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Review Article

Challenges and prospects of renewable energy in Nigeria: A case of bioethanol and biodiesel production

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ABSTRACT

Achieving an affordable clean energy in accordance to the sustainable development goal (SDG 7) is a challenge in Nigeria and other nations in Africa. Most of the currently used energy strategies are either not sustainable or poorly maintained. Nigeria is a major exporter of fossil fuel but currently faced with serious energy crisis, which necessitates the search for a sustainable renewable form of energy as alternative to fossil fuel in order to meet the SDG 7. Biofuel has been identified as a sustainable form of renewable energy in Nigeria with sugarcane, cassava, plant seed and waste materials being possible feedstocks for bioethanol and biodiesel production. The feedstocks are predominantly available and accessible with the possibility of maximizing them to drive socio-economic growth. Use of waste materials and non-edible underutilized seed oil such as *Jatropha curcas* will help minimize the controversies associated with the use of food materials as feedstock for biofuel production in Nigeria and other nations in Africa. Furthermore, focus should be on developing the Nigerian waste management strategy, which has the potential of generating sufficient energy to drive the economy and serve as means of employment. It is also high time for Nigeria to develop its own technology to run biofuel production from its currently developed cassava and sugarcane industry. It might be necessary to create more awareness on the importance of biofuel as well as provide suitable business environment for local and international investors.

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Contents

1. Introduction

Provision of affordable and clean energy is one of the seventeen sustainable development goals, which is paramount in most countries in Africa such as Nigeria. SDG 7 interconnects with other goals because it plays a vital role in socio-economic development (Ramchandra and Boucar, 2011). Over the years, the demand for energy has increased in African countries due to rapid population growth, increase in small-scale industries and local technological inventions. This demand is high in Nigeria being the most populous black nation in the world, a population of about 200 million people. Unfortunately, this demand is rarely met as access to affordable and clean energy in Nigeria faces several challenges. Consequences of this inaccessibility to energy include

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poverty, poor health services, decline in economic growth, poor research development and socio-economic imbalance (Oyedepo, 2012). The electricity generation capacity in different electricity generation stations in Nigeria according to Bello-Imam (2009) is presented in Table 1. It is obvious that the demand is still not met and the situation remaining the same over the years. In Nigeria, energy consumption goes into household, industrial, agricultural, transport and commercial sectors (Emodi and Boo, 2015; Emodi and Ebele, 2016).

The persistent inconsistency in the availability and market price of electricity and petroleum products in the Nigerian energy industry reflects the inefficiency to meet demand and makes the challenge more conspicuous. The country is rich in conventional energy resources, which comes mainly from crude oil, coal and natural gases. However, apart from the inefficiencies the energy industry faces, the conventional resources have other issues such as being nonrenewable and may facilitate environmental degradation. This has pointed attention towards finding alternative to the conventional energy resources in Nigeria.

With the low level of scientific development in Nigeria, the country depends on attracting foreign investors to help strengthen the energy sector and uses this as a means of scaling up rural development. This step has positive impact on the nation's gross domestic products. One key area of interest as an alternative is the renewable energy resource. Interestingly, Nigeria is endowed with various renewable energy resources of which biomass, hydropower, solar, wind and potentials for hydrogen utilization are the most abundant. To achieve the best use of these resources, the Nigerian government has shifted attention towards biofuel industry with intensified efforts on the agricultural sector (Onuoha, 2010). This has increased the support for renewable resource as alternative to fossil fuel in Nigeria and with the current state of environmental pollution, use of clean energy source, which is environmentally-friendly will be the best way to go.

Biofuel is an example of resource that can serve as alternative to the conventional fossil fuel in Nigeria. Biofuel is a non-fossil fuel derived biomass, it can be categorize as; bioethanol, biomethanol, biodiesel, biohydrogen and biogas (Amigun et al., 2011). Among the different categories, bioethanol and biodiesel are the most common categories in Nigeria. This review aims to present a brief overview of the current challenges faced by biofuel development in Nigeria and the possible prospects of developing an affordable and sustainable biofuel as an alternative form of renewable energy to replace fossil fuel in Nigeria.

2. Biofuel production in nigeria

Biofuel production is a possible venture in Nigeria. Most of the states have the potential of being able to produce biofuel with the agricultural endowment. However, technological advancement and governmental policy are not well framed or developed to cater for this. A few preliminary tests have been conducted using feedstocks like, sugarcane, cassava, coconut, oil palm and soya. However, having the large capacity for oil plantation and cassava cultivation makes these products stand out as major promising feedstocks for biofuel production in Nigeria. Despite the huge success attained with the preliminary studies, the land tenure and agricultural system operated in Nigeria still poses a serious challenge.

Land plays a key role in the agricultural sector. The traditional land tenure practice in Nigeria used to depend on communal ownership, which is considered as customary land tenure practice. With civilization, the communal ownership emerged to become individual ownership under the auspice of the federal government with the land use decree. Despite the land use decree, the customary land tenure practice continues to dominate which gives the community control over land use. Communal control over land in Nigeria creates a lot of bottleneck for investors due to tribal and ethnic clashes over land dispute. This has brought huge drawbacks to use of fallow land in some of the rural communities with massive arable land; most especially in the use of these lands to grow feedstock for biofuel production. The current major challenge is the invasion of farmland by grassing herdsmen. The herdsmen have become major threat to farming in most rural areas in Nigeria, which has recorded severe loss of human lives. This has created many communal issues bringing a setback to use of farmland for cultivating feedstock for biofuel production.

High production cost has also been identified as one of the challenges faced by biofuel production in Nigeria (Aliyu et al., 2017; Haruna et al., 2017). Currently, the estimated cost of production is higher than the present cost of fossil fuel. This makes it discouraging to embark on the production of biofuel mainly bioethanol and biodiesel. In some cases, the feedstocks used can also serve as food, which has caused a competition between the resources serving as feedstock for biofuel and at the same time being food. Since this may likely be a threat to food, the current move is to consider the use of feedstocks that are nonfood. With new discoveries in science and technology, it is important that priority should be given to processes that makes biofuel production environmentally friendly and cost effective. Although access to new technology for biofuel production is a challenge in Nigeria due to cost and maintenance but government can help to give interventions and subsides to ease procurement and maintenance. Apart from this, it is important to develop technology that are Nigeria based, cheap and sustainable under conditions that exist in Nigeria. Weak government policy and lack of public awareness is a challenge to biofuel acceptance in Nigeria. It is important to bring standard policy in place to promote biofuel in Nigeria; this should provide a platform for industries, non-governmental agencies, private investors, research institutes and academia to thrive (Balogun, 2015).

Competition between biofuel feedstock and food is a compelling challenge in Nigeria. It is an obvious fact that since the rise in price of food in 2007, the competition between the cost of food and biofuel became a problem (Rathmann et al., 2010) even until date. This is so unfortunate because this should not have been the case in Nigeria. Nigeria has no constraint of arable land; the country has 785,000 km^2 of accessible farmland without any limitation but prospective possibility of improved agricultural output and efficiency (UN, 2011; Abila, 2012). With information available, the inventory of forest plantation from different states in Nigeria is shown in Fig. 1 (FAO, 2010) which further shows availability of cultivable farmland. However, the neglect of these available lands is high due to lose of interest in agricultural sector of the nation resulting in reduction in the nation's food basket while population increases. The loss of interest may be attributed to poor wages, lack of access to agricultural loan, poor facilities, high admission requirement for agricultural courses at high institutions of learning and urge for white-collar jobs in urban communities. All of these have resulted in the low turnout of agricultural produce, which makes biomass as feedstock for biofuel production less available in Nigeria.

The use of renewable form of energy is not well established in Nigeria apart from the hydrogenation of energy, which has been inconsistent due to poor maintenance. The government is making effort to initiate programs to create awareness and enlightenment on the use of renewable energy resources; this include developing policies, incentives and regulatory environment necessary for biofuel to thrive in Nigeria (Onuoha, 2010).

Effort from the Jatropha growers, processors and exporters association of Nigeria has shown that Nigeria requires 2.4 million litres of biodiesel on a daily basis to adequately implement the Paris agreement on climate change (PUNCH, 2016).

Table 1
Electricity generation at different stations in Nigeria.
Source: Bello-Imam (2009) with permission.

Station	Installed capacity (MW)	Measured output (MW)	No of units	Output as % of installed capacity
Oji	30	NA	4	NA
Delta	900	366	20	40.67
Kainji	760	445	12	58.55
Ijora	60	8	3	13.33
Sapele	1020	62	10	6.08
Afam	960	85	18	8.85
Jebba	560	339	v6	60.54
Egbin	1320	243	6	18.41
Shiroro	600	281	6	46.83
Total	6210	1829	85	29.45

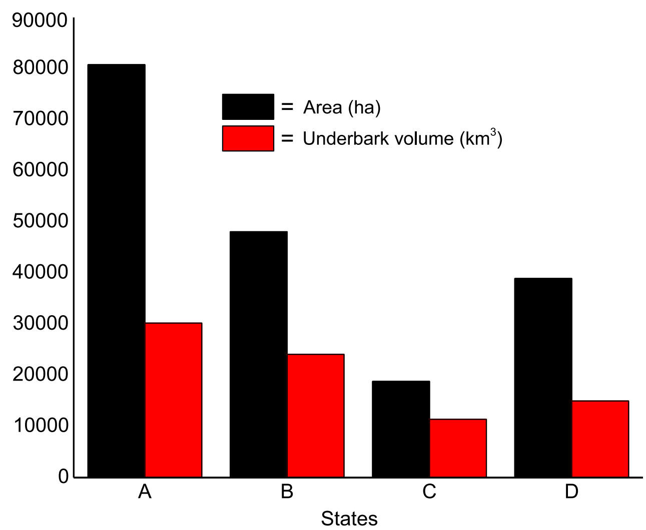

Fig. 1. Inventory showing forest plantation distribution across Nigeria (FAO, 2010). A = Lagos, Ogun, Oyo, Osun, Ondo and Ekiti state. B = Edo, Delta, Abia, Imo, Anambra, Enugu and Ebonyi state. C = Rivers and Bayelsa, Cross Rivers, Akwa-Ibom and Benue state. D = Kwara, Kogi, Niger, Kebbi, Kaduna, Kano, Plateau, Nasarawa, Adamawa and Taraba state.

Table 2
Types of feedstocks for bioethanol production.

Feedstock type	Examples	References
1st generation	Cotton, yam, moringa, cassava, maize, sugarcane, castor, sunflower, sweet sorghum, rice, millet,	Ackom et al. (2013), Diop et al. (2013) and Kemausuor et al. (2013)
2nd generation	Sugarcane bagasse, grasses, reduced waste, perennial grasses, corn stover, wheat straw, corn stover, kraft pulp and wood	Ackom et al. (2013), Evtuguin (2016), Zabed et al. (2016) and Ndongsok et al. (2018)
3rd generation	Microalgae	Dutta et al. (2014) and Bastos (2018)

2.1. Biothanol production in Nigeria

Use of bioethanol is important as a replacement for fossil fuel being that it reduces carbon emission. The Nigerian target is to promote ethanol industry, which will make use of agricultural products as a renewable resource for improving the quality of fossil-based fuel in Nigeria with an initial plan of 10% blend (E-10) with petrol and a 100% (E-100) domestic production by year 2020 (NNPC, 2007; Onuoha, 2010). The prospective feedstocks for bioethanol in Nigeria are sugarcane and cassava. Both cassava and sugarcane industry in Nigeria are still growing to meetup with demand for biofuel as previous cultivation was for local consumption. There is a gradual progress but slow in bioethanol production in Nigeria. This is based on the cultivation of cassava and sugarcane. However, while Nigeria has good geographical conditions to favor biofuel production, the country still lacks a large scale bioethanol production sector which can serve commercial production purpose. Despite the huge amount of money spent on the biofuel program launched in 2007 (NNPC, 2007; Onuoha, 2010); the outcome is still very discouraging (Ohimain, 2010; Ishola et al., 2013). Use of bioethanol offers benefits such as; possibility of being blended with petrol, reduced hydrocarbon content and carbon oxide emission, high octane number and heat of vaporization, and compatibility with current engine design (Balat et al., 2008; Walker, 2011; Deenanath et al., 2012). Different feedstocks have been identified for the production of bioethanol and have been grouped into; first, second and third generation feedstocks based on the carbohydrate source as shown in Table 2.

The first-generation feedstocks are predominantly from sucrose rich materials such as sugarcane, the second generation are those from nonedible lignocellulosic biomass such as corn stalk, wheat straw and grasses while the third generation include those from microalgae biomass.

The second-generation feedstocks are sometimes referred to as agrowastes. They are most favored for bioethanol production due to their availability and affordability. They may vary in composition but the major component being cellulose. These are mainly used as feedstocks in Europe and United States of America but use is limited in Africa (Kim and Dale, 2004; Sarkar et al., 2012) due to poverty and lack of adequate technology to put this to implementation. The cellulosic biomass, lignocellulose is a polymer, which is a network of cellulose, hemicellulose and lignin (Devarapalli and Atiyeh, 2015). The lignin binds the cellulose and the hemicellulose together and prevents microbial attack, which avoids depolymerizing the cellulose and hemicellulose to fermentable sugars (Sarkar et al., 2012; Devarapalli and Atiyeh, 2015). The conversion of second-generation feedstock to bioethanol is more complex than the first generation feedstock (Stöcker, 2008). The conversion process for the second-generation feedstock goes through three operations, which are; pretreatment to liberate hemicellulose and cellulose; hydrolysis of cellulose and hemicellulose and finally fermentation (Balat et al., 2008).

Tiwari et al. (2014) reported the use of rotten fruits from market as feedstock using fermentative bacterial in a process that is adoptable in developing countries. Byadgi and Kalburgi (2016) effectively separated lignin, hemicellulose and cellulose to enhance bioethanol production via an optimized condition for the pre-treatment. Hydrolysis to sugar was achieved using *Cytophaga huchnosonni* and finally fermented using *Saccharomyces cerevisae*. Cutzu and Bardi (2017) also achieved fermentation to obtain bioethanol using *Saccharomyces bayanus* and by varying

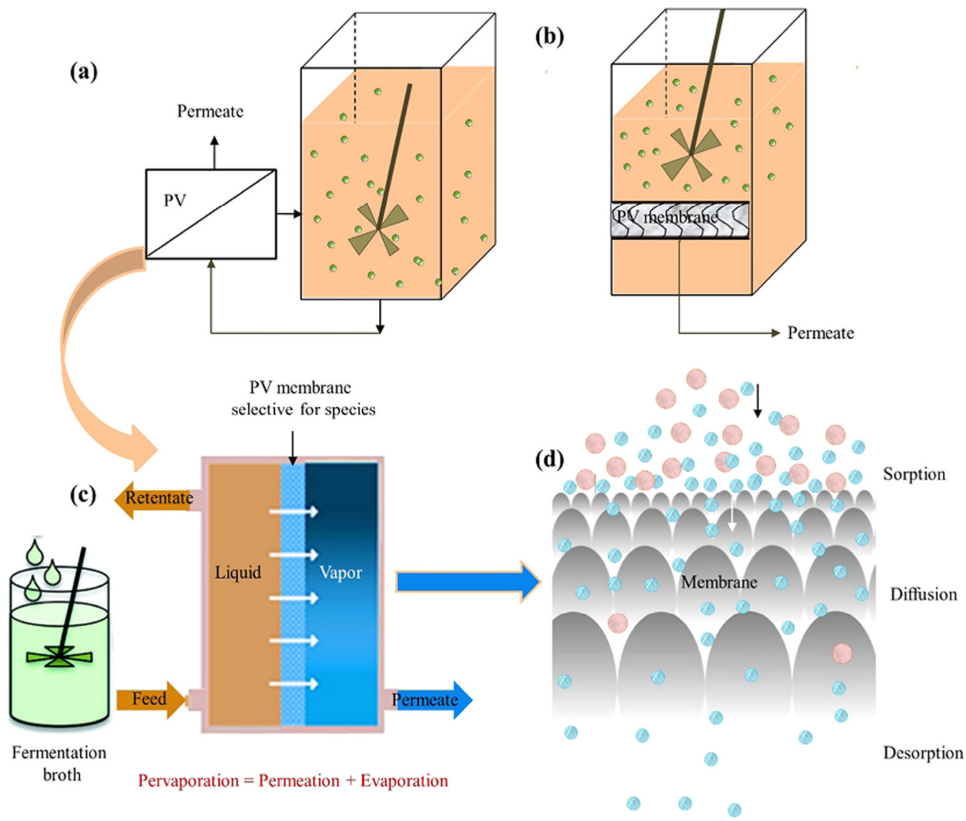

Fig. 2. (a) External configuration of pervaporation unit (PV: pervaporation membrane), (b) internal configuration of pervaporation unit, (c) schematic of pervaporation process and mechanism, (d) solution diffusion mechanism (Khalid et al., 2019) with permission.

temperature and pressure, a yield of 93.35% bioethanol was attained. Among the second-generation feedstock known, attaining efficient conversion when using waste paper is still a challenge because of its recalcitrant structure due to possible interaction of cellulose chain with hemicellulose and lignin to form a lignin-carbohydrate complex that makes it difficult to form fermentable sugar. Recently, Umamaheswari et al. (2017) applied a different approach on seaweed (as feedstock) using potassium dichromate. Current study by Hossain et al. (2018) suggests the use of *Wickerhamia* sp. as a promising candidate for bioethanol production from starchy biomass. The study further presented an enhanced bioethanol production via consolidated bioprocessing with statistically optimized medium. Most recently reported method (Khalid et al., 2019) involves the use of membrane technology that depends on the mechanism of pervaporation (Kang et al., 2015; Ong et al., 2016) as shown in Fig. 2. Use of this method has several advantages over other known methods mainly for the dehydration of bioethanol from fermented systems (Singh and Rangaiah, 2017). Apart from dehydration, the current use of membrane technology for bioethanol production has shown other advantages such as; fast conversion rate, high yield, minimal waste generation, the regeneration capacity for reuse makes it cost effective and better than previously reported methods (Ingale et al., 2014; Wong and Sanggari, 2014; Mickel et al., 2017). Although the first generation feedstock is currently used in Nigeria but there is need to consider the second-generation feedstock for bioethanol production due to the advantages it brings. With recent global discoveries of new methods in the use of second-generation feedstock and available biomass resources in Nigeria, it is certain that use of bioethanol may serve as a viable means to cleaner energy in Nigeria.

2.2. Biodiesel production in Nigeria

Biodiesel is considered as an alternative fuel for diesel engines. Technically, it is defined as mono-alkyl esters of fatty acids obtained from vegetable oils or animal fats. It is derived from the chemical reaction (known as transesterification reaction) between vegetable oil or animal fat and alcohol in the presence of a catalyst. This is described in Fig. 3. It is renewable, it can be used pure or in a blend with diesel fuel. It reduces environmental pollution encountered from fossil fuel and can be produced from common feedstocks. Depending on the feedstock used, the fuel properties of biodiesel still rely on the component fatty acids present in the feedstock and ultimately on the carbon chain length of the fatty acids and the unsaturation (double and triple bonds) present on the carbon chain (Azad et al., 2016). Certain factors have also been reported to affect biodiesel yield as well as its quality; these factors include composition of feedstock, free fatty acid content, and water concentration (Tabatabaei et al., 2019). However, the extent of this effect depends on the production techniques used. Common feedstocks used are; vegetable oils, animal fats, waste or used oils, etc. Nigeria is rich in vegetable oil, which makes production of biodiesel achievable. Embarking on its production has some credits such as market for excess production of vegetable oil and animal fat, cleaner environment since the exhaust emissions from biodiesel are lower than those from regular diesel fuel and reduces dependence on petroleum product.

Vegetable oil and animal fats are the primary raw materials for biodiesel production. These raw materials are mainly triglycerides and free fatty acids. The production process is initiated with catalyst. The choice of catalyst is very important during this process of production. Different forms of catalysts have been used in the past, this includes, acid, base and biocatalysts. Among

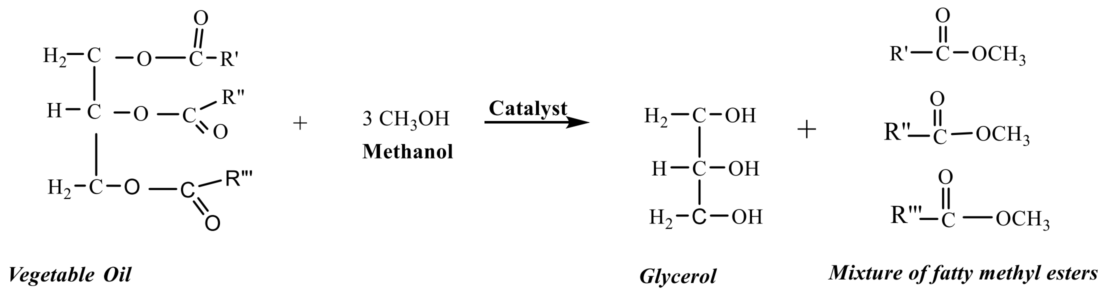

Fig. 3. Transesterification of vegetable oil to produce mixture of fatty methyl esters (biodiesel).

Table 3
Representative chemical catalysis for biodiesel production on reactors.
Source: Yan et al. (2014) with permission.

Reactor type	Feedstock	Catalyst	FAME yield (%)
Membrane reactor	Canola oil, methanol	NaOH, H_2SO_4	96, 64
Zigzag micro-channel reactor	Soybean oil, methanol	NaOH	81.5–99.5
Oscillatory flow reactor	Rapeseed oil, methanol	NaOH	99
Trickle bed reactor	Rapeseed oil, methanol	Alkaline	95
Rotating packed bed	Soybean oil methanol	KOH	97.3
Stirred-tank reactor	Palm oil, methanol	KOH	58.5–97.3
Reactive distillation reactor	Canola oil, methanol	KOH	94.4

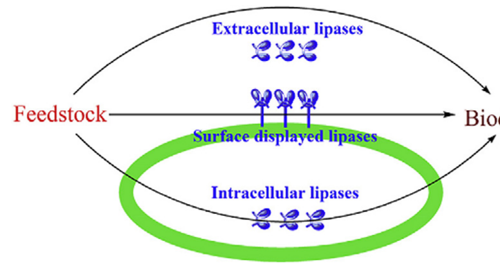

Fig. 4. Three types of genetically engineered lipases for biodiesel production (Yan et al., 2015).

the catalysts used, biocatalysts are expensive for industrial scale production (Yan et al., 2010), the acid catalysts require high molar ration of alcohol to oil, long reaction time, high pressure and susceptibility to metal corrosion (Edirin and Nosa, 2012). However, the base catalyst is viable due to the short reaction time, low catalyst concentration and low alcohol to oil ratio (Ayoola et al., 2019). The essence of the catalyst is to act as a solubilizer since the alcohol is sparingly soluble in the oil phase. Several catalysts have been developed over time to improve on the transesterification process for better yield during production. Yan et al. (2014) and Yan and Yan (2017) as presented in Table 3 previously reported a few of these. It is a well established fact that the use of base catalyst for biodiesel production gives high yield but this still has some drawbacks such as difficulty in the recovery of glycerol, difficulty in removal of catalyst from product, emulsification when soap is produced, and treatment of wastewater generated. However, use of biocatalyst like lipase might be a promising means to combating these drawbacks. This has led to the development of new generation genetically engineered lipases that can mediate in in-vitro biodiesel production.

These lipases are intracellularly produced by microbial cell as described in Fig. 4 (Yan et al., 2015).

Alcohol choice also varies but the primary alcohol used is methanol while other commonly used alcohols are ethanol, isopropanol and butanol. One major impurity usually encountered is phospholipids, which are removed from the biodiesel during degumming step. During production, care must be taken to avoid contamination from water since low molecular weight alcohol are hygroscopic; unfortunately, the presence of water molecules can interfere with the transesterification reaction. So, certain chemical parameters must be considered when setting up a biodiesel production unit in order to have utmost yield. These chemical parameters are; choice of catalyst, quality of reactants, choice of primary reactant, and effect of products on overall reaction. Moreover, operating parameters such as, temperature, mixing intensity, triglyceride to alcohol ratio, reactor resident time and pressure must be taken into consideration as well.

Some problems have been associated with biodiesel usage (Kaisan et al., 2013) but these have been addressed overtime with better techniques and huge success being recorded. One of the currently used methodology is the microwave irradiation-assisted alkaline-catalyzed transesterification (Milano et al., 2018). This was recently reported for the production of biodiesel from mixture of waste cooking oil and *Calophyllum inophyllum* oil. Success was achieved using response surface methodology based on Box–Behnken experimental design. This method is effective in boosting biodiesel yield as well as producing biodiesel with superior quality. This method is better than previously improved method (Silitonga et al., 2011; Ong et al., 2014; Giwa et al., 2016). It is faster, energy-efficient and of superior quality when compared with previously used methods. Apart from the use of vegetable oil and animal fat as primary feedstock, other alternatives have been reported. Kara et al. (2018) reported the use of waste fish oil with high free fatty acid content. Adewuyi et al. (2012a,b) reported the use of underutilized seed oils. Aransiola et al. (2012), Atabani et al. (2013), Ong et al. (2013) and Bhuiya et al. (2014) have reported the use of nonedible oils as alternative feedstock. A few other works have reported the use of microalgae. The use of microalgae has been found to have economic benefits (Akubude et al., 2019) as shown in Fig. 5.

The lipid content of some microalgae have been determined for possible use as feedstock for biodiesel production. A few of the reported strains in Table 4 are available in Nigeria. This shows that use of microalgae as source of feedstock is a potential resource for biodiesel production in Nigeria. Several techno-economic studies have been conducted to find most suitable process in term of performance and cost efficiency for biodiesel production from microalgae, in this regards, several assumptions had been considered to propound sustainable models.

Rios et al. (2013) developed a model shown in Fig. 6. This production model imbibed path that have cultivation, flocculation and filtration to spray-dry, harvest, and pretreatment units in order to produce biodiesel. This model requires minimum amount of energy, which makes it suitable for operation in Nigeria.

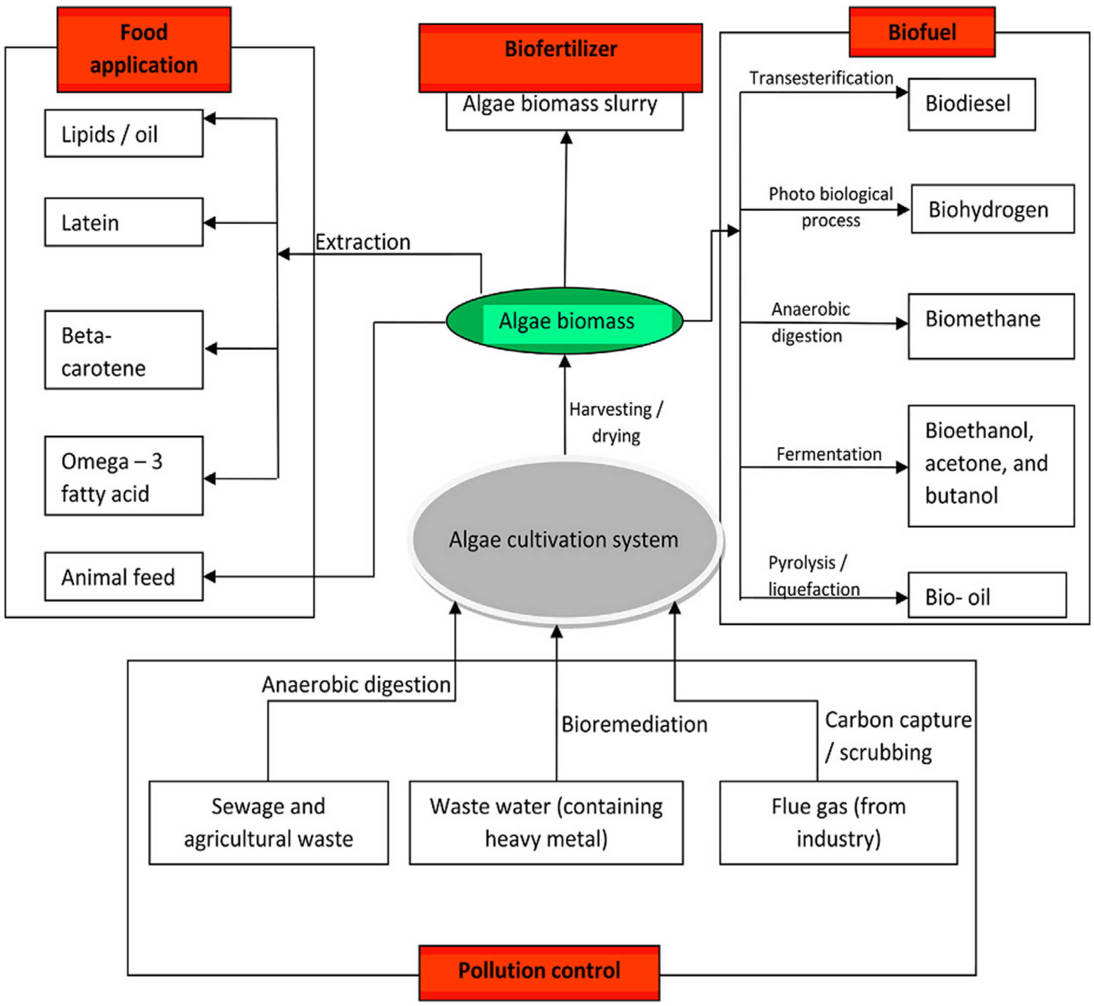

Fig. 5. Economic benefits of microalgae (Akubude et al., 2019) with permission.

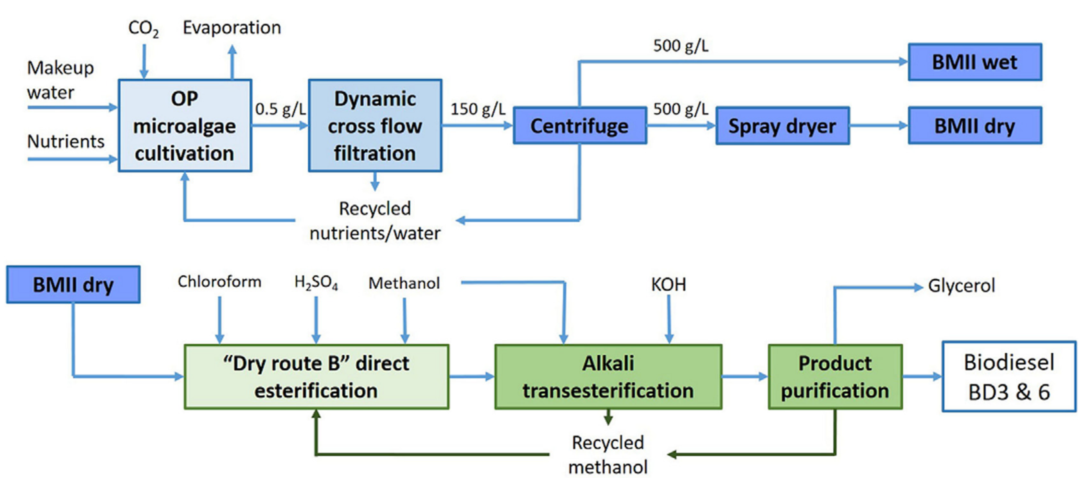

Fig. 6. Microalgae biodiesel production path (Rios et al., 2013) with permission.

2.3. Challenges of biofuels production in selected West African countries

Biofuel initiative in West African countries is centered around the development of energy sources from agricultural sector with keen interest on expanding energy supply and mitigating dependence on fossil fuels (Popoola et al., 2015). Table 5 compares the challenges facing biofuel production in some West African countries. It is obvious that the process of biofuel production in these countries depends on agricultural feedstock. Lack of comprehensive national bioenergy policy and food insecurity are two major challenges common among all the West African countries compared in Table 5. Challenge on climate change was noticed in Cameroon and Burkina faso. The climate change issue

Table 4
Lipid content of microalgae for biodiesel production.

Microalgae	Lipid (%)	Reference
Schizochytrium limacinum	33.9	Tang et al. (2011)
Botryococcus braunii	17.6	Santana et al. (2012)
Pavlova sp.	17.9	Cheng et al. (2011)
Nannochloropsis sp.	25.0	Andrich et al. (2006)
Chlorella vulgaris	22.0–54.0	Chen et al. (2011)
Graesiella sp.	33.4	Wen et al. (2016)
Dunaliella primolecta	23.0	Chisti (2007)
Neochloris oleoabundans	42.0	Singh et al. (2017)
Phormidium autumnale	20.7	Siqueira et al. (2016)
Crypthecodinium cohnii	20.0	Mata et al. (2010)

in these countries have shown negative effect on the agricultural cultivations compared to other countries examined. Apart from this, water scarcity is also a challenge in Cameroon. There is no doubt that access to clean drinking water is a challenge in most African countries, however, Cameroon suffers from sufficient water supply for agricultural practice, which has negative impact on agricultural resources as feedstock for biofuel production. This has been a blow on the sugarcane, jatropha and cassava, which have been identified as feedstock for biofuel in Cameroon. Access to financial support in form of loan or seed fund to startup a biofuel business is a challenge in Cameroon, such support is expected to empower prospective individuals who are interested in biofuel business. Insufficient or low infrastructural development has also been identified as a challenge in Burkina faso which is not a problem in other countries studied. Lack of access to advance technology and high production cost were among the challenges identified in Nigeria, which may be related to the challenge of low infrastructural development in Burkina faso. Undoubtedly, demand for biofuel has led to rise in concern between land for food delivery and land for biofuel production. The problems associated with the land tenure system in Nigeria may also be considered similar to the land demand and conflict in Cameroon, land availability and right in Burkina faso, appropriation of land by foreign investors in Mali and land tenure in Senegal. Several biofuel projects have been initiated by governmental and nongovernmental agencies in West African countries such initiatives include, Mali-Folkecenter Nyetaa in Mali, Ghana BioEnergy Ltd in central Ghana, Fondation Faso Biocarburant in Burkina faso and biofuel industry equity fund in Nigeria. These initiatives have contributed to the promotion of biofuel in West Africa. Nigeria is currently improving on the need for biofuel production. Moreover, currently, there are commercial-scale ethanol distillates companies in Nigeria, which are making use of agricultural feedstock for bioethanol production. Several biomass such as jatropha, sugarcane, sunflower, cassava, sweet sorghum and cottonseed were identified as potential feedstock for bioethanol and biodiesel in the countries compared, however, jatropha was the only feedstock that cut across all the West African countries studied.

3. Prospect for bioethanol and biodiesel as biofuel in Nigeria

The prospect of biofuel in Nigeria is great. Previous study by Ong et al. (2014) reported a sensitivity analysis, which concluded that variation in feedstock would significantly have impact on the life cycle cost of biodiesel production; however, the price of biodiesel may become compatible with that of diesel fuel if incentive and subsidy policy is in place. Currently, the Nigerian government still provide subsidy on the cost of fuel diesel, which still places the pump price at $ 0.64 per litre. If such subsidy and support are introduced on biofuel for consumers, it will go a long way to the economic survival of biofuel in Nigeria. Poor maintenance, ageing infrastructure, vandalization and political gains may be attributed to low power supply in Nigeria. This power supply is less than 50% of the installed 6000 MW capacity generated (Oyedepo, 2012; Onabanjo and Di Lorenzo, 2015). Nigeria was estimated to operate 60 million electric generators, which depend on fossil fuel, which is valued at $ 0.25 billion USD (NESP, 2014; UN, 2015). The actual cost of power generation from fossil fuel becomes high due to these challenges. However, biofuel might be the way to go in Nigerian economy since both 1st and 2nd generation feedstocks are readily available in Nigeria with less political and ethnic attention unlike the case of fossil fuel. Onabanjo et al. (2017) recently reported the environmental burden associated with biofuel sustainability in Nigeria using life-cycle assessment method. This study revealed that a self-generated energy from use of 5 kVA fossil diesel in Nigeria may emits 1625 kg CO_2 eq./MWh, apart from other pollutants in contribution to greenhouse gas, which suggests a contribution of about 89 million tonnes CO_2 eq. per year to climate change. However, the use of biodiesel has the capacity of reducing this hazard by 76% (Onabanjo et al., 2017). There are indications that the next generation of clean energy in Africa will have to come from renewable energy with biofuel playing a key role. Nigeria is a relatively poor country; however, Nigeria has good access to unexploited land, which has attracted remarkable investment in sugarcane and cassava plantation.

3.1. Sugarcane

There are indications that over 400,000 hectares of land are available in rural Nigeria that can boost high yield of sugarcane production (Agboola and Agboola, 2011; Moses et al., 2017). It is a tropical crop suitable for warm climate condition and sufficient rainfall. Being the second largest consumer of sugar in Africa, the capacity to cultivate sugar in Nigeria is high coupled with the incentives coming from government to encourage the sugarcane industry (Gourichon, 2013). This support from government has been a major driver for Nigeria having the largest sugarcane refinery in Africa. The bagasse generated after the juice of the sugarcane is removed is a huge resource for biofuel production in Nigeria. This makes it a win–win situation for Nigeria. Being the largest hub for sugarcane refining in Africa, the turnout of bagasse is very high making investment in bioethanol a viable venture for energy production in Nigeria. Moreover, the Nigerian government has also made it a 5 years tax-free holiday for investors in the sugarcane industry. In year past, Nigeria has been the least in term of production (FAOSTAT, 2012), but the intervention from the government has been helpful. Irrespective of the constrains from lack of water, irrigation is used as palliative and the climate condition is suitable. Despite having the largest refinery plant in Africa, the number of milling plants available in Nigeria is small. Sugarcane production is state based in Nigeria and it is distributed mainly among the states in the northern region of the country as shown in Fig. 7. Although there is also some level of importation of fine sugar into Nigeria to meet up with demand, however, this importation is being discouraged with the high duty fees that is currently charged on imported fine sugar in order to grow local sugar industries. Interestingly, a typical Nigerian refinery produces an average of 82.2 kg of refined sugar and 31 kg of bagasse per tonne of sugarcane (Gbabo et al., 2004; Nasidi et al., 2010). The total fermentable sugar content of the bagasse has been reported to be around 46% (Nasidi et al., 2010) which means that the 31 kg of bagasse will have about 14.26 kg of fermentable sugar. According to Eq. (1) below, it means that the 14.26 kg fermentable sugar gives 7.29 kg of ethanol making the estimated industrial production capacity about 92% (Nwachukwu and Lewis, 1986; Pandey, 2008; Nasidi et al., 2010).

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (1)$$

Table 5
Comparison of the challenges to biofuel production among selected West African.

Country	Challenges	Types of raw materials	References
Cameroon	I: Food insecurity; II: Land demand and conflict; III: Climate change; IV: Insufficient institutional support and weak institutional coordination; V: Access to financial support; VI: Water scarcity; VII: Lack of comprehensive national bioenergy policy	Sugar cane, jatropha, cassava	Amigun et al. (2011); Ackom et al. (2013), Fouepe et al. (2015) and Ndongsok et al. (2018)
Burkina faso	I: Low infrastructural development; II: Climate change; III: Food insecurity; IV: Environmental issues; V: Land availability and right; VI: Lack of coordination between public actors and stakeholders; VII: Lack of comprehensive national bioenergy policy	Jatropha	Chapuis (2014), Gatete and Dabat (2017) and Derra and Temple (2018)
Ghana	I: Land degradation; II: Food insecurity; III: Lack of mandate for biofuel blends; IV: Low production yield; V: Lack of incentive to encourage local industries; VI: Environmental impacts; VII: Lack of comprehensive national bioenergy policy	Jatropha, cassava, sweet sorghum, oil palm	Kemausuor et al. (2013), Ayamga et al. (2015) and Ahmed et al. (2017)
Mali	I: Appropriation of land by foreign investors; II: Very small-scaled farming exploitations; III: Policies and priorities; IV: Food insecurity; V: Lack of comprehensive national bioenergy policy	Jatropha	Boccanfuso et al. (2012), Favretto (2014) and Gatete and Dabat (2017)
Senegal	I: Food insecurity; II: Environmental threat; III: Land tenure system; IV: Lack of comprehensive national bioenergy policy	Jatropha, cotton seed, sunflower	Chapman and Campbell (2014), Dafrallah and Ackom (2016) and Ba (2018)
Nigeria	I: Food insecurity; II: Land tenure system; III: High production cost; IV: Lack of access to advance technology; V: Weak government policy and lack of public awareness; VI: Lack of comprehensive national bioenergy policy	Cassava, sugarcane, jatropha	Balogun (2015), Aliyu et al. (2017) and Haruna et al. (2017)

This estimated production capacity of 92% may increase under certain elevated production conditions. This yield reflects the importance of the positive impact that the use of sugarcane bagasse may have on the future of biofuel in Nigeria.

3.2. Cassava

Currently, Nigeria play a leading role in the cultivation of cassava in the world. The production is well developed in Nigeria. It is a major economy sustenance crop as well as a cash crop. It has a well established processing technique for food product and cattle feed. It has exceptional capacity in that it adapts easily to climate change and tolerates drought conditions, low soil fertility and a few pest (Eguono, 2015). It is grown in almost all the states in Nigeria but its production dominates the southern part of the country. It is grown throughout the year, which makes it preferable to other seasonal crops. The availability throughout the states in Nigeria and the fact that it is not a seasonal crop but readily available all through the year are indicators suggesting it as a dependable and realizable resource for biofuel in Nigeria. Overtime, the Nigerian government has been playing active role in helping local farmers with incentives to grow cassava. With the landowner decree, government provides free land with substantial support for interested farmers to grow cassava. This has resulted in an overturn of about 15 tons of an average national cassava per hectare of land (Ohimain, 2010), which is adequate to support a kick off bioethanol production in the nation. Few works from Nigeria have also reported the development of new methods for converting cassava to bioethanol (Ajibola et al., 2012). Being a starchy material makes it a high yield feedstock for bioethanol production, which requires the use of enzyme for its fermentation process. Although this stage requires some level of expertise with enzymatic engineering but it is evolving and still currently growing in Nigeria, which makes process design an important aspect that needs to evolve with the adapted production technique in Nigeria.

3.3. Plant seed

Plant seeds are superb materials that have found several applications. The demand has increased overtime either as food or for industrial uses. Plant seed oil is a triglyceride that can serve as feedstock for biodiesel production. The plant seed can serve as source of oil, starch and cellulose. The starch and cellulose can serve as feedstock for bioethanol while the oil can be used for biodiesel production. The endowment of plant seed makes it unique. Nigeria is blessed with several plant resources some of which are non-conventional and are underutilized. Most of these underutilized seeds are discarded as waste with no specific use. Finding application for these rich resources places Nigeria at an advantage of making use of this biomass for biofuel purpose. A number of unexploited and underutilized plant seeds in Nigeria have been identified and characterized (Oyekunle et al., 2007). Oil have been isolated from some of these seed for the purpose of biodiesel production (Adewuyi et al., 2012a,b) while cellulose have been isolated and characterized from some (Adewuyi and Pereira, 2017). Since these are currently considered as waste in Nigeria, the use of these underutilized and unexploited seeds can be viewed as a waste to wealth concept, which will go a long way enriching biofuel development in Nigeria. Apart from the non-conventional seed oils, some of the well-known seed oils are still underutilized. Example are soybean and jatropha (*Jatropha curcas*) oils. The potential for these seed oils as biodiesel feedstock is high in Nigeria. Although the food industry demand for soybean is high due to its high protein content but its potential use as a possible source of biofuel cannot be undermined. Unlike soybean, the non-edibility of jatropha oil makes it stand an advantage as a feedstock for biodiesel production.

3.4. Waste materials

Waste generation in Nigeria is high. Waste handling and disposal is a challenge in Nigeria. Finding application for domestic

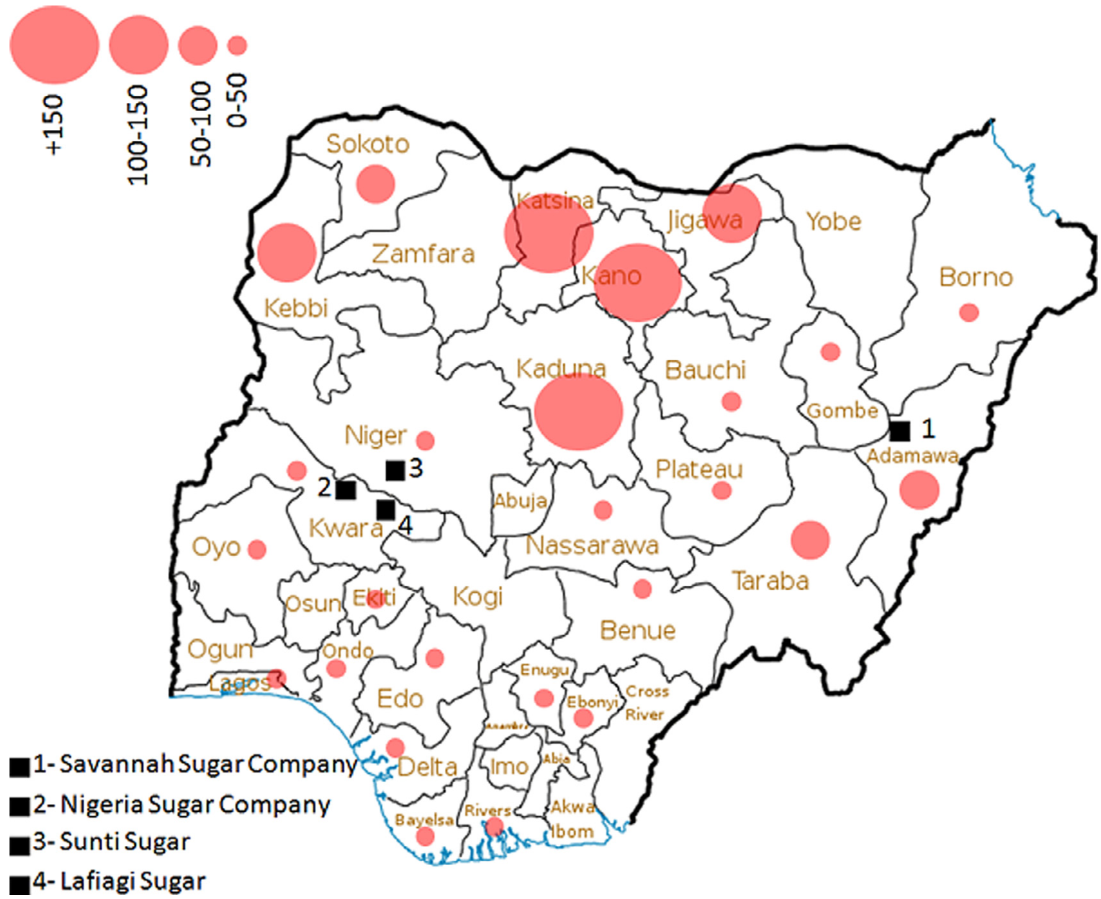

Fig. 7. Sugar production per state in Nigeria and the localization of major mill (USDA, 2010; Gourichon, 2013).

and industrial waste will go a long way solving this problem. Wastes generated in the rural and urban area can be used as feedstock for biofuel production in Nigeria. This may be solid municipal wastes with millions of tons of these disposed off in landfill dumps; about 25 million tons of municipal wastes are generated annually in Nigeria according (Sokan-Adeaga and Ana, 2015). High tons of waste are also generated from animal wastes in Nigeria. With the currently growing interest in poultry business in Nigeria, high animal waste generation is inevitable with the hope of converting waste to wealth. Forest residue cannot be left out. This includes wastes generated form wood logging and processing. Some of this are; sawdust, leaves, branches, stumps, etc. The amount of organic waste generated in Nigeria as at 2013 is presented in Fig. 8 as reported by Suberu et al. (2013). This huge organic waste rich in biomass can serve as feedstock for biofuel production. The Nigerian population is high and waste generated on annual basis is high meaning that the waste generated can be processed as feedstock for biofuel.

The Nigerian waste may be domestic, industrial or animal and plant wastes. When domestic, they may be municipal solid waste, which is either biogenic or non-biogenic and it requires different separation techniques. Waste separation is a challenge most especially in the rural areas where there are no adequate waste management facilities to achieve this. This might be an area to look into in order to actualize the use of domestic waste in rural Nigerian community. The industrial waste require a more organized structure to separate the waste, as this may be organic or inorganic waste. Government needs to help local industries in Nigeria in the area of waste management, most especially in disposal management and treatment. Animal and plant waste are mainly organic. Rotten fruits, vegetables, and tubers can serve as

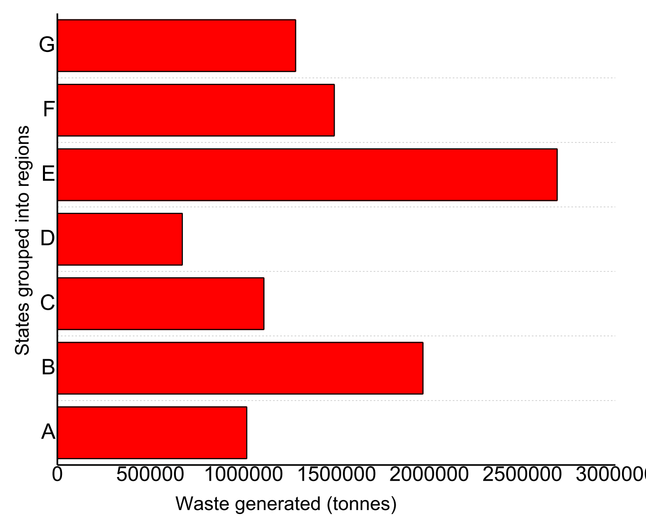

Fig. 8. Waste generation in Nigeria (Suberu et al., 2013).

feedstock for bioethanol instead of being discarded while seeds from some of the fruits can be separated and processed as sources of oil for biodiesel production.

4. Conclusion

The challenges and prospects of using biofuel as a renewable source of energy in Nigeria was discussed. Challenges hampering the development of biofuel as a form of renewable energy in Nigeria includes; land tenure system, high production cost, weak governmental policies and competition between biofuel feedstock and food. Based on the currently existing technology in Nigeria, coupled with available and accessible resources, bioethanol and biodiesel were identified as the most sustainable source of biofuel as renewable energy that can be easily maintained. Cassava, sugarcane, plant seed and waste materials are viable biomass resources identified as feedstocks for the production of bioethanol and biodiesel in Nigeria. With the current rising demand for cleaner energy, Nigeria needs to diversify to biofuel as alternative to fossil fuel and at the same time maximizing her biomass resources for socio-economic growth. Nigeria needs to pay more attention to its waste management strategy, which has the potential to generate sufficient energy to drive the economy and serve as means of employment. It is also high time for Nigeria to develop its own technology to run biofuel generation from its currently developed cassava and sugarcane industry. It might be necessary to create more awareness on the importance of biofuel as well as encourage and create suitable business environment for local and international investors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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