Case study
Residues to Energy: A Study on Improving the Renewable Energy Mix in Nigeria

ABSTRACT

The quest for the reduction of global warming which is largely associated with Carbon IV Oxide emission and the reduction of the dependency on fossil fuels for energy generation is a continuous task. Biofuels are coming in to fill the gap with the potential of reduced emissions and being renewable. While biofuels feedstock at times can compete with food cultivation for land and water, some feedstock is just allowed to rot away as wastes and some of such in Nigeria are Mango seeds, African Star Apple seeds, Orange peel and African Pear. This result in environmental pollution and economic loss. The current fraction of renewable energy in Nigeria annual energy production is negligible, and its fraction in the consumed energy is about 3%. This narrative can change with the exploration of her vast agricultural residues. This study seeks to explore some agricultural residues in Nigeria and waste oil, determine their suitability in the generation of energy when converted to biodiesel, and the conversion of biodiesel residue to energy resources. The enormous amount of agricultural residues in Nigeria can be put into use in the generation of biodiesel with comparable favourable characteristics with petroleum diesel and biodiesel wastes also into useful energy sources resulting in a cleaner environment and revenue generation. It is projected that the percentage contribution of renewables to produced energy will be 19% and 47% for her energy consumption.

Keywords: Biodiesel, Crude glycerol, Emission, Petroleum diesel, Residue

1. INTRODUCTION

Biofuel production has been on the increase in recent times due to the dwindling reserves of fossil fuels, and importantly to aid the reduction of the emission of CO_2, a greenhouse gas [1] which is believed to be responsible for global warming and by extension climate change [1,2,3,4,5]. Biofuels are renewable energy sources produced through biological processes through anaerobic digestion of agricultural materials generally referred to as biomass and are classed under first, second, and third generations [6]. The advancement of knowledge has made it possible to convert agricultural residues to biofuels [7]. Available data shows that 16% of the total fuel requirement for road transport for the year 2030 can be met if the European union member countries' agricultural residue and wastes can be converted to biofuels, and a reduction of about 60% in greenhouse gas emission can be achieved [8], while by the year 2050, biofuels are projected to cater for 30% of the global energy requirement [9].

The average annual total production and consumption of energy in Nigeria in the year 2017 are 5.9 quadrillion BTU and 1.5 quadrillion BTU [10], and in the year 2019, the figures are 6 quadrillion BTU and 1.7 quadrillion BTU [11] respectively. The country's total energy consumption per capita stands at 0.8 toe. It will not be out of place to project the consumption for the year 2021 at about 1.9 quadrillion BTU. The percentage contribution of

Renewables/Nuclear energy of the country total consumption stands at about 3.3 % [10-11]. This is as illustrated in Fig. 1.

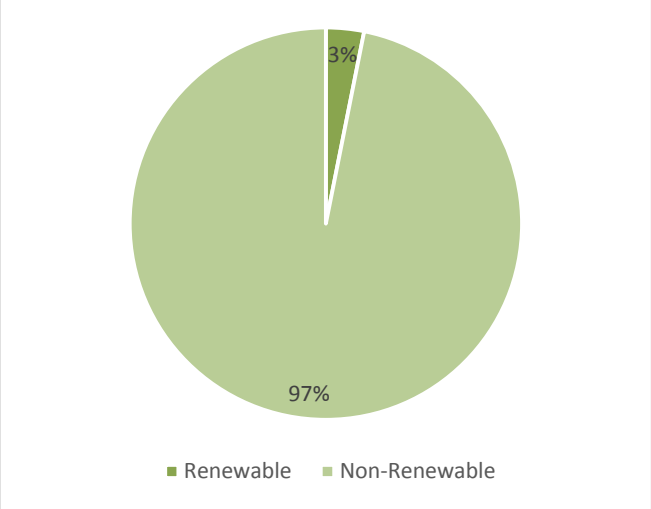

Fig. 1. Energy Source by Consumption Distribution in Nigeria

It is also imperative to note that the percentage contribution of fossil fuels to the total energy consumption is slightly increasing, hence, a need to reverse the trend with a shift to biofuels to trim back on this and force a reduction of her greenhouse gas emissions which stood at about 104.27 $MtCO_2e$ in 2018 [12]. Nigeria intends to grow her renewable energy mix of the total consumption to about 10 % from the current average of about 3 % by the year 2025.

Biodiesels are a type of biofuels similar to conventional diesel produced by the process of transesterification of oils [13,14,15] and are currently enjoying increased usage in compression ignition internal combustion engines [3,16,17]. Biodiesels are classified as first-generation biofuels, which compete for land and water with food production. Presently, Nigeria is not into the commercial production and consumption of biodiesel, as the only African nations that currently does are Togo, Niger, and Ghana [18]. However, this narrative has to change as many nations are producing and consuming this renewable energy source to check climate change and reduce dependency on fossil fuels.
In order to make the production of biodiesel more economical in comparison to conventional diesel, it is necessary to critically look at its feedstock which contributes significantly to its production cost [19-20] and proffer cheaper alternatives which will compete for less with food production, land and water. The use of agricultural residue offers a leeway out of this impasse, and studies are now being conducted by scholars along this area. This study seeks to explore some common agricultural residues in Nigeria and waste oil, review literature concerning the production of biodiesel from them and estimate its potential energy contribution. Also, the subsequent use of biodiesel residues for further economic purpose, and prevention of environmental pollution.

2. BIODIESEL FROM SOME AGRICULTURAL RESIDUES

A suitable and economical means of the production of biodiesels for use in energy generation that will not be in competition with food production lies with the use of agricultural residues. While the production of biodiesel from specific cultivated crops will compete for land and water with food and cash crops, production from agricultural residues will not and

also lead to the reduction of environmental pollution through there improper disposal. Some common agricultural residues in Nigeria which remains untapped but with huge potential for use in the production of biodiesel are Mango seed, African star apple seed, Orange peel, and Pear seed. Properties like calorific value, flash point, viscosity, and density of the agro-residue biodiesels were compared with that of petroleum diesel.

2.1 MANGO SEED OIL

Mango is a fruit which is very popular in the southwestern part of Nigeria, and in other climes. It is a seasonal fruit in this part of the world, and during its season, several tonnes of it is wasted and allowed to rot away, asides the huge tonnes of its seedlings that get rotten away after the consumption of the edible portion. These agricultural residues which are being allowed to waste is a huge feedstock for biodiesel production as several studies carried out by researchers is an attestation to this. The average annual production of Mangoes in Nigeria stands at about 900,000 metric tonnes with only a small portion of exports as more than 70% of it are wasted [22] due to non-processing. The average fraction of Mango seed weight of the fruit can be put at about 9% [23] and, thus, the available feedstock for biodiesel production from Mango in Nigeria can be put at 81,000 metric tonnes. The estimated yield of biodiesel from mango seeds can be (40-50) % by weight of the feedstock [24].

The properties of the produced biodiesel from Mango seed oil have comparable properties like to that of petroleum diesel [21,25-28]. The biodiesel yield from Mango seed oil increases with increase in temperature [29], this could be as high as 98.58% at 200^0C [25]. The performance of compression ignition engines can be optimized when used as a blend with petroleum diesel [25-26], with a blend ratio of between 20-25% giving the best results [25,26,30]. The Free Fatty Acid (FFA) content of Mango seed oil however, necessitates for more than a step esterification process to allow for its reduction [27].

2.2 AFRICAN STAR APPLE SEED OIL

African Star Apple popular referred to as “Agbalumo” in the southwestern part of Nigeria and as Udara or Agwaluma at some other parts is also a seasonal fruit which comes in abundance at its due season. The absence of the necessary storage and processing facilities leads to its wastage. After the consumption of the fruit, there is always a residue which is the seeds. The seeds have been researched upon by several scholars and their findings show the possibility of an oil extraction [31-33]. The African Star Apple seed oil has the potential of been processed to biodiesel by transesterification with properties similar to petroleum diesel [31,34], and yields of about 16.8 % have been reported with the use of an appropriate catalyst [31]. It is a viable alternative fuel to petroleum diesel in compression ignition engines.

However, the popularity of the African Apple in many parts of the country has not sadly led to germane interest of quantifying its annual production. The interest has been along the line of its nutritional, medicinal, and industrial values. This study will thus, not quantify the expected amount of biodiesel that can be gotten from its residues. The relative low biodiesel yield from the seeds is a reflection of its reduced viability for use as a biofuel.

2.3 ORANGE PEEL OIL

Hitherto Orange peels have been considered as a waste, however, with the push for alternative fuel, research has shown that Orange peels can be used to create wealth by its conversion to biodiesel with comparable properties to petroleum diesel [35-36]. Using the Orange peel biodiesel as a pilot fuel in compression ignition engines improves the emission

and performance characteristics of the engine [37], and when mixed with water in appropriate ratios also results to performance and emission characteristics improvement [38]. The seeds of the Citrus family; Orange, Tangerine, Lemon etc. have also been proven to be a feedstock for biodiesel production [31]. Citrus production in Nigeria stood at 4.16 million tonnes in the year 2019 [39].
Orange peels weigh about 35% of the total fruit weight, an indication of about 1.46 million tonnes of feedstock availability in the country. Studies have shown that Nigerian orange peels yield of biodiesel is about 28 ml per 4.5 kg of feedstock [36]. Conversion of the entire feedstock to biodiesel will give about 7,500 metric tonnes of biodiesel production.

2.4 PEAR (DACRYODES EDULIS) SEED OIL

Another potential agricultural residue for biodiesel production is the seed of the African pear. The seed of the fruit is usually discarded as waste, however, relying on studies conducted on the viability of using it as a feedstock for biodiesel production is a wakeup call to think otherwise [40-41]. The African pear seed oil biodiesel has comparable properties with petroleum diesel [40] making it an alternative fuel for use in compression ignition engines, and the pretreatment of the extracted oil helps in improving its biodiesel yields.
Data on the annual production of African pear in Nigeria is limited, however, it is documented that Nigeria and Cameroon accounts for about 70% of its global production [42]. Annual production values of the fruit for Cameroon is also as scarce as it is for Nigeria. Anuual commercial figures of 11,000 metric tonnes was quoted for Cameroon in the year 1999 [43] in literature, and on this basis, an estimate is being made for its figures in Nigeria. To be modest, it is assumed that Nigeria contributes 30% of the 70% of the duo contributions of the global production indicating a conservative estimate value of 8,250 metric tonnes.
The seed weight of an African pear can be up to 31% of its total weight [44], based on the estimated production figures, about 2,500 metric tonnes of feedstock is available annually for its biodiesel production. Studies have shown a 29% oil yield by weight from African pear and a 67% biodiesel yield from the oil [41].

3. PROJECTED RENEWABLE ENERGY GENERATION FROM AGRICULTURAL RESIDUES

The estimated amount of biodiesel which the country can tap-in by exploring the potentials inherent in the considered agricultural residues is presented in Table 1, and the change which her energy mix will witness in terms of annual production is presented in Figure 2.

Table 1. Estimated Biodiesel Yields from the Considered Agricultural Residues

Feedstock	Available Quantity (Mt)	Expected Biodiesel (Mt)	Expected Energy (quadrillion BTU)
Mango Seeds	900,000	32,400	1.188
Orange Peel	4,160,000	7,500	0.246
African Pear	8,250	500	0.016

The expected energy from the agro-residues is obtained from their characteristics heating values which from the considered literatures averages to 34 MJ/kg for Mango seed oil biodiesel, 52 MJ/kg for African star apple seed oil biodiesel, and 24 MJ/kg for orange peel oil biodiesel.

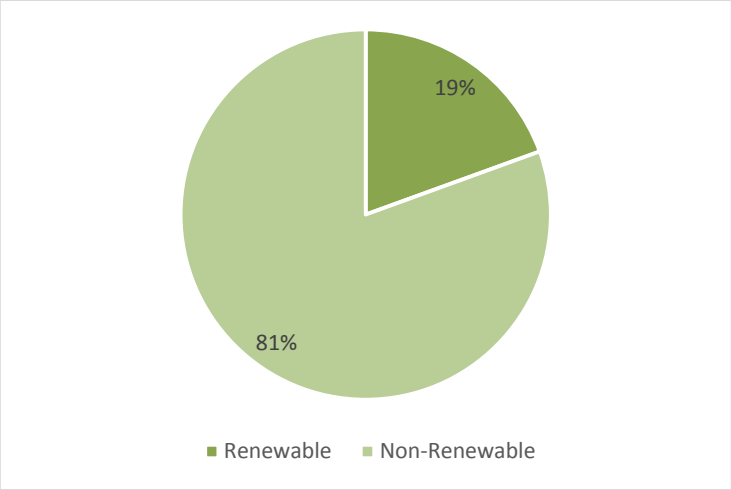

Fig. 2. Projected Energy Source by Production Distribution in Nigeria

The local consumption of the projected energy from these biodiesels will definitely help in improving the per-capita-energy consumption in Nigeria, and also make her more green. The projected energy mix by consumption based on the local consumption of the produced biodiesels is as shown in Figure 3.

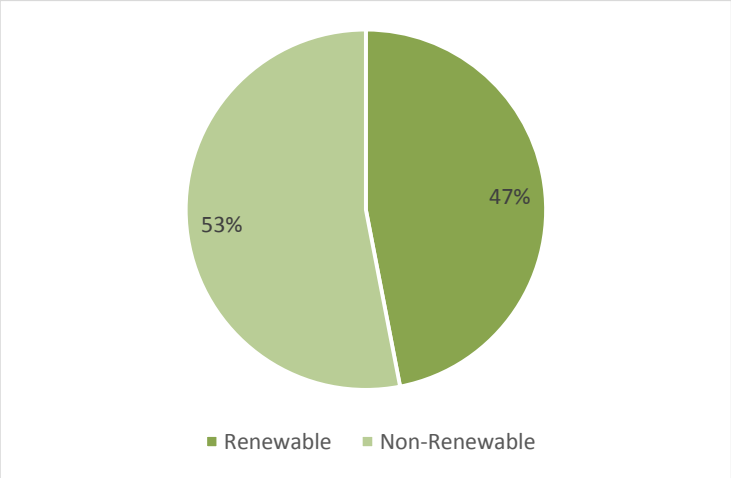

Fig. 3. Projected Energy Source by Consumption Distribution in Nigeria

4. BIODIESELS FROM USED/WASTE OILS

Used/Waste oils are a potential feedstock for biodiesel production [45], and are now increasingly being produced from it, as evidenced from studies conducted by some researchers [46-47]. The produced biodiesels have comparable properties to that of conventional diesel and better emission characteristics [48-49], even as animal fat wastes showed great potential for biodiesel production [50-51]. The risk of having these waste oil to add to environmental degradation can be avoided by the conversion to biodiesel. Waste cooking oils are usually pretreated because of the changes in its chemical composition occasioned by the high temperature during use leading to an increased amount of FFA

which reduces the content of Fatty Acid Methyl Ester (FAME) in the biodiesel [19,52]. Biodiesel with FAME content of about 94% has been produced from waste cooking oil by pretreatment and subsequent transesterification in the presence of catalyst [51]. The energy requirement for the two-way production process of biodiesel from used/waste oil can also be minimized with the use of microwave heating as against the use of conventional heating methods [20]. Second-used cooking oil has been converted to biodiesel by scholars and it was reported that such had an optimum ester content of 92.76% [53].

5. USE OF BIODIESEL RESIDUE

Large quantity production of biodiesel leads to the production of a large number of residues [54-57], these residues can, however, be used to generate bio-products and energy [15-16,55]. Significant among biodiesel production residues are wastewater, crude glycerol, methanol, and solid end-products such as seed cakes [4,56]. Conversion of these residues will in no small way to help in the provision of a healthy environment, and also, serves as a boost to the economy. The direct disposal of the residues will pose environmental issues. The purification of crude glycerol to the form which can be utilized by the pharmaceutical industries is very expensive [57], and at present, it is been utilized for bio-products production and wastewater applications [58].

Some of the bio-products include bio-methane, bio-ethanol, bio-hydrogen, and bio-butanol among others. The crude glycerol has the potential of improving methane yields either with or without the use of acidic and alkali catalysts [59], can act as an enzyme for ethanol fermentation [60], conversion to hydrogen with the aid of suitable catalyst using different production methods [61-62]. Crude glycerol from biodiesel production has been effectively used to produce polyol and castor oil glycerides [15] and as blends with glycerol in its pure form for the production of polyurethane foams (PUF) [63]. This has led to less dependence on petroleum products in the plastic industries. Studies on the microbial transformation of the crude glycerol have also established it as a source for the production of many essential needs like animal feeds [64], biomass [65], and ethanol [66] among a host of others.

Crude glycerol is also employed for the generation of renewable energy with the utilization of thermochemical and biological processes [15].

The methanol in the biodiesel residue is removed using distillation methods [56], and can be used subsequently for biodiesel production and for other purposes.

The solid residue from biodiesel production has also shown the potential of being economical from the findings of studies conducted by researchers. Granular activated carbon has been prepared using microwave activation from oil palm biodiesel residue [67], absorbents has been generated from Raphanus sativus L. press cake from biodiesel production [68], Jatropha and cotton seed cake for hydrogen production [69-70], and many others as animal feeds [57].

It is estimated that for every litre of biodiesel that is produced, about 1.2 litres of wastewater will be generated [71-72], this is huge, considering the fact that millions of litres of biodiesel are required on a daily basis for energy generation in compression ignition engines. The wastewater has grease and oil portions and is alkaline in nature, requiring treatment before disposal so as not to cause environmental harm [72-73]. Several processes are now being employed for the treatment of the wastewater to remove the grease and oil, and the reduction of the alkaline nature such that the water can be released back to the environment and used for other activities [15].

4. CONCLUSION

The enormous amount of agricultural residues in Nigeria can be put into use in the generation of energy resource.
Biodiesels have comparable favourable properties like heating values, viscosity, flame point, and density with petroleum diesel. This was the basis of comparison used in this studies based on results outlined in literature.
The percentage mix of renewables in the annual produced energy in Nigeria was projected to change to 19% and that of the annual consumption to 47% form a little above 3% at which it currently stands.
Likewise, waste oil and the residue left after their use for biodiesel production can be further converted into several energy sources. This will result in a reduced negative impact of biodiesel production on the environment as against to what would have being with the outright disposal.
An economical boost and a cleaner environment will be achieved with the adoption of the outlines of this study.

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