JREE: Vol. 10, No. 4, (Autumn 2023) 119-130

Journal of Renewable Energy and Environment

Journal Homepage: www.jree.ir

Materials and Energy Research Center
MERC

Research Article

Biofuel Commercialization in Developing Countries: Readiness and Prospects

Mosees Emetere [a,b], Wisdom O. Joel [c]

[a] *Department of Physics, Bowen University, Iwo, Nigeria.*
[b] *Department of Mechanical Engineering Science, University of Johannesburg, South Africa.*
[c] *Department of Biochemistry, Covenant University, Ota, Nigeria.*

PAPER INFO

Paper history:
Received: 6 January 2023
Revised: 23 June 2023
Accepted: 17 July 2023

Keywords:
Biofuel,
Energy,
Renewable Energy,
Prospects

ABSTRACT

Several researchers have reported the prospects of biofuel commercialization in several countries across the globe. With over 400 million tons of biomass and 150 million tons of agro-waste produced annually in most developing countries, the prospect of biofuel commercialization looks promising. However, it is crucial to adopt a forward-thinking approach and anticipate potential challenges that may arise, building upon the lessons learned from current obstacles. This paper review addresses the current issues that have discouraged some developing countries against embracing biofuels as an economical tool to mitigate poverty. Also, future challenges that may scuttle biofuel commercialization in developing countries was discussed to provide a workable blueprint towards wealth creation. This review identified policies and political unwillingness as fundamental challenges that must be overcome in developing countries to attract investors. Other identified salient challenges include mono-economy, poor technical know-how, poor technology, government hypocrisy, lack of funds, sustainable biomass resources, inadequate farmland, poor policies, and weak infrastructure. It is recommended that conscious short- and long-term planning be implemented to actualize biofuel commercialization in developing countries.

https://doi.org/10.30501/jree.2023.379263.1533

1. INTRODUCTION

Biofuel is a form of renewable source of energy that refers to liquid fuel (such as biodiesel, bioethanol, etc.) or gaseous fuel (such as biogas) produced from biomass which is mainly plant or animal waste or oil. Currently, the production of biofuel has attracted African countries on a global scale, indicating thoughtful interest in ambiguous and scale-large production. In some developed countries, biofuels are sold on a commercial scale, such that users visit a filing station to purchase whatever quantity of biofuel they desire. Economically, the cost of producing biofuel is relatively low because it does not require complex processes. Few countries (such as the United States of America, Japan, Brazil, and some parts of Europe) around the globe have taken biofuel to a commercial scale. Brazil produces an estimation of 21 billion liters of bioethanol every year, while Japan and China are aiming for a biofuel capacity of 6.3 billion liters (Zhou and Elspeth, 2009). The United States of America has proven that the biofuel project is lucrative and has created 70,000 direct jobs that generated $20 billion and 200,000 indirect and induced jobs that generated $23 billion (€21.1 billion) in 2019 (Biofuel, 2020). Before biofuel became commercial, individuals and local communities in some parts of the world engaged in various feedstocks for energy production (Kemausuor et al., 2013).

Feedstocks are categorized into three main classes: homogeneous (wood chips), quasi-homogeneous (agricultural and forest residues), and non-homogeneous (solid waste), with average economic values of around $110/ton, $62/ton, and $31/ton, respectively (Elegbede and Guerrero, 2016). In light of the raw materials (biomasses) used for biofuel production, it is clear that huge resources are wasted on a yearly basis. If half of the wasted resources are fully utilized, developing countries could potentially generate over 80 billion liters of biofuel. This possibility can be substantiated by considering factors such as population (e.g., human biogas production), arable land (biomasses, e.g., inedible seeds, dead tree trunks, and fallen leaves), and agricultural practices that incorporate agro-waste (Emetere et al., 2018; Emetere and Adesina, 2019).

The most common biofuels are bioethanol, biogas, and biodiesel. Bioethanol is synthesized from carbohydrates like cellulose biomass. Coarse grain and sugarcane are two of the most common ethanol feedstocks, but their prevalence may vary depending on the region. Biodiesel is generated from fats and oils. Vegetable oil is one of the most common feedstocks used in biodiesel production, while non-agricultural feedstocks like waste are becoming more relevant in regions like the United States and Europe. The biogas largely depends on agro-waste, human excreta, and a few biomasses as its feedstock. The above information further corroborates the importance of this review to address Items 1 and 7 in Sustainable Development Goals (SDG) in developing countries.

*Corresponding Author's Email: emetere@yahoo.com (M. Emetere)
URl: https://www.jree.ir/article_176462.html

Please cite this article as: Emetere, M. & Joel, W. O. (2023). Biofuel Commercialization in Developing Countries: Readiness and Prospects, *Journal of Renewable Energy and Environment (JREE)*, 10(4), 119-130. https://doi.org/10.30501/jree.2023.379263.1533.

The main hindrance to unlocking the business potential of biofuel commercialization is the sentiment toward fossil fuels. The use of fossil fuels in developing countries will continue for a long time because their main source of income and the lifestyle of their populace revolve around fossil fuels. For example, fossil-fuel generators have been given substantial credit in terms of powering organizations and houses in most developing countries. In other words, dissociating the mental attachments or sentiments of its population from fossil fuels is a difficult task. A broad spectrum of energy requirements in rural and urban settlements in Africa is presented in Figure 1. Over 80% of the energy usage in both rural and urban settlements comes from fossil-fuel generators or automobiles. This reality further corroborates the huge pollution from fossil fuels in its atmosphere. The commercialization of biofuel in developing countries will lead to a reduction in overdependence on fossil fuels and promote lower carbon emission into the atmosphere. Renewables have a lower carbon footprint and can lead to a reduction of over 90% of the carbon footprint (IRENA, 2019). Szetela et al. (2022) reported that the carbon footprint of more than forty-three countries, which had significantly invested in renewable energy projects, resulted in reduced carbon dioxide emissions during the period 2000–2015.

Some accruable benefits of biofuel commercialization to developing countries include poverty reduction, increase in employment rate, conversion of waste into wealth, a safer environment, diversification of the economy, and social emancipation. Recent biofuel projects in Africa are basically tailored towards automobiles or domestic cooking alone. However, its further applications include providing heat for homes, generation of energy, and removal of paint and adhesives, lubrication, etc.

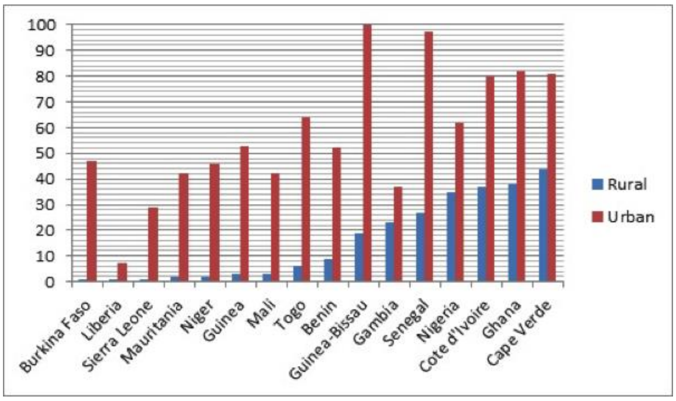

Figure 1. Energy consumption in rural and urban areas in Africa

In the past ten years, there has been a noticeable presence of biofuel companies in some developing countries. For example, in Nigeria, the Green Energy and Biofuels (Geb) Bio-Refinery Project was developed by Small and Medium Entrepreneurship Fundamentals (SMEFunds). Their product was bio-ethanol gel cooking fuel made from waste products such as sawdust and water hyacinth. Within the two-year pilot phase, the company produced 700,000 liters of biofuel (ADBG, 2021). Contec Global Energy is a biofuel company that produces ethanol from edible cassava tubers. In recent years, little has been heard from these companies. According to the Nigerian national newspaper titled ‘Nigeria puts brakes on ambitious biorefinery plan’, the bottlenecks facing the commercialization of biofuels are poor infrastructure, lack of funding for private companies, and government hypocrisy (Aduloju, 2021). Business_list (2022) flagged the fourteen best biomass fuel companies in Nigeria. Not much progress had been observed in their operations, except for the company's proposal to scale up production, which poses significant challenges due to the unique problems that exist in developing countries. Overcoming these challenges would require considerable effort.

Biofuel is an extremely important commodity for developing countries as it contributes to the following: combating climate change through its low-carbon content; addressing higher energy consumption due to an expected world population increase of 8 - 10.5 billion by 2050; securing energy supply by reducing reliance on fossil fuel sources; creating job opportunities for rural and urban women and youths; and making the most of scarce resources such as waste and residue. Canabarro et al. (2023) have extensively elaborated on the immense benefits of biofuels for developing countries, including Argentina, Brazil, Colombia, and Guatemala. As biofuel commercialization progresses, and countries identify bioresources, certain peculiar problems have emerged. These issues, observed in countries that have already commercialized biofuels, may be a source of concern for emerging economies. In this review, the common challenges against biofuel commercialization are discussed. Also, the observed challenges of countries with commercialized biofuel are examined in light of their political framework. This review serves as the blueprint for overcoming energy poverty in most developing countries.

2. GLOBAL VIEW ON BIOFUEL COMMERCIALIZATION AS A GAME CHANGER

Global adoption of biofuel as an economic and energy tool is unprecedented. Most developed countries have already overcome the bottlenecks of funding and consumer patronage. With the active participation of the industry, there are customized machinery, automobiles, or devices that work on biofuels. However, the challenge remains the sustainability of the biofuel project due to the limited feedstock. Agro-waste was used as feedstock in Europe and the United States of America (Guyomard et al., 2011); however, this type of feedstock cannot sustain a large consumer base. Cellulosic biomass, e.g., hemicellulose and lignin, became another potential source of feedstock for bioethanol production (GAIN, 2019). Some developing countries use rotten fruits from the market as feedstock (Tiwari et al., 2014). Also, sawdust was adopted for bioethanol production using fermentative bacteria to achieve accurate fermentation. Scientists have proffered ways of adopting other feedstocks so that food security would not be threatened. Algae became a novel feedstock as the global production rate of algae biomass was around 10,000 tons in 2007 (DOE, 2010). At the moment, China leads the world in algae biodiesel production. The USA and Australia are also recognized for their adoption of algae biodiesel.

At the moment, the United States of America (USA) has optimized bioethanol production using domestically grown maize to about 132.6 billion liters (Biofuel International, 2020). Like the USA, Brazil has a tremendous bioethanol production of over 21 billion liters on a yearly basis. The governments of nations are currently funding the biofuel project (GAIN, 2019). This funding development has made countries like the

Netherlands, the United Kingdom, Indonesia, Japan, Malaysia, the Philippines, Thailand, China, India, Argentina, and France large producers of biofuel (Guyomard et al., 2011). Wang (2019) reported the geographical distribution of world biofuel production in 2019. Most of the countries (e.g., the US, Brazil, China, etc.) that invested in the biofuel project are reaping huge proceeds. For example, in 2019, ABF Economics, on behalf of the Renewable Fuels Association (RFA), reported that the bioethanol industry supported almost 350,000 jobs and generated almost $43 billion (€39.6 billion) in gross domestic product. More so, 280,000 of the employees came from indirect and induced jobs that generated $23 billion (€21.1 billion) in income for American households (biofuels, 2020). Brazil's total 2019 ethanol production is estimated at 34.45 billion liters, an increase of four percent compared to the revised figure for 2018 (Biofuel International, 2020). The global market performance for biofuels is presented in Figure 2.

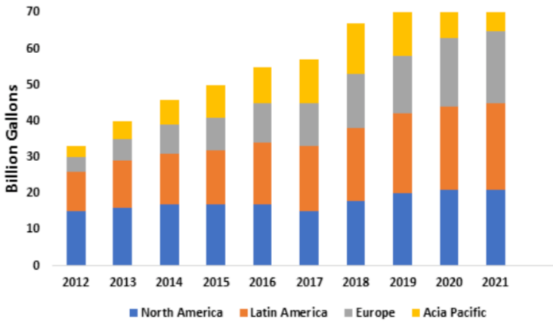

Figure 2. Biofuel production by region (IRENA, 2019)

Figure 2 shows that countries in Latin America, North America, Europe, and Asia have consistently invested into biofuel. What implications does this data hold for oil-dependent economies in developing countries? It means that crude oil prices will eventually crash beyond expected (Defterios, 2020), leading to inflation, poverty, loss of job, and criminality amongst other dangerous outcomes. With the importation of fossil-fuel ethanol of about $33 million in 2018, it is clear that the biofuel market in developing countries is huge, judging by its bioresources.

3. POTENTIALS AND PROSPECTS OF BIOFUEL IN DEVELOPING COUNTRIES

Developing countries have access to unquantifiable feedstock resources. For example, there are large-scale farmers scattered all over the countries due to their agrarian occupation. The database on small-medium farmers in developing countries is large and can be extrapolated to accurately estimate the quantity of agro-waste that can be obtained from larger and smaller farmers (Agricdemy, 2020). Lee (2017) claimed that there were about sixteen million small and medium farmers in some developing countries. In addition, there are a large number of local farmers whose names are not in the existing database. This fact can be substantiated by the diverse trainings and workshops on piggery, poultry, snail, and fishery farming organized for graduates, jobless, and retirees (Oji, 2020). The accumulation of agro-waste from these sources is enormous. The agro-wastes include post-harvest waste such as rice husk, Guinea corn husk, corn stalk, millet stalk, cassava peelings, coconut shell, tomato or pepper stalk, withered vegetables, feathers, cow dung, poultry droppings, pig dung, horse dung, rabbit dung, fish bones, bean peels, palm fruit waste, palm kernel, etc. Aside from the post-harvest wastes, there are abundant biomasses such as inedible seeds for biodiesel production, broken branches of trees for bioethanol production, seedpods for ethanol production, inedible leaves for biodiesel production, dried leaves for bioethanol, sawdust, etc. Energy sources and prospects in developing countries have been analyzed by the IEA (2012), with biomass accounting for over 84.9% of its total renewable resources. The biomass sources include wood fuel and charcoal, which accounted for 85% of total energy consumption. Garba and Umar (2015) reported that Nigeria had the potential to produce 434.6 million metric tons of rice straw and 0.9 million metric tons of rice husk. Ogbonna et al. (2015) reported that Nigeria's potential for large-scale microalgae cultivation was a good sign for biofuel commercialization. More so, the inedible seeds namely Jatropha, Cassia fistula, Abrus precatorius, etc. can serve as sources of oil, starch, and cellulose. Starch and cellulose can serve as feedstock for bioethanol, while oil can be used for biodiesel production (Biofuel, 2020).

There are tropical crops in developing countries that can be adopted for bioethanol production. A typical example of such a crop is sugarcane. Moses et al. (2017) reported that there were over 400,000 hectares of land in rural communities in sub-Saharan Africa that could enhance sugarcane cultivation. Another tropical crop is cassava. Cassava is high in starch and cellulose and can be cultivated easily. There are tropical weeds, such as tiger nuts (Cyperus esculentus), that grow with minimal supervision. It is a tough, erect, fibrous-rooted perennial plant that has found relevance in medicine and the food industry as a flavoring agent for ice cream and biscuits, etc. Oyedele et al. (2015) reported that tiger nut oil possessed a high level of commercial value. In other words, there are several tropical weeds and crops that can sustain the biofuel project in developing countries.

Sustainable agricultural production and utilization of resources are among the added values of the advancements in biofuel industries in most developed countries. In 2016, the value of arable land (hectares) in Nigeria was 34,000,000. At the moment, only 41% of the arable land is being cultivated. It is believed that cultivated lands are still underutilized. This is evident in the Nigerian agriculture sector's contribution to GDP between 2013 and 2016, which was between 22 and 25%. The Nigerian agriculture sector's contribution to GDP shows no significant improvement.

India's biofuel project already has a list of biomasses accruable for agriculture (Figure 3). With this estimate, both the government and investors can fund agricultural activities to empower biofuel distillers and plants. The starch and cellulose crops can serve as feedstock for bioethanol, while the oil-rich crops can be used for biodiesel production. Examples of starch and cellulose crops that can be found in sub-Saharan Africa include millet, sorghum, sugarcane, maize, guinea corn, cassava, cotton, paddy, rice, etc. According to the World Bank (2020 , maize production in Nigeria is about 9180270 metric tons; millet production is 1271100 metric tons; and sorghum production is 6897060 metric tons (World Bank, 2020). In 2018, farmers in four local government areas of Kebbi State (Zuru, Danko-Wasagu, Fakai, and Sakaba) in northern Nigeria were reported to have massive cultivation and production of millet, guinea corn, and maize.

In 2010, Nigeria produced approximately 45 million metric tons of cassava, which is almost 19% of the world's production (IITA, 1990). The average yield per hectare is 10.6 tons. Fortunately, the crop is produced in 24 of the country's 36 states (Kristen and Jerrod, 2015). Analysis proves that the present average national yield of cassava of about 15 tons per hectare is suitable to meet the demand for bioethanol plants.

The oil-rich crops or plants that are cultivated in Asia, Africa, and Latin America include palm trees, soy beans, groundnuts, coconuts, sunflowers, etc. AMREC (2017) reported that 13 out of the 36 states in Nigeria are the main producers of soy beans, i.e., Benue, Kaduna, Plateau, Niger, Nasarawa, Kebbi, Kwara, Oyo, Jigawa, Borno, Bauchi, Sokoto, Taraba, and the FCT. Ajeigbe et al. (2015) reported that China, India, Nigeria, the USA, and Myanmar are the leading groundnut-producing countries in the world. The chaff of the oil crop can also be used for bioethanol production. Aside from the known crops, there are other biomasses that are abundant, i.e., jatropha seeds, shrubs, and even wastes from agricultural activities.

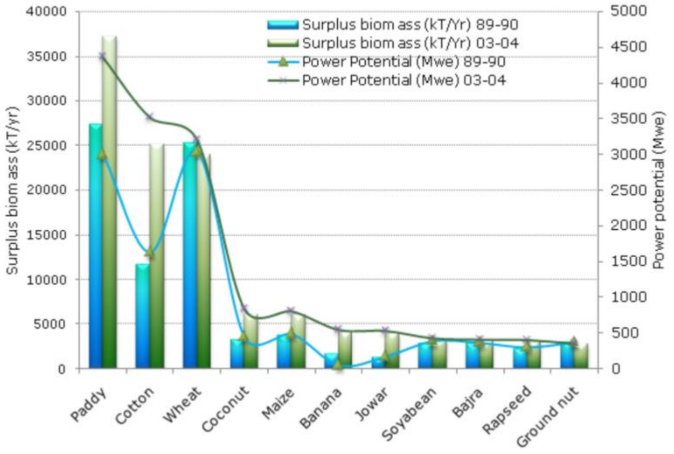

Figure 3. Biomass resources in India (Bikramjit and Indranil, 2008).

4. DRAWBACKS OF BIOFUEL PROSPECTS IN DEVELOPING COUNTRIES

Salient challenges may mitigate or stifle biofuel commercialization in developing countries. These challenges include poor technology, sustainable biomass resources, inadequate farmland, policies, and infrastructure. In addition, the main drawback of the economies of developing countries is their extensive mono-economies. In oil-dependent countries, the economy is heavily dependent on fossil fuels as the apex and most controversial source of energy. Some oil-dependent countries, such as Nigeria, rely on imports of finished fossil fuel products, thereby leading to paranoia about the escalation of the price of gasoline. Furthermore, the dependence on fossil fuel for energy demand, i.e., either for automobiles, generators, or industrial machines, has created new challenges such as the depletion of the total volume of the oil reserve and an increase in air pollution and emissions of pollutants (Emetere and Akinyemi, 2017). The diversion from fossil fuel to biofuel is expected to boost the economy by creating different classes of market among the small, medium, and major players in the economy. For example, if biofuel production in developing countries moves to the commercial stage, it will first create jobs for rural women and farmers, as they will be involved in going to the forest and farms to trade agro-waste and biomass. Medium players are the companies that will produce biofuel in commercial quantities. Major players are the consumers, i.e., the populace. In other words, the adoption of biofuel in developing countries would activate the economy and reduce poverty by 18%. However, this project cannot simply be achieved by the eradication of fossil fuels, but by the drive on the fossil-biodiesel ratios for the start. The conversion of natural gas into biogas products, as projected by big oil companies, may provide resources for biofuel commercialization. The inevitable eradication of fossil fuels, as seen in the investments of notable countries, is a clear reason why mental detachment from fossil fuels should be the next program for government officials and policymakers in various parts of the globe. Based on these proven biomass resources, the drawbacks of biofuel commercialization in developing countries are discussed in the next section.

Another notable drawback is the lack of public awareness of the aforementioned resources. This is deliberate, as government organs at all levels have not come to terms with the reality of fossil-fuel eradication or mitigation in the coming years. The records of health conditions due to land and air pollution are too numerous to jettison. Additionally, there has been an increase in oil spillage, resulting in the elimination of aquatic and terrestrial organisms and animals. Low access to potable water and an agrarian setting for rural dwellers are fast becoming a mirage. Moreover, some agro-waste is disposed of at the nearest dumpsite. Bioaerosols, which can contain fungi, bacteria, or viruses, are a cause for concern as their generation and proliferation are more prominent when there is a high volume of fossil-fuel pollution in the atmosphere. Therefore, apart from their potential to stimulate the economy, reducing air pollution from fossil fuels would significantly contribute to lowering the incidence of respiratory and cardiac illnesses or diseases in both infants and adults.

Another futuristic drawback to commercial biofuel production in most developing countries is the farmer's disposition to sell edible seeds to biofuel companies rather than the populace. This inevitable situation would lead to the use of edible seeds such as soya seed, palm fruit, moringa seed, maize, and olive seed for biodiesel production. This challenge will certainly have a significant impact on food prices and food security. For developing countries, food security is low, as seen in the high importation of rice from China, India, etc. Rice importation alone is about 6.3 million tons of milled rice, with an annual consumption per capita of 29 kg (FMARD, 2016). In other words, most developing countries are not ready for the commercialization of biofuel, judging by their population and low supply chain for biomass when consumption reaches its peak. So, the immediate solution is to have a proper takeoff platform, i.e., enhance the yield of feedstock and provide aiding infrastructure such as roads, electricity, and water to improve feedstock production.

One of the main challenges confronting most developing countries is policymaking. Most researchers have argued that policy implementation is the main challenge in developing countries. The best policy is judged by its performance. Biofuel commercialization becomes lucrative when policies are made to encourage the use and production of biofuels. This gesture has improved biofuel production globally (Guyomard et al., 2011) to 95.4 million metric tons of oil equivalent, thereby increasing its profit to over 59% yearly (Figure 4). Figure 5 presents the global renewable biofuel production over the years. Coincidentally, this chart also infers the slow pace of policy-making in developing countries and how it has impacted biofuel production. It is clear that this slow response is largely due to the vested interests of politicians in other spheres of business across countries.

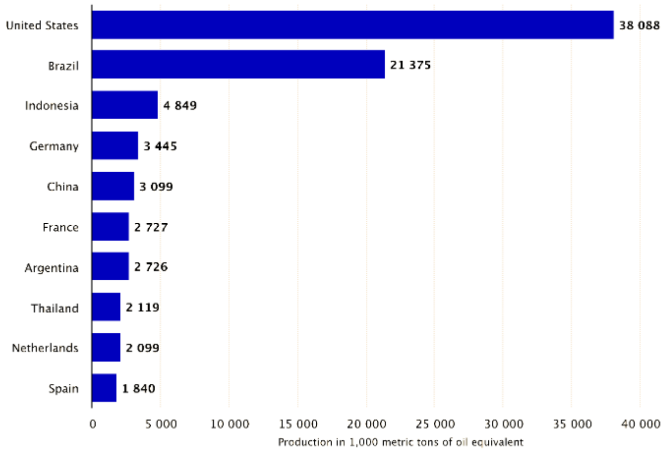

Figure 4. Global renewable biofuel production over the years (Biofuel, 2019)

There is no doubt that US policies to promote alternative and renewable energies should be among the best in the world. The focus of US policy on renewable energies is to improve the environment and the economy. For example, the Clean Air Act of 1970 created initiatives to reduce pollutants from mobile sources. Then, the Energy Policy Act of 1992 was enacted to reduce the nation's dependence on imported oil and improve air quality.

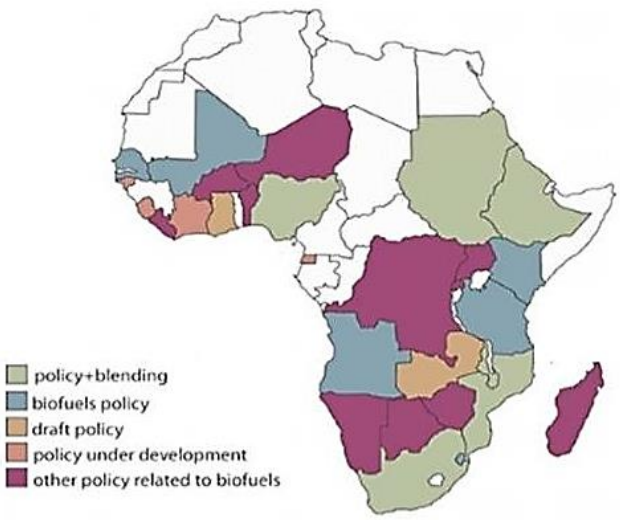

Figure 5. Overview of nation policy on biofuel in Africa (Kiggundu et al. 2017)

In the case of Nigeria, this would be the greatest hurdle the nation would endeavor to overcome because of its dependency on fossil fuel importation. Reliance on mono-economy may be tempting, as global influences can crash the economy. For example, oil prices are determined by a lot of factors, which include price wars (launched by key players), war, international politics, and pandemic outbreaks (Schnepf and Yacobucci, 2013). The willpower to diversify the economy does not lie in the hands of the government alone. The role of the investor is crucial to activating the biofuel project in various developing countries. For example, after the US Energy Policy Act of 1992, there was a need to bring in investors; this idea gave birth to the Energy Policy Act of 2005, which called for tax incentives for alternative fuels as well as other policy initiatives. When this supportive policy was properly executed, there was a need to diversify the biofuel project into renewable fuels (including corn-based ethanol), advanced biofuels, biomass-based diesel, and cellulosic biofuels. This feat was achieved via the Energy Independence and Security Act (EISA) of 2007. This initiative led to growth in the US ethanol industry. In 2012, the ethanol industry contributed approximately $43.4 billion to the gross domestic product (RFA, 2012; Urbanchuk, 2013). Also, the ethanol industry's influence on household income has grown from US$29.9 billion in 2012 to US$43 billion in 2019 (Hoekman, 2009). More so, this progress extends to both the agricultural and rural sectors (RFA, 2012).

On the other hand, in the context of policy-making in a developing country, the Nigerian Bio-fuel Policy of 2007 was implemented to facilitate the establishment of biofuel distilleries and plants, with the government providing over US$ 50 million as equity investment (OGNPBI, 2007). The objective of the policy is to have a significant impact on petroleum product quality. Unfortunately, the policy did not make room for the commercialization of the biofuel. The projection made for 2020 was 480 million liters. In comparison to the US, which produces 4.328 billion gallons per year, Brazil's 30.755 billion liters of ethanol in 2018, Argentina's 700 million liters per year, and China's 19,005 million liters per year (NS Energy, 2019), it is sad to note that the projection did not come to fruition. The policy had no form of tax rebate for investors. Rather, it made projections on tax revenue accruable to the project. Lastly, the policy did not foresee scarce biomass resources and how to make them sustainable. It is no surprise that this policy never saw the light of day. Hence, the way forward is to expunge all existing (i.e., faulty) policies and re-enact workable ones that would be of interest to investors.

Another notable challenge facing most developing countries is inadequate infrastructure, such as roads and electricity. Since biofuel commercialization would naturally affect both agricultural and rural sectors in the short and long term, the primary transport segment (between the farm and an all-season access road) is important, as it ensures crop movement from the farmer to the biofuel distilleries and plants. Also, good roads avoid post-harvest losses and crop deterioration (Oyatoye, 1994). Many agricultural scientists in Nigeria have reported poor infrastructure for two decades (Oyatoye, 1994; Akinola, 2003). The issues with electricity in some developing countries are worrisome, as investors would have to spend more on powering machines. Figure 6 gives a typical outlook on electricity generation in Africa and why it is considered a major challenge. For example, in 2015, the energy needs of Nigeria were 10.713 GWh/year; however, current power generation in the country is less than 3000 MW (World Bank, 2020). Based on all that has been discussed above, there is a need to examine the technical know-how of researchers in developing countries to prepare for the challenges. This leads us to the next section on past research work done on biofuels.

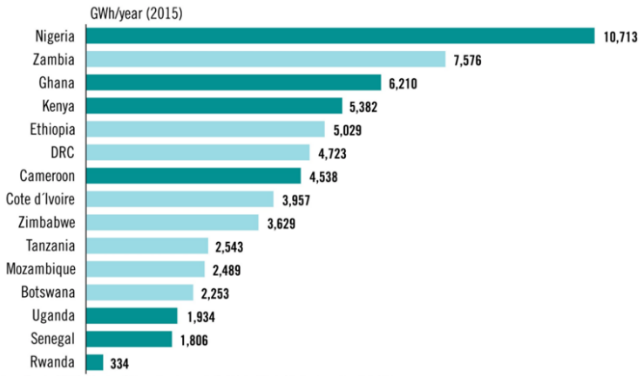

Figure 6. Energy demand of African countries in 2015 (Nordsid, 2019)

5. Technical Analysis Biofuel Production Feasibility in Developing countries

On the basis of their feedstock, biofuel production has been classified into three families: first, second, and third generations. Agricultural crops are used in the first-generation biofuels, where biogas, biodiesel, and bioethanol are the most common examples, whereas the second generation employed the digestion of sugars such as sugar beets, maize, and wheat, as well as starch, to yield biogas, otherwise known as biomethane. Bioethanol can also be made from sugar fermentation, such as that of corn, potatoes, or sugarcane used in the United States and Brazil, respectively (Lackner, 2017). Third-generation biofuels are obtained from photosynthetic microbes such as microalgae and cyanobacteria in order to manufacture higher alcohols and lipid-based products (Hammer et al., 2020). Due to the biochemical composition of these microbes, which includes carbohydrates, fats, and proteins, they have gained prominence over lignocellulosic biomass. Higher carbohydrate contents allow for the production of higher alcohols and bioethanols, whereas the lipid fraction facilitates the production of biodiesel, isoprenoids, and other lipid-based compounds. Two very illustrative examples are Spirulina maxima, with 60–71% w/w of proteins, and Schizochytrium spp., with 50–77%w/w of lipids (Razaghifard, 2013). Green diesel is a biodiesel that has been used as an alternative energy source for diesel fuel. Green diesel is a biofuel. It is produced from food sources that contain triglycerides and fatty acids, such as vegetable oil and crude palm oil. Green diesel has also been observed to be derived from algae, a third-generation feedstock that is considered livestock for next-generation biofuel production. They could be micro- or macroalgae, as both do not require pre-treatment since they are free lignin (Kumar et al., 2018). Microalgae store energy in their cells in the form of lipid droplets (Pragya & Pandey, 2015). They include green algae and cyanobacteria, which are both made of polyglucans, such as starch and glycogen, and sugar alcohols, like glucuronic acid and mannitol. Microalgae ensure the release of fermentable sugars through hydrolysis because of their cellulose and hemicellulose cell walls (Kumar et al., 2018). Algae generally yield more at a higher growth rate than energy crops. Microalgae have the ability to grow in both artificial and natural surroundings, their CO2 uptake rate is high, and they are environmentally friendly (Jutakridsada et al., 2019). However, due to cultivation, harvesting, and downstream processing limitations, commercial usage of third-generation feedstock is minimal (Tarafder et al., 2021). The fourth-generation biofuels come from bioengineered microorganisms such as algae, yeast, fungi, cyanobacteria, and crops to improve the efficiency of the process and the yield of the products.

Biofuel production involves a lot of processes, which include chemical, thermochemical, and biochemical conversions (Table 1). The biochemical conversion involves anaerobic digestion, alcoholic fermentation, and photobiological hydrogen gas production (Subramani et al., 2015). Biochemical processes employ enzymes (Table 2) to process raw materials into fuels. Lipase and phospholipase are the most important enzymes in biodiesel production (Hood & Bauer, 2016). Lipase transforms free fatty acids (FFA) and triacylglycerols into fatty acid methyl esters (FAME), which are the major components of biodiesel. Phospholipase converts phospholipids into diacylglycerols, which serve as substrates for lipase. Cellulase digests cellulose into reducing sugars, which are then fermented into ethanol by yeast or bacteria (Ashraf et al., 2021). Anaerobic digestion is employed for treating wet organic waste. It is a fermentation process that involves the conversion of biodegradable materials by bacteria in the absence of oxygen into biogas such as methane, carbon (IV) oxide, and other gases such as methane, CO2, and hydrogen sulfide. Fermentation takes place in two phases in an airtight digester vessel by bacteria (acid-forming bacteria and methane-forming bacteria) (Hashemi et al., 2019; Rajput & Visvanathan, 2018). The first is the liquefaction phase, where complex organic substances are hydrolyzed to simple organics such as fatty acids, alcohols, and sugars by the acid-forming bacteria. The second phase is the gasification phase, where the simple organics are converted into biogas by methane-forming bacteria. Biogas and digestate are the products of anaerobic digestion and can be processed to make secondary goods (Zang et al., 2016). Biogas can then be used to generate electricity, heat, and fuel for transportation. Digestate can indeed be transformed into fiber with reduced nutrient content, making it suitable for use as a soil conditioner. Additionally, the liquor produced during the process, which contains higher nutrients, can be utilized as a liquid fertilizer (Mohamed et al., 2022). Anaerobic digestion reduces toxic gas emission and odor below unprocessed waste odor levels.

Biomass materials comprising sugar, starch, or cellulose can be converted into alcohols through microorganisms such as yeast and bacteria. The table below shows examples of some biofuels and their production pathways, including the substrates and microorganisms that catalyze their production (Kim & Gadd, 2019).

In the third generation of biofuel production, the pathways are genetically modified to optimize the yield of biofuels. Such modifications include endogenous overexpression, heterologous overexpression, expression cassettes, and inactivated gene expression. For example, by genetically modifying Clostridium for an overexpression of the TER (trans-enoyl-coenzyme A reductase gene), butanol production increased (Wen et al., 2020). Overexpressed SFA1 (alcohol dehydrogenase) in genetically modified S. cerevisiae with lignocellulosic hydrolysate substrate gives a higher yield of ethanol (Zhu et al., 2020; Rajeswari et al. 2022). The acetone, butanol, and ethanol yields are far better when Clostridium with overexpressed sol-operon and EC cassette is applied (Wang et al., 2019). An activated Entner-Doudoroff pathway, enhanced by an engineered E. coli strain and a glucose-inducible system, along with the deletion of side pathways, leads to a higher yield of 2,3-butanediol. This innovative approach offers the potential for increased efficiency in 2,3-butanediol production (Sathesh-Prabu et al., 2020). Likewise, iso-butanol production increases in P. putida when soluble transhydrogenase is inactivated with the overexpression of ILVC and ILVD and the introduction of feedback-resistant acetolactate synthase, aldehyde dehydrogenase, and ketoacid decarboxylase (Nitschel et al., 2020).

There are indeed numerous challenges associated with the biochemical processes involved in biofuel production. These obstacles have impeded the rapid and widespread production of sustainable biofuels. However, if these issues can be effectively addressed and resolved, the production of biofuels has the potential to become more consistent and widespread, leading to a more sustainable and reliable source of energy.

The table below (Table 3) highlights some challenges involved in the production of specific biofuels derived from alcohol, hydrocarbons, and fatty acids..

Based on the above report, it is reasonable to suggest that the industrial production of all types of biofuel is feasible in developing countries, considering the cost, availability of required feedstock, and technical expertise. Table 4 illustrates the CO2 emissions in renewable and non-renewable sources, highlighting the significant impact of renewable energy on the carbon footprint over a geographical area.

Table 1. Pathways involved in the biochemical production of biofuels

Pathway	Substrate	Microorganism	Biofuels
Butyrate/ Acetone-Butanol Ethanol (ABE) pathway	Sugar	Clostridium sp.	n-butanol acetone, ethanol, hydrogen gas
Ethanol/Entner-doudoroff pathway	Sugar	Saccharomyces cerevisiae, zymomonas mobilis	Ethanol
1,2-propanediol pathway	Deoxy sugars, glucose, 1,2-propanediol	Salmonella typhimurium	1,2-propanediol, propanol, propionate
Butanediol	Sugar	Klebsiella, Enterobacter	2,3 butanediol, hydrogen gas
Mixed acid fermentation	Glucose	Escherichia, Shigella	Ethanol, hydrogen gas

Table 2. Biochemical processes involved in some biofuel production

Feedstock	Decomposition	Intermediate	Products
Sugarcane	Hydrolysis	Sugars	Ethanol
Lignocellulosic	Biochemical/Gasification/pyrolysis/liquefaction	Sugars/Syngas/lipids/oil	Ethanol/Hydrogen/Methanol/hydrocarbon biofuels
Algae and oil-seeds	Lipid extraction	Lipids/oil	Biodiesel / Hydrocarbon biofuels

Table 3. Challenges involved in the production of specific biofuels

(a) Alcohols-based biofuels		
BIOFUEL	**MICROBE**	**CHALLENGES**
Butanol	Clostridium acetobutylicum Clostridium tyrobutyricum	The toxicity of butanol decreased growth rate and cell density.
Isobutanol	S. cerevisae P. pastoris	
2, 3 Butanediol	Z. mobilis Synechococcus elongatus	Cell growth inhibition with increased titres of butanol (Fu et al., 2021).
1,3-PD 2,3-BD	Klebsiella pneumoniae	Competition between Iso-butanol and other pathways to produce other metabolites might be a limiting factor for increased level of iso-butanol (Wess et al., 2019;Yang et al., 2016).
Isopentanol	S. cerevisiae	Overproduction of KIV mitigates the production of other alcohols (Siripong et al., 2018).
2,3-BDO	Pichia Pastoris	(Oliver et al., 2013; Park et al., 2017; Yang Zhang, 2018)

(b) Hydrocarbon-based biofuels		
BIOFUEL	**MICROBES**	**CHALLENGES**
Isobutyraldehyde	E. coli	Combined deletion of genes caused decreased iso-butanol production (Rodriguez & Atsumi, 2012).
Alkane	E. coli	Endogenic formation fatty alcohols thought to be competitive with alkane production
Heptadecane (10.2 mg/l) Pentadecane (2.7 mg/l)	A. carbonarius	An unknown, innate fatty aldehyde dehydrogenase networks diverted the fatty aldehydes back to the fatty acid metabolism (Sinha et al., 2017).
Alkenes	Cupriavidusnecator	The expression of aferredoxin ferredoxin-NADP + reductase system sharply lowered the C-flow towards fatty aldehydes (Crepin et al., 2018).
(c) Fatty-acid-derived biofuels		
BIOFUEL	**MICROBES**	**CHALLENGES**
FAEEs	Yarrowia lipolytica	Need to enhance production of FAEEs to reach commercially acceptable level (Yu et al., 2020).
Oleic acid	Rhodosporidium toruloides	Fatty acids produced showed promising potential to be blended with vegetable oils (Tsai et al., 2019).
FFAs	S. cerevisiae	Creating higher titers of FAs requires substantial amounts of acetyl-CoA, ATP, and NADPH, making it difficult to engineer (Ferreira et al., 2018).
Odd-chain FA	Y. lipolytica	Difficulty in assessing toxicity and understanding the role of propionic catabolism in odd FA production (Tai & Stephanopoulos, 2013).

Table 4. CO_2 emission from renewable and non-renewable sources

RENEWABLE ENERGY FUELS

S/N	Fuel	CO_2 Emission (C/Ti)	Reference
1	Gasohol E10	2.159	Nicha et al., 2014
2	Gasohol E20	2.159	Nicha et al., 2014
3	Gasohol E85	0.482	Nicha et al., 2014
4	Natural gas	15.3, 56.74	Khan et al. 2019; Geraldine et al., 2014
5	Biodiesel (B5)	2.284	Nicha et al., 2014
6	Liquefied petroleum gas (LPG or LP gas)	2.041, 17.2, 65	Nicha et al., 2014; Khan et al. 2019;
7	Biogas	0	Geraldine et al., 2014
8	Compressed natural gas (CNG)	1.737	Geraldine et al., 2014

NON- RENEWABLE ENERGY FUELS

1	Diesel Fuels (HSD)	2.395, 20.2	Nicha et al., 2014; Khan et al. 2019
2	Gasoline	18.9	Khan et al. 2019
3	Kerosene	19.6	Khan et al. 2019
4	Residual Fuel Oil	21.1	Khan et al. 2019
5	Naphtha	20.0	Khan et al. 2019
6	Refinery Gas	18.2, 56.9	Khan et al. 2019; Geraldine et al., 2014
7	Coking Coal	25.8, 80	Khan et al. 2019; Geraldine et al., 2014
8	Fuel Oil	78	Geraldine et al., 2014
9	Waste Oil	78	Geraldine et al., 2014
10	Gas Oil	74	Geraldine et al., 2014

6. POLITICAL WILLINGNESS TO COMMERCIALIZING BIOFUEL IN DEVELOPING COUNTRIES

Outcomes leading to political economy are simply the political decisions that have been reached through consultation with stakeholders (Anderson et al., 2013). In reality, policies are created and enhanced by politicians, not economists. For example, Statista (2021) reported that Nigeria imported petrol worth about 688 trillion naira between January and March 2021. This information could also be a game changer if the government provides 20% of the cost of gasoline or ethanol importation into the country as incentives to investors. In most developing countries, investors are discouraged by politicians who, at one end, consider the interests of stakeholders. In oil-rich developing countries, many stakeholders have become accustomed to the substantial income generated from fossil-fuel-associated businesses. Most stakeholders are politicians who would constantly disrupt biofuel commercialization through unstable or unreliable decision-making or policy formulation. Some of the stakeholders may be lobbyists that lobby governments into policy positions. Some of the stakeholders are ideologists who believe that biofuel would cause greater problems. Some of the stakeholders are the farmers who are expected to produce the biomass used for biofuels. In the US, the use of edible crops for biofuels has been criticized because an equivalent of 330 million people could have been fed with the grain grown by American farmers in 2009. In developing countries, some of the stakeholders constitute small and medium businesses that rely on fossil fuels. Hence, the weakness of the political class to negotiate with the various stakeholders in developing countries is one of the main challenges facing biofuel commercialization.

Zilberman et al. (2014) proposed that in such a case of conflicting interests, the political outcome of introducing incentives for biofuel operators to pay the price of externalities would be a soft-landing pad, especially in an environment with associated bottlenecks such as mono-economy, unreliable technical know-how, poor technology, government hypocrisy, lack of funds, sustainable biomass resources, inadequate farmland, policies, and infrastructure. Canada and Brazil prioritize some exporters operating in the Middle East. The US government provided subsidies worth at least US$43 billion to the renewable energy and biofuel industries in 2009 (Robbins, 2011). After the incentives given in 2009, the US still subsidies biofuels to the tune of US$7 billion a year, while China provides around US$2 billion in direct subsidies a year. These political decisions in the US were initiated by mid-western states, which led to the campaign on certain biofuel policies that have been adopted by US government agencies (Notaras, 2018). The dividend of the emerging policies was the production of 10 billion gallons of biofuels in 2010 and 15 billion gallons in 2015, with a projection of 36 billion gallons in 2022.

One of the misleading agitations by some ideologists against biofuel commercialization is land use, populace addictions to fossil fuels, and food prices. Some policymakers in developing countries are already leveraging on this idea to continue the fossil-fuel addictions that have brought about high importations of essential goods and services (Robbins, 2011). A significant growing human population is expected to impact land use and, by extension, food prices. For example, in most developing countries (as seen in Mozambique), corporations have preference over the government in land allocation. This action has led to food insecurity and resource deprivation. Another sect of ideologists sees the call for biofuel commercialization as a 'biofuel complex' ideology that has far-reaching political implications. They believe that the political economy of the 'biofuel complex' is indeed parochial as it may lead to 'land grabs' across the world (Monsalve et al., 2008; Cotula, 2009), political-economic-ecological instabilities, destabilization of existing agrarian structures, etc. Contrary to all these, another school of thought believes that biofuel commercialization is a new profitability frontier for the agribusiness and energy sectors (McMichael 2009). Policy debates by countries that have commercialized biofuels clearly show that conscious economic planning is vital in balancing political decisions across different stakeholders (Franco et al., 2010; Hollander, 2010; Gillon, 2010). In other words, the challenges of biofuel commercialization in developing countries can be overcome through conscious political decisions.

5. CONCLUSIONS

In a nutshell, this review established that despite the awareness of biofuel for the past two decades, developing countries are far from commercializing biofuel, judging from the points raised in the review. Aside from the immediate danger of environmental pollution from fossil fuels that has been reported in most developing countries, biofuel commercialization is a new profitability frontier for agribusiness and energy sectors with huge short-term gains. This development means that developing countries stimulate their economies to avoid inflation, poverty, loss of jobs, and criminality, among other dangerous outcomes, whenever crude oil prices crash.

The biomass resources in developing countries were wholly examined, with high prospects for the use of agro waste such as rice husk, guinea corn husk, corn stalk, millet stalk, cassava peelings, coconut shell, tomato or pepper stalk, withered vegetables, feathers, cow dung, poultry droppings, pig dung, horse dung, rabbit dung, fish bones, beans peels, palm fruit waste, palm kernel, etc. The main question in this abundant biomass resource is sustainability. It is noted that the future drawback of commercial biofuel production in developing countries is inadequate planning and policy formulation to prevent land grab, food insecurity, social imbalances, and political instabilities.

The drawbacks of the biofuel project in developing countries were discussed. Salient challenges that may mitigate or straggle biofuel commercialization in developing countries include mono-economy, poor technology, sustainable biomass resources, inadequate farmland, policies, technical know-how, and infrastructure. The technical know-how was discussed in depth. It was clearly seen from the technical trends that researchers in developing countries have a lot to do in expanding the scope of affordable biofuel processing techniques.

In order to improve biofuel production yield, technological advancement and technical know-how are well needed to boost biofuel commercialization. Recommendations to enhance biofuel commercialization include fostering synergy between industry, academia, and government. Conscious political decisions, such as providing incentives and negotiating with stakeholders, are essential to create an enabling environment for investors. Governments should formulate standardized policies that promote active participation from financial institutions. Public-awareness programs should be launched to educate the populace about the benefits of biofuels. Additionally, providing reliable infrastructure, such as good roads, proper water, and power supply, will boost feedstock production. Finally, the formulation of workable policies to attract investors is crucial for the successful development of the biofuel industry.

6. ACKNOWLEDGEMENT

The authors appreciate the host institutions.

REFERENCES

1. ADBG, (2021). Nigeria - Green Energy & Biofuels (Geb) Bio-Refinery Project - SEFA Project Summary Note. https://www.afdb.org/en/documents/nigeria-green-energy- biofuels-geb-bio-refinery-project-sefa-project-summary-note

2. Aduloju Bunmi, (2021). Nigeria puts brakes on ambitious biorefinery plan. https://africaoilgasreport.com/2021/04/energy-transition/nigeria-puts-the-brakes-on-ambitious-biofuels-refinery-plan/

3. Agricdemy, (2020), Nigeria agriculture data. https://agricdemy.com/post/nigeria-data (Accessed 02/04/2020)

4. Ajeigbe, Hakeem A., Farid, W., Ayuba, K., Babu, N. M., Candidus, A. E., Damilola E., & Abubakar, I., (2015). A Farmer's Guide to Profitable Groundnut Production in Nigeria. http://oar.icrisat.org/8856/1/2015-084%20Gnut%20Production%20in%20Nigeria.pdf (Accessed 4/4/2020)

5. Akinola, S. R. (2003). Coping with Infrastructural Deprivation through Collective Action among Rural People in Nigeria. *Nordic Journal of African Studies, 16(1),* 30–46. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=6d98b88afc2c4d7b82c96738e5fdd6cd4558cc6c

6. AMREC (2007). Mapping of soybean production areas in Nigeria. http://www.propcommaikarfi.org/wp-content/uploads/2013/08/28-Mapping-of-soybean-production-areas-in-Nigeria-3-07-1.pdf (Accessed 4/4/2020)

7. Anderson, K., Rausser, G., & Swin- nen, J. (2013). Political economy of public policies: insights from distortions to agricultural and food markets. Journal of Economic Literature 51(2), 423-477. http://dx.doi.org/10.1257/jel.51.2.423

8. Ashraf, A., El-Desouky, M.G., & El-Afify, M.A., (2021).Thermal and Spectroscopic Studies of Some Prepared Metal Complexes and Investigation of their Potential Anticancer and Antiviral Drug Activity against SARS-CoV2 by Molecular Docking Simulation. *Biointerface Resarch in Applied Chemistry, 12,* 1053-1075, https://doi.org/10.33263/BRIAC121.10531075.

9. Biofuel (2019), Biofuels and Bioenergy. https://chemicalengineeringnob.com/biofuels-and-bioenergy-conference-2019-in-netherlands/ (Accessed 3/4/2020)

10. Biofuel International (2020), US ethanol industry generated $43 billion in 2019, despite policy challenges https://biofuels-news.com/news/us-ethanol-industry-generated-43-billion-in-2019-despite-policy-challenges/ (Accessed 3/4/2020)

11. Business_list (2022). Best Biomass Fuel Companies in Nigeria. https://www.businesslist.com.ng/category/biomass-fuel

12. Canabarro, N.I., Silva-Ortiz, P., Nogueira, L.A.H., Cantarella, H., Maciel-Filho, R., & Souza, G.M., (2023).Sustainability assessment of ethanol and biodiesel production in Argentina, Brazil, Colombia, and Guatemala, *Renewable and Sustainable Energy Reviews*, *171*, 113019, https://doi.org/10.1016/j.rser.2022.113019.

13. Cotula, L. (2009). Land grab or development opportunity?: Agricultural investment and international land deals in Africa. London: International Institute for Environment and Development (IIED) https://www.iied.org/12561iied

14. Crepin, L., Barthe, M., Leray, F., Guillouet, S.E., 2018. Alka(e)ne synthesis in Cupriavidus necator boosted by the expression of endogenous and heterologous ferredoxin–ferredoxin reductase systems. *Biotechnology and Bioengineering 115 (10),* 2576–2584. https://doi.org/10.1002/bit.26805.

15. Defterios John, (2020), Why oil prices are crashing and what it means, https://edition.cnn.com/2020/03/09/business/oil-price-crash-explainer/index.html (Accessed 04/04/2020)

16. DOE, U. S. National Algal Biofuels Technology Roadmap. Maryland, (2010). https://www.energy.gov/eere/bioenergy/articles/national-algal-biofuels-technology-roadmap

17. Elegbede, I., & Guerrero, C., (2016), Algae Biofuel in the Nigerian Energy Context, *Environmental and Climate Technologies, 2016/17,* 44-60 http://dx.doi.org/10.1515/rtuect-2016-0005

18. Emetere Moses Eterigho & Akinyemi M.L. (2017) Atmospheric Dynamics of Air Pollution Dispersion and Sustainable Environment in Nigeria, *Journal of Urban and Environmental Engineering, 11 (1)*, 51-57 https://core.ac.uk/download/pdf/143483494.pdf

19. Emetere Moses Eterigho, Solomon Jack-Quincy, Akolade Adejumo, Oluwatobi Dauda, Israel Osunlola, Damola Adelekan & Oladipupo Adeyemi (2018). Empirical Analysis of biodiesel effect on the automobile properties of diesel engine: A case study of Olive and Soya biomass, *Energy Science & Engineering, 6(6),* 693-705. http://dx.doi.org/10.1002/ese3.244

20. Emetere Moses Eterigho, & Adesina, T. A., (2019), Short review on the prospects of human biogas utilization in Nigeria, *IOP Conference Series: Earth and Environmental Science 331 (1),* 012051 http://dx.doi.org/10.1088/1755-1315/331/1/012051

21. Ferreira, R., Teixeira, P.G., Siewers, V., & Nielsen, J., 2018. Redirection of lipid flux toward phospholipids in yeast increases fatty acid turnover and secretion. *Proc Natl Acad Sci USA 115 (6),* 1262–1267. https://doi.org/10.1073/pnas.1715282115.

22. FMARD-Federal Ministry of Agriculture and Rural Development. (2016), The Agriculture Promotion Policy (2016-2020). Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria. pp.1-59. https://www.fao.org/faolex/results/details/en/c/LEX-FAOC165890/#:~:text=The%20present%20Agriculture%20Promotion%20Policy%20is%20founded%20on%20the%20following,7)%20Factoring%20climate%20change%20and

23. Franco, J., Levidow, L., Fig, D., Goldfarb, L., Hönicke, M. & Mendonca, M. L. (2010). Assumptions in the European Union biofuels policy: frictions with experiences in Germany, Brazil and Mozambique. *The Journal of Peasant Studies, 37(4),* 661–98. http://dx.doi.org/10.1080/03066150.2010.512454

24. Fu, H., Hu, J., Guo, X., Feng, J., Yang, S.-T., & Wang, J., 2021. Butanol production from Saccharina japonica hydrolysate by engineered Clostridium tyrobutyricum: The effects of pretreatment method and heat shock protein overexpression. *Bioresource Technology 335*, 125290. http://dx.doi.org/10.1016/j.biortech.2021.125290

25. GAIN (2019), Brazil: Biofuels Annual, https://www.fas.usda.gov/data/brazil-biofuels-annual-5 (Accessed 3/4/2020)

26. Garba, N.A., & Umar Z. U., (2015) Rice straw and husk as potential sources for mini-grid rural electricity in Nigeria, *International Journal of Applied Sciences and Engineering Research, 4(4),* 523–530. https://www.semanticscholar.org/paper/Rice-straw-%26-husk-as-potential-sources-for-rural-in-Garba-Zangina/415bf204b298172eee2684078098e8f9b11cabcc

27. Geraldine Henningsen, Arne Henningsen, Sascha T. Schröder & Simon Bolwig, (2014). "The Development of Environmental Productivity: the Case of Danish Energy Plants," IFRO Working Paper 2014/04, University of Copenhagen, Department of Food and Resource Economics. http://okonomi.foi.dk/workingpapers/WPpdf/WP2014/IFRO_WP_2014_04.pdf

28. Gillon, S. (2010). Fields of dreams: negotiating an ethanol agenda in the Midwest United States. *The Journal of Peasant Studies, 37(4),* 723–48. http://dx.doi.org/10.1080/03066150.2010.512456

29. Guyomard Hervé, Forslund Agneta, & Dronne Yves (2011), Biofuels and World Agricultural Markets: Outlook for 2020 and 2050, https://www.intechopen.com/books/economic-effects-of-biofuel-production/biofuels-and-world-agricultural-markets-outlook-for-2020-and-2050 (Accessed 3/4/2020)

30. Hammer, S.K., Zhang, Y., & Avalos, J.L., (2020). Mitochondrial compartmentalization confers specificity to the 2-ketoacid recursive pathway: increasing isopentanol production in Saccharomyces cerevisiae. *ACS synthetic biology 9 (3),* 546–555. http://dx.doi.org/10.1021/acssynbio.9b00420

31. Hashemi, S.S., Karimi, K., & Karimi, A.M. (2019). Ethanolic ammonia pretreatment for efficient biogas production from sugarcane bagasse. *Fuel*, *248*, 196-204, https://doi.org/10.1016/j.fuel.2019.03.080.

32. Hoekman, S. Kent. (2009): Biofuels in the US–challenges and opportunities. *Renewable energy 34,* 14-22. https://doi.org/10.1016/j.renene.2008.04.030

33. Hollander, G. (2010). Power is sweet: sugarcane in the global ethanol assemblage. *The Journal of Peasant Studies, 37(4),* 699–721. http://dx.doi.org/10.1080/03066150.2010.512455

34. Hood Elizabeth E., & Lorenz Bauer (2016). Catalysts and Enzymes in Biofuel Production. https://www.biofuelsdigest.com/bdigest/2016/06/06/catalysts-and-enzymes-in-biofuel-production/ 30th/01/2022.

35. IEA (2012). Energy balance for Nigeria . OECD/IEA . http://data.iea.org. Accessed 1st September 2012.

36. IITA (1990), Cassava in tropical Africa:A Reference Manual https://www.iita.org/wpcontent/uploads/2016/06/Cassava_in_tropical_Africa_a_reference_manual_1990.pdf (Accessed 4/4/2020)

37. IRENA (2019). Global energy transformation: A roadmap to 2050 (2019 edition), International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/apps/DigitalArticles/-/media/652AE07BBAAC407ABD1D45F6BBA8494B.ashx (Accessed 11/5/2023)

38. Jutakridsada, P., Saengprachatanarug, K., Kasemsiri, P., Hiziroglu, S., Kamwilaisak, K., & Chindaprasirt, P., (2019). Bioconversion of Saccharum officinarum leaves for ethanol production using separate hydrolysis and fermentation processes. *Waste and Biomass Valorization, 10*, 817-825, https://doi.org/10.1007/s12649-017-0104-x.

39. Kemausuor, F., Akowuah, J.O., & Ofori, E., (2013). Assessment of feedstock options for biofuels production in Ghana. *J. Sust. Bioenergy Syst. 3*, 119–128. http://dx.doi.org/10.4236/jsbs.2013.32017

40. Khan, A., Jamil, F. & Khan, N.H. (2019). Decomposition analysis of carbon dioxide emissions in Pakistan. *SN Appl. Sci. 1*, 1012 . https://doi.org/10.1007/s42452-019-1017-z

41. Kiggundu Nicholas, Isa Kabenge, Samuel Gyebi Arhin, & Noble Banadda, (2017). Impacts of Biofuel Policies on Welfare and Food Security: Assessing the Socioeconomic and Environmental Tradeoffs in Sub-Saharan Africa, *International Journal of Renewable Energy Research, 7(4),* 2162-2171 https://doi.org/10.20508/ijrer.v7i4.6272.g7264

42. Kim, B., & Gadd, G. (2019). Anaerobic fermentation. In Prokaryotic Metabolism and Physiology (pp. 230-267). Cambridge: Cambridge University Press. https://doi.org/10.1017/9781316761625.008.

43. Kristen Schubert and Jerrod Mason, (2015), Cost-Benefit Analysis of USAID/Nigeria's MARKETS II Program. https://www.usaid.gov/sites/default/files/documents/1865/150305%20MARKETS%20CBA%20REPORT%20FINAL.pdf (Accessed 4/4/2020)

44. Kumar, V., Sindhu, R. K., & Kumar, S. (2018). Comparative analysis of green diesel versus petro-diesel in compression ignition engine. *Bioscience biotechnology research communications, 11(1)*, 128-135. http://dx.doi.org/10.21786/bbrc/11.1/18

45. Lackner, M., Winter, F., & Palotas, A., (2013) Combustion: from basics to applications. Wiley-VCH, Weinheim. ISBN 978-3-527-33376-9. http://dx.doi.org/10.1002/9783527667185

46. Lee Justin (2017), Nigeria to register 16M farmers in biometric database. https://www.biometricupdate.com/201703/nigeria-to-register-16m-farmers-in-biometric-database (Accessed 02/04/2020)

47. McMichael, P. (2009). The agrofuels project at large. *Critical Sociology, 35(6)*, 825–839 http://dx.doi.org/10.1177/0896920509343071

48. Mohamed G. El-Desouky, Muhammad A. Khalil, Ashraf A. El-Bindary, & Mohamed A. El-Bindary. (2022). Biological, Biochemical and Thermochemical Techniques for Biofuel Production: an Updated Review, *Biointerface Research in Applied Chemistry 12(3)*, 3034 – 3054 https://doi.org/10.33263/BRIAC123.30343054.

49. Monsalve, S. Suárez, Monsalve Suárez, Ulrike Bickel, Frank Garbers, Lucia Goldfar, & Vilmar Schneider. (2008). Agrofuels in Brazil. https://fianat-live-7318544636224c40bb0b0af5b09-745b6a8.divio-media.net/filer_public/6a/3e/6a3ed02b-8513-4996-82d0-a70c75a81a45/agrofuelsinbrazil.pdf

50. Moses, N., Mohammed, S., Saidu, H., Galadima, A.I., Umar, D.M., Abubakar, K., Kefa, M., & Billah, C., (2017). Determination of physicochemical parameters and riparian land effect on kwadon stream. *J. Adv. Res. Design,36,* 13–24. https://www.akademiabaru.com/doc/ARDV36_N1_P13_24.pdf

51. Nicha Sritong, Kamphol Promjiraprawat, & Bundit Limmeechokchai, (2014). CO2 Mitigation in the Road Transport Sector in Thailand: Analysis of Energy Efficiency and Bio-energy, *Energy Procedia*, *52*,131-141, https://doi.org/10.1016/j.egypro.2014.07.063.

52. Nitschel, R., Ankenbauer, A., Welsch, I., Wirth, N.T., Massner, C., Ahmad, N., McColm, S., Borges, F., Fotheringham, I., Takors, R., & Blombach, B., (2020). Engineering Pseudomonas putida KT2440 for the production of isobutanol. *Eng. Life Sci. 20 (5-6),* 148–159. https://doi.org/10.1002/elsc.201900151.

53. Nordsid, (2019), Price And Need For Reliable Electricity Are Spurring Solar Sales To Businesses. https://nordsip.com/2019/01/24/price-and-need-for-reliable-electricity-are-spurring-solar-sales-to-businesses-press-release (Accessed 4/4/2020)

54. Notaras M. (2018). All Biofuel Policies Are Political, https://ourworld.unu.edu/en/all-biofuel-policies-are-political

55. NS Energy, (2019). Top five countries for biofuel production across the globe, https://www.nsenergybusiness.com/features/top-biofuel-production-countries/ (Acessed 04/04/2020)

56. Ogbonna, I.O., Moheimani, N.R. &Ogbonna, J.C. (2015) Potentials of microalgae biodiesel production in Nigeria, *Nigerian Journal of Biotechnology*, *29*, 44–55. http://dx.doi.org/10.4314/njb.v29i1.7

57. OGNPBI (2007), Official Gazette of the Nigerian Bio-fuel Policy and Incentives. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/laws/1517.pdf (Accessed 04/04/2020)

58. Oji Chuka (2020), Snail Farming Business Plan In Nigeria, https://www.pinterest.ca/pin/25966135334283235/ (Accessed 02/04/2020)

59. Oliver, J.W.K., Machado, I.M.P., Yoneda, H., & Atsumi, S., (2013). Cyanobacterial conversion of carbon dioxide to 2,3-butanediol. *Proc Natl Acad Sci USA 110 (4),* 1249–1254. https://doi.org/10.1073/pnas.1213024110.

60. Oyatoye, E. T. O. (1994). The impact of Rural Roads on Agricultural Development in Nigeria: A case study of Kwara State. *Ife Journal of Agriculture, 16,* 114-122. https://ija.oauife.edu.ng/index.php/ija/article/view/574

61. Oyedele O. A., Oladipo I. O. & Adebayo A. O., (2015), Investigation into Edible and Non-edible Oil Potentials of Tiger Nut (Cyperus esculentus) Grown in Nigeria, *Global journal of Engineering, Design & Technl., 4(4),* 20-24 https://www.longdom.org/articles-pdfs/investigation-into-edible-and-nonedible-oil-potentials-of-tiger-nut-cyperus-esculentus-grown-in-nigeria.pdf

62. Park, J.M..,Rathnasingh, C.., & Song, H., (2017). Metabolic engineering of Klebsiella pneumoniae based on in silico analysis and its pilot-scale application for 1,3-propanediol and 2,3-butanediol co-production. *Journal of Industrial Microbiology and Biotechnology. 44(3)*, 431-441. http://dx.doi.org/10.1007/s10295-016-1898-4

63. Pragya, N., & Pandey, K. K. (2016). Life cycle assessment of green diesel production from microalgae. *Renewable energy, 86,* 623-632. http://dx.doi.org/10.1016/j.renene.2015.08.064

64. Rajeswari Shanmugam, Divya Baskaran, Panchamoorthy Saravanan, Manivasagan Rajasimman, Natarajan Rajamohan, & Yasser Vasseghian,(2022). Production of ethanol from biomass – Recent research, scientometric review and future perspectives, *Fuel, 317,* 123448, https://doi.org/10.1016/j.fuel.2022.123448.

65. Rajput, A.A., &Visvanathan, C., (2018). Effect of thermal pretreatment on chemical composition, physical structure and biogas production kinetics of wheat straw. *Journal of environmental management, 221*, 45-52, https://doi.org/10.1016/j.jenvman.2018.05.011.

66. Razaghifard, R. (2013). Algal biofuels. *Photosynth Res;117*,207e19. http://dx.doi.org/10.1007/s11120-013-9828-z

67. Renewable Fuels Association (RFA). 2012. 2012 Ethanol Industry Outlook. Renewable Fuels Association, Washington, DC. https://www.renewableenergymagazine.com/noor-hal-cuellar/ethanol-industry-outlook-2012-the-challenge-is (Accessed 24/12/2023)

68. Robbins Martin, (2011). Policy: Fuelling politics, *Nature, 474,* S22–S24 http://dx.doi.org/10.1038/474S022a

69. Rodriguez, G.M., & Atsumi, S., (2014). Toward aldehyde and alkane production by removing aldehyde reductase activity in Escherichia coli. *Metabolic Engineering. 25*, 227–237. http://dx.doi.org/10.1016/j.ymben.2014.07.012

70. Sathesh-Prabu, C., Kim, D., & Lee, S.K., (2020). Metabolic engineering of Escherichia coli for 2, 3-butanediol production from cellulosic biomass by using glucose-inducible gene expression system. *Bioresource technology. 309*, 123361. http://dx.doi.org/10.1016/j.biortech.2020.123361

71. Schnepf, R., & B. D. Yacobucci. (2013). Renewable Fuel Standard (RFS): Overview and Issues. Congressional Research Service, Washington, DC. https://sgp.fas.org/crs/misc/R40155.pdf (Accessed 24/12/2023)

72. Sinha J., and Indranil Biswas, (2008). Rural Energy security in India: reality checks. https://nistads.res.in/all-html/Rural%20Energy%20security%20in%20India_%20reality%20checks.html (Accessed 4/4/2020)

73. Siripong W, Wolf P, Kusumoputri TP, Downes JJ, Kocharin K, Tanapongpipat S, & Runguphan W., (2018) Metabolic engineering of Pichia pastoris for produc-tion of isobutanol and isobutyl acetate. B*iotechnol Biofuels 11*,1 https://biotechnologyforbiofuels.biomedcentral.com/articles/10.1186/s13068-017-1003-x (Accessed 24/12/2023)

74. Statista (2021). Petrol import into Nigeria between the 1st quarter of 2018 and the 1st quarter of 2021. https://www.statista.com/statistics/1165962/petrol-import-in-nigeria/

75. Subramani Velu, Angelo Basile, & Nejat Veziroglu (2015). Compendium of Hydrogen Energy Hydrogen Production and Purification 1st Edition - May 23, 2015 eBook ISBN: 9781782423836. Hardcover ISBN: 9781782423614. https://doi.org/10.1016/C2014-0-02671-8

76. Szetela Beata, Bekhzod Djalilov, & Raufhon Salahodjaev (2022). Renewable Energy and CO2 Emissions in Top Natural Resource Rents Depending Countries: *The Role of Governance, Frontiers in Energy Research, 10,* 1-5. https://doi.org/10.3389/fenrg.2022.872941 .

77. Tai, M., & Stephanopoulos, G., (2013). Engineering the push and pull of lipid biosynthesis in oleaginous yeast Yarrowia lipolytica for biofuel production. *Metabolic Engineering. 15*, 1–9 http://dx.doi.org/10.1016/j.ymben.2012.08.007

78. Tarafdar, A., Sirohi, R., Gaur, V.K., Kumar, S., Sharma, P., Varjani, S., Pandey, H.O., Sindhu, R., Madhavan, A., & Rajasekharan, R., (2021). Engineering interventions in enzyme production: Lab to industrial scale. *Bioresource technology 361*, 124771. https://doi.org/10.1016/j.biortech.2022.127770

79. Tiwari, S., Jadhav, S.K., Sharma, M., & Tiwari, K.L., (2014). Fermentation of waste fruits for bioethanol production. *Asian J. Biol. Sci. 7*, 30–34. http://dx.doi.org/10.3923/ajbs.2014.30.34

80. Tsai, Y.-Y., Ohashi, T., Wu, C.-C., Bataa, D., Misaki, R., Limtong, S., & Fujiyama, K., (2019). Delta 9 fatty acid desaturase overexpression enhanced lipid production and oleic acid content in Rhodosporidium toruloides for preferable yeast lipid production. *Journal of Bioscience and Bioengineering. 127 (4),* 430–440. http://dx.doi.org/10.1016/j.jbiosc.2018.09.005

81. Urbanchuk, J.M. (2013). Contribution of the Ethanol Industry to the Economy of the United States. http://ethanolrfa.3cdn.net/af18baea89e31dadbe_68m6bnto3.pdf. (Accessed 04/04/2020)

82. Wang T., (2019). Global biofuel production by select country 2018. https://www.statista.com/statistics/274168/biofuel-production-in-leading-countries-in-oil-equivalent/ (Accessed 4/4/2020)

83. Wang, P., Zhang, J., Feng, J., Wang, S., Guo, L., Wang, Y., Lee, Y.Y., Taylor, S., McDonald, T., & Wang, Y., (2019). Enhancement of acid re-assimilation and biosolvent production in Clostridium saccharoperbutylacetonicum through metabolic engineering for efficient biofuel production from lignocellulosic biomass. *Bioresource technology. 281*, 217–225. http://dx.doi.org/10.1016/j.biortech.2019.02.096

84. Wen, Z., Ledesma-Amaro, R., Lu, M., Jin, M., & Yang, S., (2020). Metabolic Engineering of Clostridium cellulovorans to improve butanol production by consolidated bioprocessing. *ACS Synthetic Biology. 9 (2),* 304–315. http://dx.doi.org/10.1021/acssynbio.9b00331

85. Wess, J., Brinek, M., & Boles, E., (2019). Improving isobutanol production with the yeast Saccharomyces cerevisiae by successively blocking competing metabolic pathways as well as ethanol and glycerol formation. *Biotechnology for Biofuels. 12 (1),* 173. http://dx.doi.org/10.1186/s13068-019-1486-8

86. World Bank (2020). orld Bank Open Data Nigeria. https://data.worldbank.org/ (Accessed 4/4/2020)

87. Yang, S., Mohagheghi, A., Franden, M.A., Chou, Y.-C., Chen, X., Dowe, N., Himmel, M.E., & Zhang, M., (2016). Metabolic engineering of Zymomonas mobilis for 2,3-butanediol production from lignocellulosic biomass sugars. *Biotechnology for Biofuels. 9 (1),* 189. http://dx.doi.org/10.1186/s13068-016-0606-y

88. Yang, Z.,& Zhang, Z., (2018). Production of (2R, 3R)-2,3-butanediol using engineered Pichia pastoris: strain construction, characterization and fermentation. *Biotechnology for Biofuels. 11 (1),* 35. http://dx.doi.org/10.1186/s13068-018-1031-1

89. Yu, A., Zhao, Y., Li, J., Li, S., Pang, Y., Zhao, Y., Zhang, C., & Xiao, D., 2020. Sustainable production of FAEE biodiesel using the oleaginous yeast Yarrowia lipolytica. *Microbiology Open. 9 (7),* e1051. http://dx.doi.org/10.1002/mbo3.1051

90. Zhang, Q., Hu, J., & Lee, D.-J., (2016). Biogas from anaerobic digestion processes: Research updates. *Renewable Energy, 98,* 108-119, https://doi.org/10.1016/j.renene.2016.02.029.

91. Zhou Adrian, & Elspeth Thomson. (2009), The development of biofuels in Asia, *Applied Energy, 86,* 11-20. http://dx.doi.org/10.1016/j.apenergy.2009.04.028

92. Zhu, L., Li, P., Sun, T., Kong, M., Li, X., Ali, S., Liu, W., Fan, S., Qiao, J., & Li, S., 2020. Overexpression of SFA1 in engineered Saccharomyces cerevisiae to increase xylose utilization and ethanol production from different lignocellulose hydrolysates. *Bioresource technology. 313*, 123724. http://dx.doi.org/10.1016/j.biortech.2020.123724

93. Zilberman David, Gal Hochman, Scott Kaplan, & Eunice Kim (2014). Political Economy of Biofuel, *Choices, 29(1),* 1–5 http://dx.doi.org/10.1007/978-1-4939-0518-8_11