also been implemented in Mozambique over the past few years. For example, the Ndzilo Production Plant has a capacity of two million litres of ethanol processed from cassava [17]. With regards to biodiesel production, jatropha oil seeds have been gaining an increasing attention in Mozambique due to their advantages, which include sustaining harsh dry conditions. Companies, such as Petromoc and SunBiofuels, have established biodiesel production factories over the past few years in order to boost the country's energy sector [17]. The Mozambican government has implemented the blending of 5%–10% (v/v) bioethanol with petrol [10].

4.6. Nigeria

There is a growing response with regards to the production of biofuels in Nigeria. Therefore, various biofuel and biodiesel production initiatives ranging from feasibility studies to refinery plant installation have been carried out [18,19]. Currently, five major commercial-scale ethanol distilleries produce up to 134 million litres of ethanol per annum in Nigeria (Ohimain, 2010). Biodiesel production projects that have been initiated include Biodiesel Nigeria Limited in Lagos State, Aura Bio-Corporation in Cross River State, and the Shashwat Jatropha in Kebbi State [18].

4.7. Senegal

Over the past few years, the Senegalese government has developed various biofuels development initiatives in order to improve the country's energy sector. This was achieved by collaborating with biofuel experts from countries such as Brazil and India. Through this initiative, several biofuel projects were carried out in Senegal, *i.e.*, the inclusion of the plantation of jatropha oil seeds, which were grown on four thousand hectares of land in the city of Touba [20]. Other feedstocks, such as castor oil and sunflower, were also assessed and cultivated on more than fifty thousand hectares of land in Kolda and Tambacounda [20].

4.8. South Africa

Biofuels are amongst the highest renewable energy contributors in South Africa, with an estimated contribution of 9%–14% [21]. In 2013, The Department of Energy in South Africa announced that it aims to begin a mandatory blending of petrol and diesel with biofuels (bioethanol and biodiesel) as of 1 October 2015, as the country moves towards strengthening its biofuel sector, thereby reducing its reliance on imported fuel [21]. The country also proposed a five-year pilot phase plan, which is aimed at achieving 2% biofuel in the country. Therefore, five companies have been granted licenses to generate bioethanol and biodiesel in South Africa. Analysis of potential feedstocks that can be used reveals that sorghum is suitable for bioethanol production, while soya beans are also potential feedstocks for biodiesel production [21]. However, maize has been excluded from these feedstocks because it is one of the country's most stable foods with an estimated annual production of 8 million tons, and this may affects the country's food security. In addition, South Africa is experiencing a very large influx of biomass generated from the agricultural, municipal, and industrial sectors. Thus, other potential biofuel options, such as biomethane, bioelectricity and biohydrogen production, would play a pivotal role in country's energy mix.

4.9. Tanzania

In Tanzania, a number of companies, NGOs, and small-scale farmers are implementing biofuel programmes in the country [22]. These initiatives are elaborated on below.

- Diligent Tanzania Ltd.—the company focuses on the production of jatropha oil and biodiesel, but offers some consultancy services to jatropha farmers.
- Kakute Ltd.—is a privately owned company, which was established in 1995. It focuses on training farmers with jatropha plantations, oil processing, and the ARI-Monduli (Alternative Resource Income for Monduli Women) project, where local women farmers are assisted in the production of jatropha oil seeds.
- MVIWATA—this is a Tanzanian farmer's organization that was initially comprised of approximately 2000 small-scale farmers, aiming at planting jatropha oil seeds.
- Kikuletwa Farm—this farm is owned by Peter Burland and previously produced aloe vera; however, in 2002, he saw a great deal of potential in jatropha oil seeds and started to plant large hectares of it on his land. He has since been contracted by various companies to produce jatropha oil seeds.
- Jatropha Products Tanzania Limited—this organization is tasked with promoting the production of jatropha in Tanzania and has been in existence for many years.

- Tanzanian Traditional Energy Development and Environment Organization—this is a Tanzanian NGO that assists rural small-scale farmers and has projects running concurrently in Dar es Salaam and the Monduli District. It supports farming related to jatropha oil seeds.

There are also other biofuel initiatives that are being conducted in Benin, Burkina Faso, Ivory Coast, Guinea, Kenya, Ethiopia, Niger, Sudan, Swaziland, Senegal, Togo, and Uganda. These are summarised in Table 1; it can be observed that molasses is a popular feedstock for bioethanol production in many African countries, while jatropha oil seeds are common for biodiesel production. Table 2 shows the oil yields extracted from different feedstocks; these oils are used in biodiesel synthesis. It can be noted that the oil yields vary significantly due to various contributing factors, such as nutritional composition of feedstocks, soil content, and climate conditions in which the energy crops are grown under [10].

Table 1. Biofuel production from agricultural waste in Sub-Saharan African countries [10].

Country	Feedstock	Biodiesel Yield (ML)	Bioethanol (ML)
Benin	Cassava	-	20
Burkina Faso	Sugarcane	-	20
Ivory Coast	Molasses	-	20
Ghana	Jatropha	50	-
Guinea	Cashew	-	10
Mali	Molasses	-	20
Malawi	Molasses	-	146
Kenya	Molasses	-	413
Ethiopia	Molasses	-	80
Niger	Jatropha	10	-
Nigeria	Sugarcane	-	70
Sudan	Molasses	-	408
Swaziland	Molasses	-	480
Senegal	Molasses	-	15
Tanzania	Molasses	-	254
Togo	Jatropha	10	-
Uganda	Molasses	-	119

ML: megalitres; -: data not available.

Table 2. Oil yields from various feedstocks across Africa [10,23].

Feedstock	Litres of Oil Per Hectare	Countries That Grow Feedstock
Palm oil	5950	Angola, DRC, Ghana, Nigeria, Tanzania
Soya beans	446	DRC, Ghana, Malawi, South Africa, Tanzania
Coconut	2689	Ghana, Mozambique, Nigeria, Senegal, Tanzania
Jatropha	1892	Benin, Tanzania, Malawi, Mozambique, Nigeria, Ghana
Sunflower	952	Angola, Botswana, DRC, Ghana, Malawi, Nigeria
Cotton seed	325	Angola, Ghana, Malawi, Mozambique, Tanzania, South Africa, Zambia, Zimbabwe
Avocado	2638	DRC, Ghana, Nigeria, Senegal, South Africa
Groundnuts	1059	Angola, DRC, Gambia, Ghana, Malawi, Mozambique, Senegal, Zambia, Zimbabwe
Cashew nut	176	Angola, Ghana, Mozambique, Nigeria, Tanzania
Castor beans	1413	Angola, DRC, Mozambique, South Africa

Biodiesel can be synthesized from various feedstocks, including edible and non-edible oils, as shown in Tables 2 and 3, respectively. However, the utilization of edible oils presents many challenges, *i.e.*, many African countries are experiencing a shortage of food supply. Therefore, non-edible oils

are ideal substrates because they do not impose a threat to food security and many can be cultivated under various climatic conditions. Furthermore, the increase in world population puts pressure on the global food supply, and, hence, biofuels experts are focusing on feedstocks that are considered waste materials and easily cultivable.

Table 3. Oil content from non-edible feedstocks.

Feedstock	Oil Content			References
	Seed (wt %)	Kernel (wt %)		
Jatropha	20–60	40–60		[24]
Karanja	25–50	30–50	-	[24]
Neem	20–30	25–45	-	[24]
Mahua	35–50	50	-	[24]
Kusum	10.65	-	-	[25]
Castor	45–50	-	-	[24]
Linseed	35–45	-	-	[24]
Sea mango	54	6.4	-	[24]
Tobacco	17–25	17	-	[26]
Mexican prickly poppy	22–36	-	-	[26]
Rubber tree	40–60	40–50	-	[24]
Persian lilac	10	-	-	[26]
Jojoba	45–55	-	-	[26]
Yellow oleander	8.41	-	67	[26]
Moringa	33–41	-	2.9	[26]
Field pennycres	20–36	-	-	[27]

-: data not available.

5. Feedstocks Used for Biofuel Production

5.1. Bioethanol Production

Bioethanol can be synthesised using various organic materials that are comprised of fermentable sugars, such cellulose and hemicellulose [28]. Research over the past few years has been focusing on the utilisation of agricultural waste in order to make this process economically feasible. It was estimated that approximately 491 billion litres of bioethanol can be produced from agricultural waste materials, such as rice straw, wheat straw, corn straw, grasses, sawdust, sugarcane molasses, and woody chips [29]. These feedstocks are advantageous for bioethanol production because they are highly abundant, inexpensive, and renewable. Moreover, bioethanol can be produced from edible feedstocks, such as barley, sugarcane, sorghum, and cassava; however, their usage is discouraged due to the food shortages facing many impoverished countries.

5.2. Biodiesel Production

Biodiesel can be produced from oils and fats that are extracted from animal fats, and non-edible oleaginous plants, such as jatropha oil seeds, and other non-edible plants, as shown in Table 3 [30].

6. Social Concerns Related to Biofuels in Sub-Saharan Africa

6.1. Land and Food Security

Land is the biggest asset that forms the foundation of all human life. Therefore, more than 60% of the people in Angola, Mozambique, Namibia, Tanzania and Zimbabwe reside in rural areas, whereas more than 70% live in rural areas in countries like Lesotho, Madagascar and Malawi [31]. There has been some scepticism with regards to the usage of land for biofuel production in Africa because a vast majority of the countries are primarily dependent on agriculture as a means of survival. Commercialisation of biofuels will require many hectares of land, and this might cause a major problem

for the livelihoods of people. For example, agricultural work is carried out by women organizations and small-scale farmers in most countries in West Africa. Therefore, if the arable land is used for cultivation of biofuel feedstocks, this will reduce their agricultural outputs and, thus, affect their basic living conditions [32].

In a meeting held in Rome in 1992, the World Food Summit defined food security as the ability of all people to access food that is needed for healthy living at all times [33]. Shortage of food has been identified as a major problem facing most countries in Africa, and was highlighted in the Millennium Development Goal (MDG) as one of its priorities [34]. Recent food security crises have also invigorated the debate of biofuel production potential in African countries, given the fact that most of them depend on local agriculture for sustenance. Land plays a crucial role in the livelihoods of Africans; therefore, food security and poverty alleviation will be achieved if the land is firstly prioritized to people's needs and is then catered to biofuel industries.

Nevertheless, countries with favourable climate conditions and land potential are at an advantage for the biofuel sector, and have the possibility of developing their agricultural regions [35]. Therefore, it is pivotal for governments in Africa to regulate the distribution of land in order to prevent the exploitation of people, especially impoverished small-scale farmers, by the biofuel markets.

6.2. Environmental Impact

From an environmental point of view, the production of biofuels may cause serious detrimental effects on the environment, such as the utilisation of large quantities of water, the utilisation of arable land that could have been used for crop farming, destruction of forests, destroying the ecosystem and biodiversity, and alteration of soil structure and fertility. Furthermore, many biofuel production feedstocks require high quality agricultural land, and use fertilisers, pesticides, and water to produce high biofuel yields [36]. Therefore, researchers have proposed various scientific methods to mitigate such problems. They have developed a useful tool that is used to determine the environmental impact of biofuels, *i.e.*, Life Cycle Analysis (LCA), which evaluates the consumption and impacts of a product throughout its life stages [30].

Several studies in the literature have used this method to evaluate the environmental impact of bioethanol production. For example, Blottnitz and Curran [35] compared bioethanol production with conventional fuels using LCA and the analysis concluded that, (i) it is more feasible to attain high bioethanol yields from feedstocks consisting of rich fermentable sugars located in tropical countries than those feedstocks which are cultivated in temperate regions; and (ii) these feedstocks must undergo hydrolysis followed by a fermentation process. Other studies used indicators to compare several feedstocks in relation to biofuel production yields [37]. One of the indicators is the replacement potential of fossil fuel (expressed in $GJ \cdot ha^{-1} \cdot year^{-1}$), and another indicator that is used is derived from the relation renewable/fossil energy (output/input) for biofuel feedstock. Pimentel and Patzek [36] showed unfavourable results for biodiesel production from sunflower and soybeans. This was due to low production yields and high energy input [38]. Table 4 shows the strengths, weaknesses, opportunities, and threats of biofuels in Sub-Saharan Africa.

Table 4. Strengths, weaknesses, opportunities, and threats of biofuels in Sub-Saharan Africa.

Strengths:	Reduction in imported petroleum oil
	Reducing the dependency on fossil fuels
	Carbon sequestration
	Reducing greenhouse gas emissions
	Energy security

Table 4. *Cont.*

Weaknesses:	High capital costs Low energy yields Requirements for large hectares of land Affects the ecological systems Ineffective governing policies
Opportunities:	Increased job opportunities Increased income for rural people Diverse fuel options Infrastructural development Increased electricity supply
Threats:	Reduction in the availability of land Affects the soil fertility Food insecurity, if edible feedstocks are used Some feedstocks requires high water content

7. Economic Evaluation of Biofuels in Sub-Saharan Africa

The economic factors involved in biofuel production include the capital costs, raw materials, plant capacity, maintenance costs, and process technology [39,40]. It has been shown in several studies of biofuel production that the cost of raw materials is considerably high, *i.e.*, it comprises 75%–80% of the total operating costs [41–44]. In the case of biodiesel production, the oils in vegetable seeds need to first be extracted, refined, then used in the transesterification process. Whereas the lignocellulosic agricultural materials used for bioethanol production must undergo a vigorous pretreatment process to ensure that the fermentable sugars are released. Other factors to consider include labour, storage, and transportation costs. A feedstock cost of US $0.539/L was estimated for biodiesel production when using refined soy oil [45]. Meanwhile, a cost of US $0.97/L was predicted for bioethanol production from sugarcane bagasse [46]. It has also been noted that the costs of biofuels vary from each region due to contributing factors, such as the type of feedstock used and production scale.

Currently, the cost of large-scale production of biofuels is high in industrialized nations. For instance, biofuel costs are considered to be three times higher than that of hydrocarbon fuels. On the contrary, in underdeveloped regions, such as Sub-Saharan Africa, the costs are very low due to low production-scales and non-existence of biofuel markets [47]. Large-scale production of biofuels in Sub-Saharan African countries will necessitate the development of novel technologies to ensure that this market is strengthened by improving the energy yields, and thus make it economically competitive to petroleum oil. This implies that various stakeholders need to be actively involved towards biofuel development initiatives in the continent [48–50].

8. Conclusions and the Way Forward

This paper examined the biofuel initiatives that have been implemented in Sub-Saharan Africa over the past few years. It also examined the opportunities and threats of implementing biofuel initiatives in this region. Biofuels could offer a great deal of relief to most oil-importing countries in Africa through the blending of imported hydrocarbon fuels with biofuels. However, many governments have been slow to introduce biofuel development initiatives in their countries due to several bottlenecks, such as lack of biofuel policies, lack of technical expertise, financial constrains, and food security and land issues. Nevertheless, with the growing global interest in biofuel programmes, Africa need to strategically position itself by assessing international developments in biofuel initiatives and acquire major skills (e.g. technical expertise, frameworks) which could be attained by collaborating with leading biofuel-producing nations through knowledge exchange and financial support. In addition, biofuel initiatives will serve as a catalyst for economic growth, infrastructure development, and social welfare in Africa. In order to ensure that biofuels technologies

are implemented in Africa, it is imperative for various governments within the continent to invest enormously in these technologies by:

- Implementing national biofuel regulatory policies and strategies that will boost their development and accelerate their large-scale production.
- Investing in biofuel infrastructure development, such as production, processing, storage, and transportation.
- Investing in biofuel resources and technical expertise.
- Collaborating with various stakeholders, such as industries, farmers, academics, and NGOs.
- More research and development programmes should be carried out in order to accelerate development.
- More research and development is needed to advance from first generation biofuels (bioethanol and biodiesel) to commercial-scale production of second (biomethane and biohydrogen) and third generation (algae) biofuels in order to strengthen the biofuel market.
- Countries like Brazil are well suited for biofuels because they have outstanding climatologic conditions and have seasonal rainfall that favours the cultivation of biofuel feedstocks. Therefore, it is mandatory for each country to assess their own resources, *i.e.*, land availability, water resources, climate conditions, and costs.
- Even though the biofuel sector has a great deal of potential in Africa, proper and systematic laws are needed to govern this sector to ensure that it does not compromise the livelihood of people and the environment. Thus, biofuel feedstocks should be cultivated on land that is not used for crop farming. Secondly, a proper environmental assessment is necessary to ensure that each country's biodiversity is not affected, *i.e.*, countries are encouraged to use indigenous biofuel feedstocks instead of alien plants in order to prevent potential threats to ecological systems.
- The impact on food security should be thoroughly assessed so that the biofuel sector uses crops that are not required for human consumption. For example, more than 95% of biodiesel produced globally is currently derived from edible oils [51]. The use of edible feedstocks imposes a large challenge on food supply, as mentioned earlier. Focus should be directed towards non-edible resources since they do not compete with human consumption and could be cultivated on barren land fields. In addition, the production of biodiesel from non-edible oils will offer several advantages, such as a reduction in production costs and mitigation of atmospheric carbon dioxide. Therefore, it is essential for governments to implement the plantation of non-edible oleaginous (e.g. jatropha oil seeds) to protect the livelihoods of people.
- Other alternative forms of energy, such as wind, solar, nuclear, and geothermal energy, should also be integrated into the energy mix in order to mitigate the pressing energy crisis facing the African continent. Sub-Saharan countries like South Africa have intensified their renewable energy production by diversifying their options. Over the past few years, the Department of Energy of South Africa has initiated a programme that focuses on the implementation of solar energy. For instance, approximately 400,000 homes are installed with solar water heaters every year [52]. The use of solar water heaters is driven by the socio-economical needs for energy security, environmental sustainability, and reducing the usage of electricity. Moreover, a five-year, long-term plan of installing solar water heaters across the country by 2020 has been proposed by the South African government. South Africa's power parastatal Eskom installed a 25-kW solar panel in 2012 as part of the initiatives from the South African government to assess this technology. Other renewable energy projects include the installation of windmills. In 2014, South Africa launched one of its biggest wind farms in Africa, *i.e.*, the Jeffrey's Bay Wind Farm, located between the farms of Jeffrey Bay and Humansdorp in Eastern Cape, which was built by the British-based company Globleleq. The farm comprises 60 (80-metre high) wind turbines, which spread over 3700 hectares, and can produce up to 138 megawatts of electricity [53].

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