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Biofuels Adoption in Nigeria

Analysis of Sustainability and Policy Issues

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Julkaisun nimike

Biopolttoaineiden tuotanto ja käyttöönotto Nigeriassa: analyysi kestävän kehityksen ja politiikan näkökulmista

Tiivistelmä

Nigeria lisää muun maailman vanavedessä biopolttoaineiden käyttöä ja tuotantoa. Tämä väitöskirja tarkastelee biopolttoaineiden käyttöönottoa koskevia poliittisia ja kestävän kehityksen kysymyksiä Nigeriassa. Tutkimus muodostuu viidestä aihepiirin keskeisiin kysymyksiin keskittyvästä artikkelista. Biopolttoaineiden tuotannon kehittäminen on Nigeriassa yhä alkuvaiheessa. Tämä tutkimus selvittää siksi muun muassa seuraavia kysymyksiä: i) maan kykyä tuottaa biopolttoaineiden raaka-aineena käytettäviä kasveja; ii) ihmisravinnon- ja rehutuotannon sekä muiden maataloustavoitteiden tasapainoa; iii) raakaöljypohjaisten tuotteiden käyttötarvearviota, joka muodostaa perustan biopolttoaineiden käytön edistämiselle, sekä iv) maan- ja vedenkäytön ”jalanjälkeä” koskevaa arviota, jota tarvitaan maan biopolttoainepolitiikan ja -kannusteiden suunnittelun tueksi.

Biopolttoaineiden kehittäminen on Nigeriassa toisessa vaiheessa, jossa luodaan perusta paikallisen tuotannon lisäykselle. Kun biopolttoaineiden valmistus pääsee vauhtiin toden teolla, maalla on hallussaan kaksi keskeistä energiantuotannon tekijää: rikkaat raakaöljyvarat ja biopolttoaineteollisuus. Pyrkimys lisätä yhdessä muiden maiden kanssa biopolttoaineiden käyttöä on Nigerian energia- ja talouspolitiikan keskeinen tavoite. Biopolttoaineiden edistäminen perustuu maan kykyyn yhdistää paikallinen tuotanto, tarvittavien voimavarojen saatavuus ja ympäristönsuojelu.

Väitöskirjan osa-artikkelit selvittävät Nigerian kykyä tuottaa biopolttoaineita. Tätä tuotantokykyä määrittävät keskeiset kriteerit ovat 1) veden saatavuus, 2) viljelysmaan määrä ja 3) ruokaturvallisuustilanne. Näiden kriteerien täyttyminen on ehto sille, että biopolttoaineiden tuotanto ei vahingoita ravinnon saatavuutta tai kansalaisten muita olennaisia tarpeita. Onko Nigerian polttoainepolitiikka jättänyt huomiotta kansalaiset pyrkiessään tekemään maasta keskeisen biopolttoaineiden tuottajan? Tähän ja muihin tärkeisiin kysymyksiin vastaavat tutkimusartikkelit käsittelevät yllä mainittujen kriteerien täyttymistä sekä biopolttoaineiden kehittämistä koskevia aloitteita ja mahdollistajia. Väitöskirja auttaa ymmärtämään syvällisemmin biopolttoaineiden kehittämisen, tuotannon ja käyttöönoton edellytysten, tavoitteiden ja osapuolten kokonaisuutta.

Asiasanat

biopolttoaineet, kestävä kehitys, raakaöljytuotteet, energiapolitiikkaa, kannustimet, kasvintuotanto, tuottavuus, Nigeria

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Abstract
Nigeria has joined the rest of the world in adopting biofuels. This doctoral thesis explores issues of policy and sustainability of biofuels adoption in Nigeria. The thesis is based on the compilation of five articles, which focus on the most important issues of the subject matter. Though biofuels development in Nigeria is still at the early stages, this study explores the following issues among others: the capacity for producing the feedstock used as raw materials for biofuels, the drivers engendering the biofuels adoption in Nigeria, the path to attain equilibrium in food, feed and other agricultural objectives, the estimation of petroleum products consumption as a foundation for promoting biofuels and the assessment of the land and water footprints for meeting the targets set forth under the Nigerian biofuels policy and incentives.

Biofuels development in Nigeria is in the second phase, in which the foundation for boosting local biofuels production is laid. With the country's entry into the global biofuels circle, it will be holding two key energy batons, one as a crude oil rich nation and another as a biofuels producing country. The aims of joining other nations in promoting biofuels production and adoption includes among other deriving environmental, economic and social benefits. The promotion of biofuels must be premised on the capacity for absorbing locally produced fuels, the availability of the required resources and favorable environment for local production.

The five papers explore in some detail the capacity for biofuels production, including the availability of the three criteria for qualifying as potential biofuels country: availability of water, arable land, and food security situation that will guarantee that fuel production does not sabotage the availability of food and other essential needs. Has the Nigerian biofuels policy overlooked key stakeholders in the quest to make the country a major biofuels producer? The paper on synthesis of the drivers, incentives and enablers promoting biofuels development helps to answer this and other questions. It also helps to understand deeper the connection between drivers, goals and stakeholders.

Keywords
Biofuels, sustainability, feedstock, petroleum products, policy, incentives, crop production, productivity, Nigeria

The Long Finnish Winter

My greatest marvel since encountering Finland
How things work as much as perfect
Despite the harsh long Finnish Winter
Plowing your entire roads and walk ways on nearly daily basis
Supplying ample grits to keep people and vehicles from skidding and falling for five months
This is no mean feat!

It gets more celestial when you think of how the airports operates
And in the harshest of winters that even so called biggest economies cannot pull
Many other airlines have disappointed me in time past
Even in the mildest of dropping snow
But not FinnAir!

And my best parts of the Finnish winter experience
Bathing the plane just before takeoff and
My rapturous ride to and from school
Cycling in the snow!

nelson abila – The Long Finnish Winter 2013.

This thesis is dedicated to my Goddess – St Stella, Finland and to my mothers who believe in the possibilities of my dreams.

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The inspiration for pursuing this doctoral research on biofuels came from my involvement in assessing the availability of alternative energy sources for Larfage WAPCo Company of Nigeria, while consulting for Winrock International. I have Winrock International and my colleague on the project – Ian Monroe to thank for stimulating the interest on renewable energy. The GIS skills picked up on that assignment were useful during the course of the PhD.

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Nelson Abila

Vaasa, 2014.

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Abbreviations and Acronyms

AGCons	Aggregate consumption of petroleum products
GDP	Gross domestic product
ConsP	Consumption of motor gasoline (Petro)
ConsK	Consumption of kerosene
ConsD	Consumption of distillate (Diesel)
ConsL	Consumption of liquid petroleum gas
LPG	Liquid Petroleum Gas
ConsOpp	Consumption of other petroleum products
ConsRoil	Consumption of residual oils
Popn	Population
Elegen	Electricity generation
Elinscap	Electricity installed capacity
NNPC	Nigerian National Petroleum Corporation
ML	Million Litres
GHG	Green House Gases
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
OLS	Ordinary Least Square
UNFCCC	The United Nations Framework Convention on Climate Change
CBD	The Convention on Biological Diversity
RAMSAR	The Ramsar Convention
ECOWAS	Economic Community Of West African States
R&D	Research and Development

List of Publications

[1] Abila, Nelson (2010). Biofuels Adoption in Nigeria: A Preliminary Review of Feedstock and Fuel Production Potentials. *Management of Environmental Quality: An International Journal.* Vol. 21 No. 6 pp. 785–795

[2] Abila, Nelson (2012). Biofuels development and adoption in Nigeria: Synthesis of drivers, incentives and enablers. *Energy Policy*, Vol 43, pp 387–395

[3] Abila, Nelson (2014). Biofuels Adoption in Nigeria: Attaining a Balance in the Food, Fuel, Feed and Fiber Objectives. *Renewable and Sustainable Energy Review*. Vol 35, pp 347–355

[4] Abila, Nelson (2015). Econometric estimation of the petroleum products consumption in Nigeria: Assessing the premise for biofuels adoption. *Renewable Energy*. Vol 74, pp 884–892

[5] Abila, Nelson (2014). Assessing land and water requirements for meeting biofuels targets for Nigeria. Paper accepted for presentation at the World Renewable Energy Congress 2014, 3 - 8 August 2014, London, United Kingdom.

1 INTRODUCTION

1.1 Background

Biofuels are increasingly making inroads into the energy sector, and the demand for them as alternatives to petroleum fuels is increasing. Around the world various countries and regions have put in place policies to promote the adoption and utilization of biofuels (Sorda et al. 2010; Smith, et al. 2013; Kumar, et al. 2013; Rajagopal and Plevin 2013; Kaup and Selbmann 2013). The surge in the promotion, adoption, development and utilization of biofuels has been ascribed to concerns over the diminishing supplies, energy security and negative health impacts resulting from the use of fossil fuel, among others (Schut et al. 2010; Mintz-Habib 2013; Abila 2012; Hammond et al. 2008; Doku and Di Falco 2012). This surge of interest in biofuels in both the producing and consuming economies (either in developed or developing world) is also linked with the increasing cost of petroleum products as well as the concern to save the environment by reversing the carbon emission associated with the use of petroleum products. With this increasing interest in biofuels as viable alternatives, and the need to solve problems associated with fossil fuels, energy concerns are taking central stage in the global development agenda. This trend culminated in the emergence of a global and regional bioenergy policy, along with support in the form of subsidies, mandates and investments (Keam and McCormick 2008).

Though Nigeria is a major exporter of crude oil globally, with huge revenues accruing from oil sales and exploration licenses and royalties, the country faces many challenges including: instability in supply and prices of the petroleum products with recurrent acute shortages; land degradation, environmental damage, air pollution and loss of biodiversity resulting from oil exploitation and utilization; serial community conflicts and union disputes, increased poverty and loss of livelihoods in the oil rich Niger Delta; food crises and food insecurity; the lack of basic infrastructure; and the collapse of the real sector. One of the articles highlights some of the key drivers that form the base for biofuels adoption in Nigeria (Abila 2012).

Apart from its huge (though declining) petroleum production capacity, Nigeria also has a very high potential for bioenergy production. An initial assessment of the feedstock availability for biofuels production in Nigeria was conducted, concluding that the country has the potential to be a major biofuels-producing country (Abila 2010). Iye and Bilsborrow (2013a, 2013b) explored alternative sources (such as agricultural residues, which are usually burnt on the farm) as other abundant sources of feedstock for biofuels (cellulosic ethanol) production in Nigeria. Other authors have also explored various other feedstock for biofuels production in Nigeria (Nyachaka, et al. 2013; Jekayinfa and Scholz 2013; Samuel et al. 2013).

It is generally acknowledge that harnessing this bioenergy potential will provide a premise for solving the various problems related to petroleum fuels highlighted above, while facilitating the development of other real sectors of the economy and enhancing socio-economic development. In 2007 the Nigerian Federal Government put in place a biofuels policy and incentives, which was aimed at stimulating biofuels adoption and development in the country. The Nigerian biofuels policy also falls in line with other countries' policies in terms of the lofty goals it sets forth. The Nigerian biofuels policy was put in place to ensure reduction in the import of refined products, as the country, for some years, has been relying largely on import for the local consumption of refined petroleum products. The policy also aims to help conserve the Nigerian crude oil reserves, improve the agricultural and allied sectors, create a biofuels economy, and stimulate overall economic growth (Farinelli et al. 2009; Ohimain 2013; NNPC 2007). The implementation of the biofuels policy, which was at the onset streamlined into two phases, has been going on for some years now. Some authors have attempted to assess how far the implementation has fared so far, but the verdicts are not too encouraging (Ishola et al. 2013; Ohimain 2013).

With Nigeria embracing biofuels utilization, this doctoral study was embarked upon to assess the various issues relating to the sustainability of the adoption of biofuels in Nigeria. The study examines the potential for biofuels production in Nigeria and explores the possibilities for reducing the nation's carbon footprint, as well as reducing the huge fossil fuels subsidy budget. Considering the instability and unpredictability of the international oil and gas market, Nigeria needs to diversify revenue sources while ensuring access to sustainable energy sources for rural and peri-urban households. A large proportion of the population still relies on the primary energy sources (such as wood fuel) for cooking, lighting, and other needs. Moreover, the low level of electricity generation in the country means that majority of households as well as small- and medium-scale enterprises are not being served by the declining energy supply from the national grid. Biofuels in fossil blends can help save costs and the environment. Many households and businesses had to resort to self-generation of electricity through the use of the ubiquitous generators; their costs for independent power generation have been reported to be very burdensome.

As the Nigeria biofuel programme is still at the early stage, it is hoped that the compilation of papers for this doctoral study will be useful for improving existing biofuels policy as well as for developing other specific policies for mainstreaming biofuels into the energy sector. Figure 1 shows the biofuels adoption and development framework, and the aspects that are crucial for ensuring sustainability.

1.2 Conceptual Framework of biofuels development and adoption in Nigeria

Biofuel sustainability entails a wide array of concerns. Key among them includes availability of feedstock production without encumbering the production of equally important products such as food (von Braun, 2007; Abila, 2014a). Other issues relate to environmental sustainability, particularly the capacity to serve as carbon sink or sequestration (Gu et al., 2012), supply chain sustainability (Mata, 2013), interconnection between social, economic and environmental indicators (Florin, 2014), issues of trade off between welfare and food security (Ewing and Msangi, 2009). The list seems endless on the wide array of issues to consider in assessing the sustainability of biofuels.

While, many approaches such as life cycle assessment (Hertwich, 2005), factor modelling, footprints analysis (Gerbens-Leenes et al., 2012), systems approach (Mangoyana et al., 2013) among other methods have been deployed in assessing the sustainability of specific biofuels and targeting specific indicators of sustainability for biofuels developments in countries and locations which already attained marked progress, this study lays the crucial foundation for the assessment of biofuels sustainability in Nigeria. The essential foundation is needed to help give form to the problems, identify and synthesis parts and their linkages. Laying the necessary foundation requires developing conceptual framework. According to Plummer and FitzGibbon (2004), "conceptual frameworks enable logical structuring of problems structuring of problems, parts identification and translation of abstract theory into specific variables and aspects that can be practically examined".

As the Nigeria biofuel programme is still at the early stage, it is hoped that the compilations of papers which are the outcome of the doctoral study will be useful for improving existing biofuels policy as well as developing other specific policies for mainstreaming biofuels into the energy sector. Figure 1 shows the conceptual framework of biofuels adoption and development in Nigeria. It detailed aspects that are crucial for ensuring biofuel sustainability. This figure from Abila (2012) is a product of literature review and a synthesis of issues relating to biofuels in Nigeria. The framework shows drivers including the global and regional cooperation and legislations to which Nigeria has signed up to that led to the country push for biofuels adoption. Other drivers are the key energy, environmental and socio-economic concerns which have prompted the country to adopt biofuels as a pathway to addressing the concerns. The figure also listed agents, incentives and enablers, actors, and key objectives Nigeria is pursuing by adopting biofuels in the energy sector.

1.3 Research Questions and Research Objectives

Three key questions formed the premise for this research. Indeed, biofuels sustainability in Nigeria can only be attained through policies that address these questions. The research questions are as follows:

1) To what extent and on what conditions does Nigeria have the capacity for producing adequate feedstock for biofuels production?

This question is fundamental, as the entire biofuels policy goals cannot thrive if Nigeria cannot produce the feedstock for producing ethanol or biodiesel. The capacity for biofuels feedstock production depends in turn on the availability of arable land, water resources and food security situation, as outlined by von Braun (2007).

2) What are the key drivers, including needs, issues, and related concerns that exist in Nigeria that will promote biofuels adoption and development? Why are certain drivers of importance?

The acceptability and adoptability of biofuels in Nigeria can only thrive if there exist drivers creating and stimulating markets for ethanol and biodiesels.

3) What is the historical and existing petroleum products consumption in Nigeria, and how does this form the basis for biofuels adoption and development?

Blending biofuels with petroleum products, for the transport and other sectors, is the basis on which the Nigerian biofuels policy was formulated. It is important to examine the historical trend and the current scenario of petroleum products consumption. It is on the basis of this that projection into the future can be made, as an argument for investment in the biofuels sector.

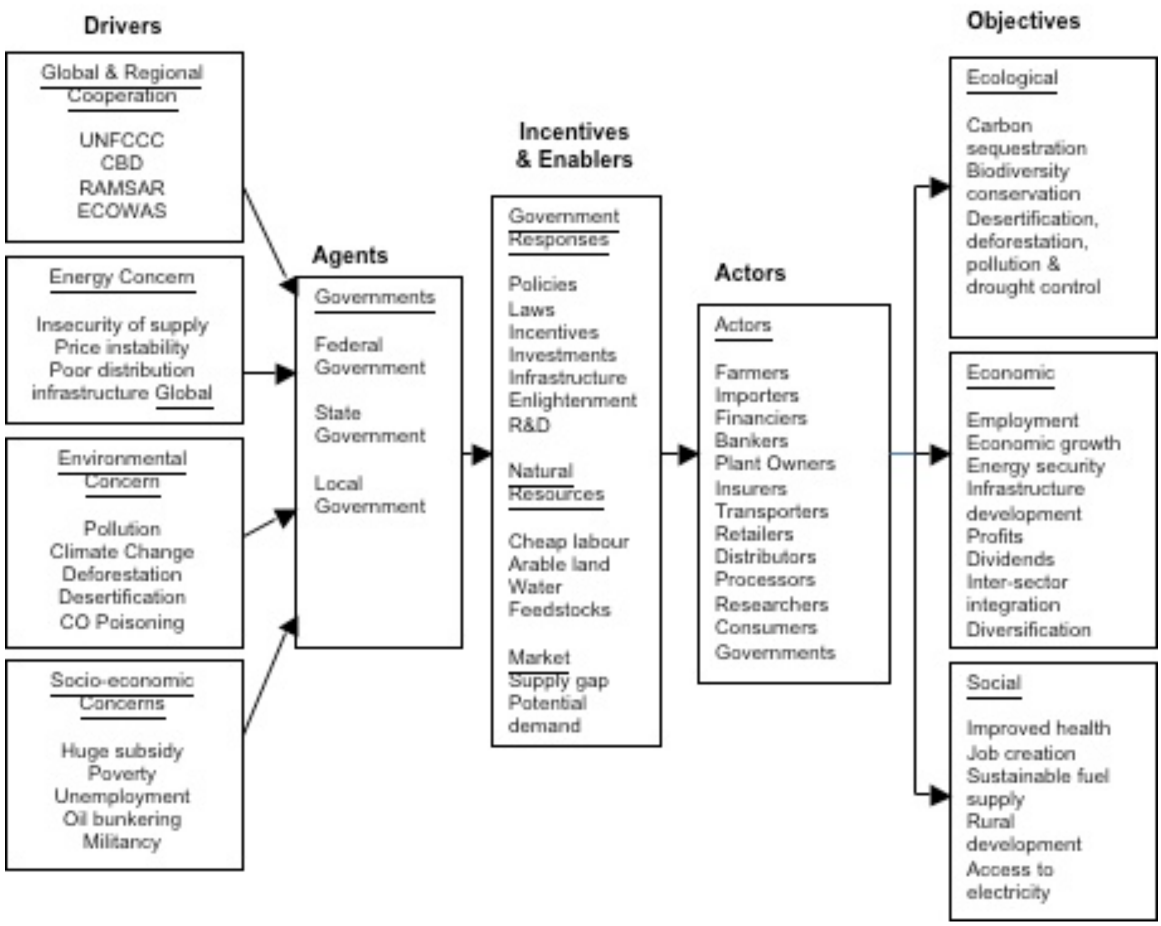

Figure 1. Conceptual Framework of biofuels development and adoption in Nigeria

Source: Abila (2012)

The research questions posed above were developed into the research objectives. In addition, considering the stage of the development of biofuels in Nigeria, the study undertakes four key assessments that are going to be essential in informing policy as Nigeria advances its biofuels development.

The broad objective of the study is to identify and assess major aspects of the sustainability of the adoption of biofuels in Nigeria. Within this framework, the study's specific objectives include to

1. Assess the feedstock and related capacity for biofuels adoption in Nigeria.
2. Synthesize and identify the drivers of biofuels adoption and production in Nigeria.
3. Estimate petroleum consumption and the capacity for biofuels substitutions.
4. Assess the water and land footprints for meeting Nigeria's biofuel targets.

1.4 Research Approach

The theme of this doctoral dissertation falls under the classification of a new and yet to be fully explored field, particularly as far as Nigeria is concerned. Nigeria's foray into biofuels development and promotion is yet at the infancy. Though few literatures already exist looking into biofuels adoption in Nigeria, these merely scratched the surface. This informed the adoption of an exploratory research approach at the start of the research. Shield and Rangarja (2013) explained that exploratory approach is adopted for a scientific inquiry when the ramifications of the problem at hand are not yet fully known. Exploratory research helps to build the bases for understanding fully a problem, help in conceptualizing the issues, in some cases create a synthesis that helps in understanding the link between various parts of a problem and how related they are.

Previous literatures have explored various aspect of biofuels development in Nigeria. Some of these areas include assessment of the enabling biofuels policy, assessment of the potentials for biofuels development, assessment of the roles of government agencies, assessment of the biofuels potentials of various feedstock in the production of ethanol or biodiesel.

This research explore on a wider scope issues relating to the potentials for biofuels production, synthesized issues and factors driving biofuels adoption in Nigeria, conducted preliminary quantitative assessment of drivers of biofuels adoption, conducted both qualitative and quantitative assessment of the capacity for producing biofuels in Nigeria and meeting the biofuels blending targets that have been set forth in Nigeria. On the whole, this research helps to create a conceptual works for better understanding of the biofuels adoption in Nigeria. It also create a link between key issues that are paramount and foundational for sustainability assessment as the biofuels development in Nigeria advances.

To provide answers to the research questions stated above, several research approaches were employed. Biofuels adoption and development in Nigeria is still at the infant state. Understanding the issues of sustainability about biofuels chains in Nigeria – including feedstock production, biofuels production, processing and distribution – requires conducting both qualitative and quantitative analysis. The approaches used for this research are largely foundational; that is, they provide a base for further analysis of the Nigeria biofuels sectors, policy, investment and sustainability. Several authors have started assessing various aspects of the biofuels development in Nigeria (Adeoti 2012; Ishola et al. 2013; Ohimain 2013a, 2013b, 2010). Figure 2 illustrates the combination of quantitative and qualitative approaches used in this study and their purposes.

The study data were sourced from mainly secondary sources, including government agencies' reports (such as the Central Bank reports, National Bureau of Statistics Annual reports, national gazette) as well as other relevant national and international databases (such as the United States Energy Information Administration and International Energy Agency).

For the analyses of data, the study adopted a range of methodologies and tools including: desk review and synthesis, econometric analysis, footprint estimation.

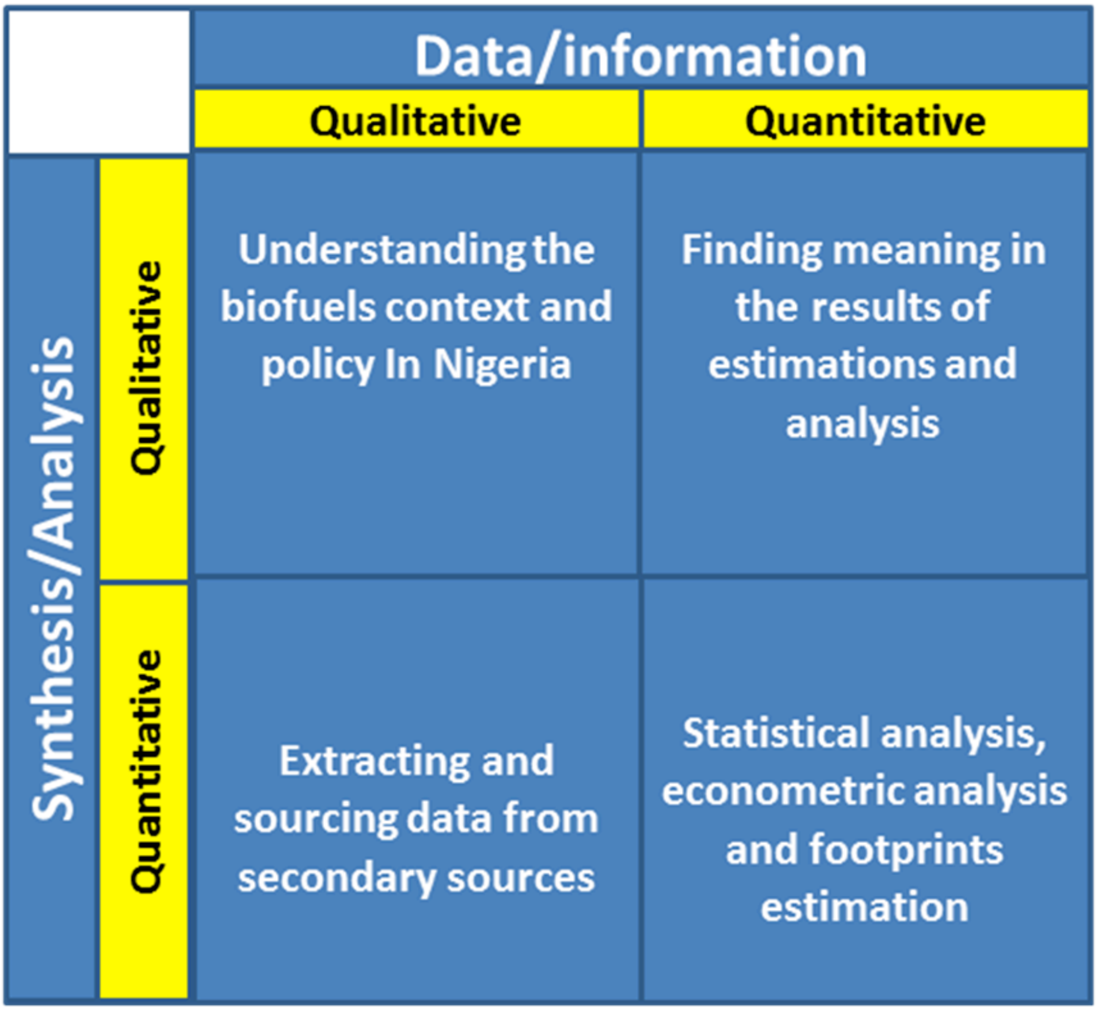

Figure 2. Quadrants of the research approaches and purpose

1.4.1 Desk review and synthesis (Paper 1, Paper 2, Paper 3)

The interpretive research approaches (qualitative), especially the desk review and synthesis of available information, helped to bring into focus the issues and factors relating to biofuels development in Nigeria, including laws, policy, actors, and goals, among other factors. The desk review and synthesis of data in Papers 1, 2, and 3 laid the groundwork for further analysis, including work that is not included in this dissertation. The analyses in these papers are the foundation upon which subsequent papers are based. The review work in paper made a preliminary assessment of the feedstock production in Nigeria which was useful for the paper

5. Paper 2 desk review of drivers is a useful build up to the econometric analysis of paper 4.

1.4.2 Econometric Analysis (Paper 4)

Paper 4 of this dissertation uses econometric analysis, using the OLS estimate to determine the response of aggregate petroleum product consumption to socioeconomic factors such GDP, population, and consumption of the petroleum products that make up the aggregate, as well as electricity generation and installed capacity for electricity generation. The econometric approach involved conducting basic statistical analysis of the variables to be included in further analysis. The paper also conducted correlation analysis to help explain the outcome of the econometrics estimations. The paper first estimated aggregated petroleum product consumption, and then assessed the response to specific petroleum products in terms of consumption, market (population), electricity generation, installed electricity generation capacity, and GDP. The purpose of this method is to help understand the trend and pattern of consumption of petroleum products for which blending targets have been set in Nigeria.

1.4.3 Footprints estimation (Paper 5)

The footprint estimation used for Paper 5 is based on the method developed by Hoekstra and Chapagain (2007). Measuring the water footprint is useful in estimating the volume of freshwater needed for producing a unit of product, in this case one tonne of biofuels crops. In addition to estimating water footprint, the study estimated land footprint required for meeting the biofuels targets for Nigeria for the first and second phases. The land footprint is based on the method used by Yang et al. (2009). Other previous studies have estimated water footprints for biofuels production (Gerbens-Leenes et al. 2008, Yang et al. 2009, Gerbens-Leenes et al. 2012). The composite method used for estimating water and land footprints is necessary for determining whether, under prevailing conditions, Nigeria has the required arable land and water resources for meeting the requirement for producing the target set for biofuels. The estimation also deduced the volume of feedstock required for meeting the set targets.

1.5 Structure of the dissertation

The dissertation has four chapters. Chapter one, the introduction, elucidates the background to biofuels adoption in Nigeria and the research question and research objectives. Chapter two, a form of literature review, explores the concept of biofuels sustainability at the global, regional, and national levels. Chapter three provides the summary of the publications and findings that make this compilation. The last chapter is the conclusion, which provides a synthesis of the outcome of the research, suggests policy implications of the study, and summarizes the research limitations and recommends possible future research studies.

2 BIOFUELS SUSTAINABILITY

2.1 Global and Regional Concerns

The emergence of a new generation of biofuels as an alternative energy source is creating both opportunities and concerns. The availability and sustainability of biofuels and the need to reduce greenhouse gas emission (GHG) make biofuels an important alternative for ensuring global energy security (Sunil et al. 2007). Several studies in different regions of the world have highlighted the regions' potential, suitability, and ecological model for minimizing the negative impact of biofuels adoption. von Braun (2007) highlighted the global distribution of biofuels production capacity and potential premised on the availability of arable land for feedstock production, water availability, and the country's current level of food security.

Nigeria is one of the countries ranked as having very high potential based on the three parameters stated above. Individual countries' assessments of potential and existing capacity for biofuels production are ongoing at different levels, considering energy sources such as jatropha, sweet corn, soybean, and oil palm, among others (FAO 2013). Keam and McCormick (2008) advocated for the application of the Life Cycle Assessment and other approaches for the assessment of the viability and suitability of biofuels in reducing emission and meeting other goals.

Amigun et al. (2011) assessed the biofuels sustainability concerns in Africa through various prisms: food versus fuel, land use and tenure security, climate change and environment, poverty impact, and gender equality. The article concluded that the adoption of practices, processes, and technologies that can improve efficiency and reduce energy and water requirements, alongside biofuels adoption, will be a necessary path to sustainability in Africa. An assessment of biofuels development in Latin America in terms of risks and opportunities similarly sees the environmental and social aspects as crucial for sustainability (Janssen and Rutz 2011).

Many other key issues of biofuels sustainability have been evaluated by various authors. These include impacts on food supply, trade, and the environment in relation to biofuels adoption and production in China (Yang et al. 2009). A global study by Zhang et al. (2010) warns of an increase in price of food products and agricultural commodities, as the demand for biofuels surges.

A more generalized assessment of biofuels sustainability by von Braun (2007) proposed a conceptual framework that identifies the political, economic, and environmental context as vital aspects for assessing biofuels. Figure 3 details the elements of von Braun's conceptual framework for assessing biofuel sustainability. This proposition argued for considering broader perspectives in assessing biofuels' issues, rather than the use of a simple yardstick of trade-offs between food and fuel. von Braun's proposition is hinges on the interaction between the three domains, when agriculture and energy are linked through biofuels.

The sustainability arguments about biofuels relate to environmental, technological, economic, and social concerns. The acceptability of biofuels depends on the following factors: 1) maximizing and stabilizing gains from biofuels adoption; 2) maximizing biofuels outputs per investment in feedstock, and processing and distribution technologies; 3) optimizing natural resources use in the biofuels era; and 4) minimizing environmental, climate, and biodiversity impacts of biofuels (production, distribution, and use).

The general issues crucial for national energy objectives include: 1) energy security; 2) stable supply of fuel; 3) environmental friendliness; 4) economic stability; and 5) GHGs emission reduction. These also have strong links to biofuels adoption and sustainability.

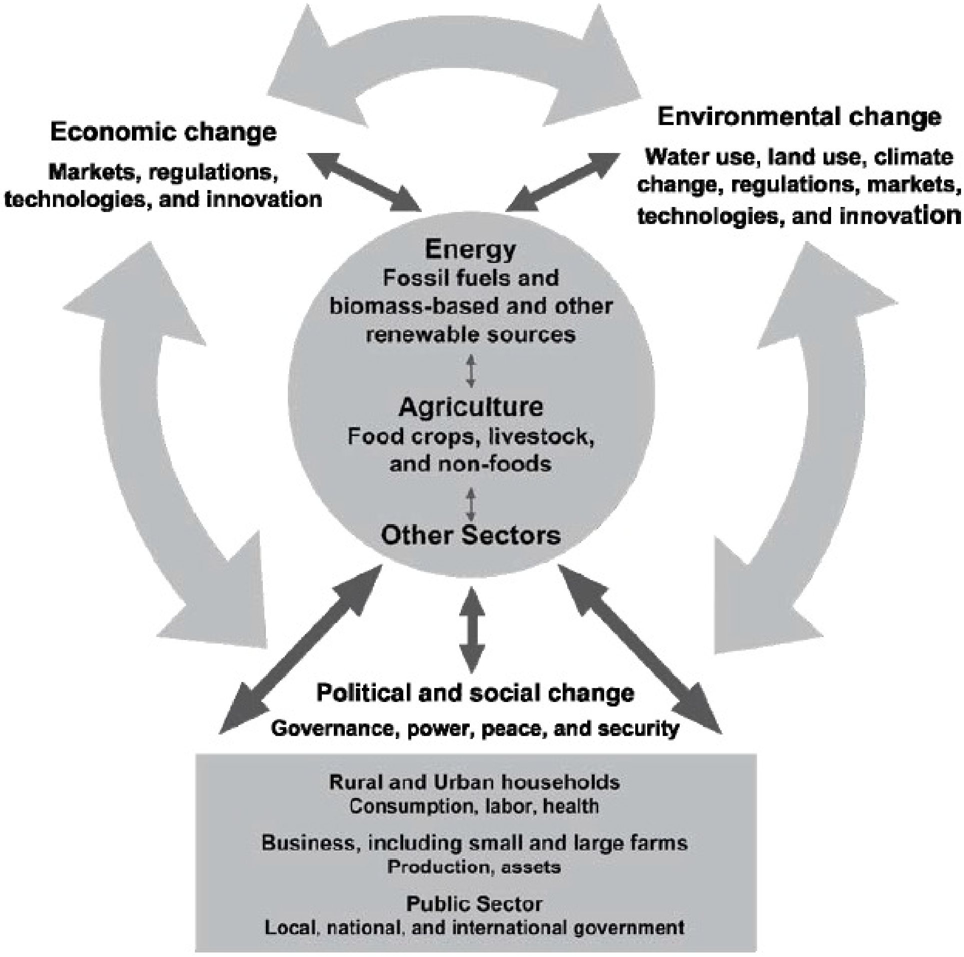

Figure 3. Energy-agricultural linkages within a broader conceptual framework

Source: van Braun 2007.

2.2 Issues for Nigeria

Biofuels sustainability issues in Nigeria are not fundamentally different from the concerns for other countries. The Nigerian biofuels sustainability concern stands on the sustainability tripod of social, environmental, and economic concerns. The social concern has to do with ensuring there are no lopsided social benefits, and that no segment of the society is disenfranchised as the country adopts biofuels. This includes ensuring small-scale farmers are not left out of participation in the benefits of biofuels development, as large corporations take up the sector. Biofuels advancement should be able to guarantee meeting the social objectives set forth in the Nigerian biofuels policy as the drivers promoting biofuels adoption.

The economic concern as highlighted by Abila (2014) is ensuring that the economic growth that will result from the growing biofuels' subsector is stable and efficient. Nigeria's adoption of biofuels should not create economic problems relating to any of the factors of production.

The ecological concern has to do with the broader environment, including the ecosystems and their constituents, and ensuring biodiversity preservation. Biofuels adoption in Nigeria should not lead to deepening deforestation or the loss of any of the fragile ecosystems, particularly the wetlands.

2.3 Sustainability approaches for Nigeria

2.3.1 Integration of objectives

In one of the articles included in this thesis, I propose a conceptual integration pathway for ensuring that there is a linkage between food, fuel, feed, and fibre that allows for by-products of one to be channelled into the production of the other, irrespective of the external inputs being deployed for their production. Figure 4 shows the proposed framework.

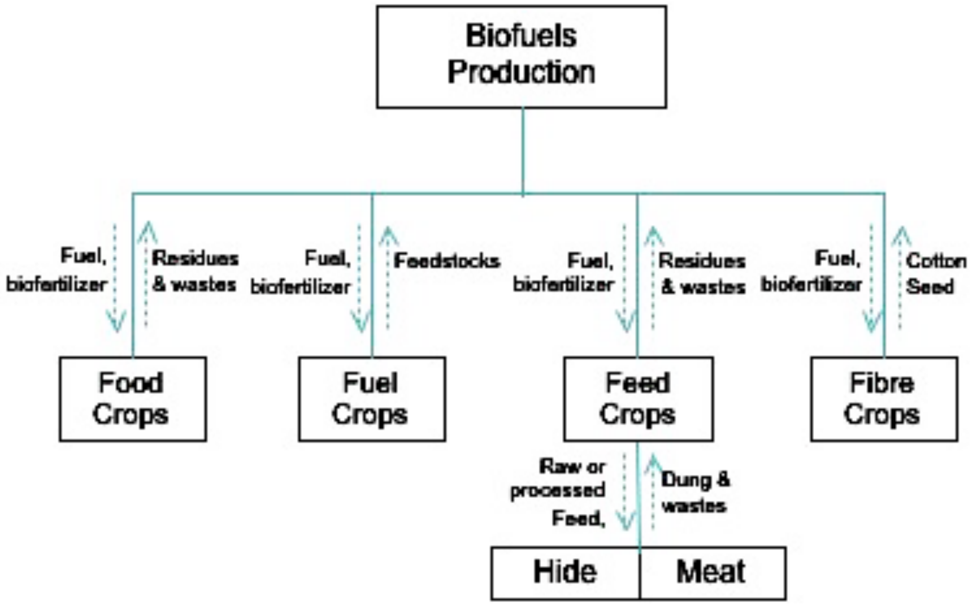

Figure 4. Conceptual integration pathway between biofuels, food, fuel, feed and fibre crops production

Source: Abila (2014a)

2.3.2 *Designating catchment areas for the production of food, feed, fuel and fibre*

The variation in the production capacities, reflecting the diversity of climatic, soil, agro-ecology and other factors, makes it necessary to designate a catchment area that can be devoted to the production of a combination of inputs. Figure 5 presents a proposed delineation of the country into three catchment areas for the production of the combination of food-feed-fuel, feed-food-fuel, and fibre-feed-food. These ordered triples express the combinations and prioritization of the belts for the production of the crops that are more suited for the objectives in each category. In the northern region of the country, we have the Sahel, Sudan, and Guinea Savannah agro-ecological zones, which are suited for the production of cotton, guinea corn, ground nut, and millet as well as sugarcane. The mid-region, which is a combination of the Derived Savannah and the southern part of the Guinea Savannah, are suited for the production of melon, sesame, maize, Shea nut, sesame, yam, cassava, and soybean, among others. The lower belt is composed mainly of the humid forest and the derived savannah agro-ecological zones, suited for producing oil palm, cassava, cocoyam, coconut, and rice, among others.

The proposition for the delineation of the country into different belts is not necessarily a rigid blueprint. There are no rigid distinctions between the agro-ecological zones, or the key climatic and soil characteristics that favor a particular group of crops. The core idea is to vary the strategies, policies, and incentives designed to enhance production and productivity and to ensure a balance in the attainment of the food, feed, fuel, and fibre objectives. Weather, soil types, prevailing food culture, and other essential relative advantages can give one region an edge over the others in the production of a particular group of crops. In addition, prioritization of the objectives may indicate that the need for meeting a particular objective is crucial than others. The designation of catchment areas for crop production should also take cognizance of future targets for each objective as well as the local capacity to absorb the produce.

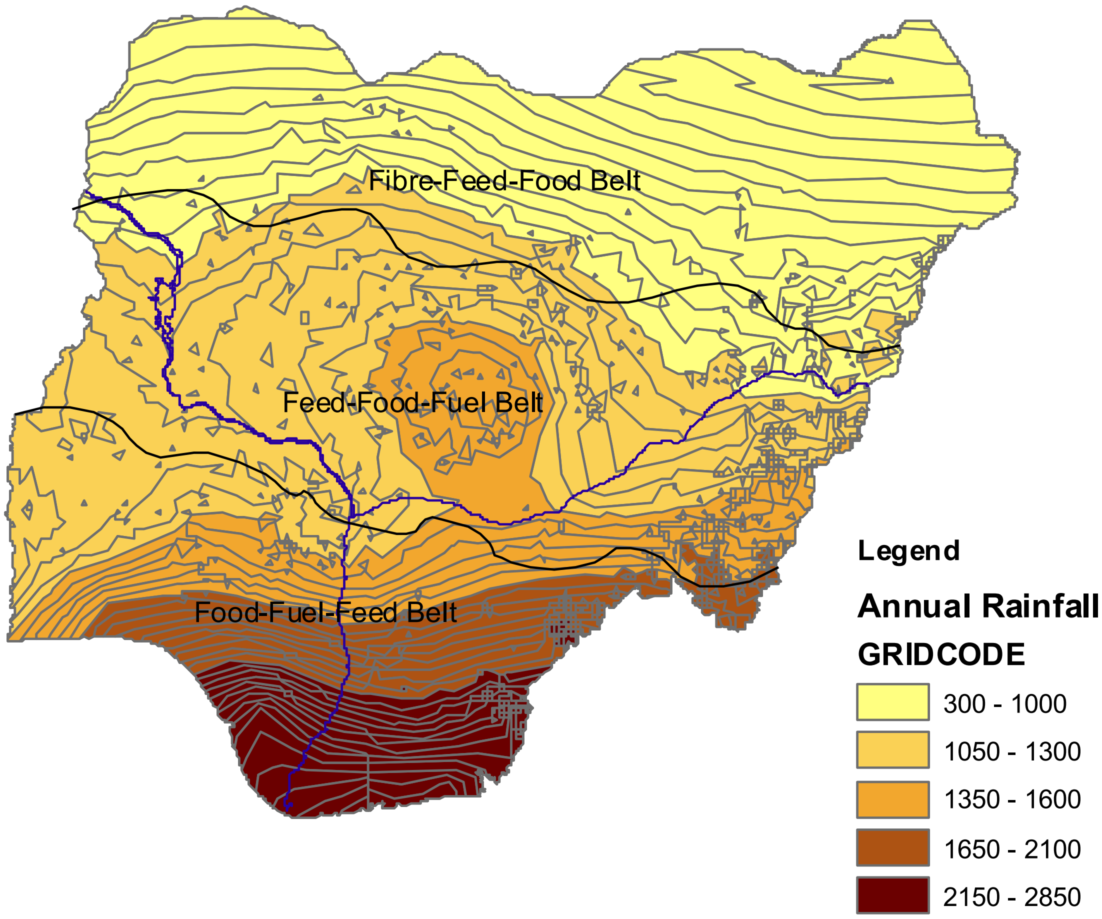

Figure 5. Proposition of catchment areas for the production of crops

Note: Rainfall in mm of precipitation.

3. SUMMARY OF PUBLICATIONS

Table 1 and Table 2 present the summary of the publications that make up this dissertation compilation, including the focus, aims, framework, method of analysis, and finding.

Table 1. List of articles compiled in this dissertation

Paper	Title	Place of Publication	Related Objective	Impact/ Citation*
Paper I	Biofuels Adoption in Nigeria: A Preliminary Review of Feedstock and Fuel Production Potentials	Management of Environmental Quality: An International Journal. Vol. 21 No. 6 pp. 785–795, 2010	I	8
Paper II	Biofuels development and adoption in Nigeria: Synthesis of drivers, incentives and enablers.	Energy Policy, Vol 43, pp 387–395, 2012	II	10
Paper III	Biofuels Adoption in Nigeria: Attaining a Balance in the Food, Fuel, Feed and Fiber Objectives.	Renewable and Sustainable Energy Review. Vol 35, pp 347–355, 2014.	General Objective	1

Paper IV	Econometric estimation of the petroleum products consumption in Nigeria: Assessing the premise for biofuels adoption.	Renewable and Sustainable Energy Review. Vol 35, pp 347–355, 2014	III	None yet
Paper V	Assessing land and water requirements for meeting biofuels targets for Nigeria.	World Renewable Energy Congress, 2014	IV	None yet

* The citations of the articles can be followed at the http://bit.ly/1gEF2ll

Table 2. Description of framework, aims, methods, and finding of the publications

Paper	Framework	Aims	Methods	Main Findings
Paper I	Laying critical foundation for the assessment of the potential for biofuels production.	To conduct preliminary assessment of feedstock and capacity for biofuels production in Nigeria	Desk review, data synthesis from secondary sources, simple statistical analysis and GIS map generation	Nigeria has immense potential for energy crops cultivation and the production of bioethanol and biodiesel.
Paper II	The synthesis of issues, factors, and enablers; simplifies the biofuels adoption complex	To synthesize drivers, incentives and enablers relating to biofuels adoption and development in Nigeria	Desk review, synthesis of existing information and data, and simple statistical analysis	The drivers of biofuels adoption in Nigeria are identified, synthesized, and categorized into endogenous and exogenous categories.
Paper III	Laying the foundation for advanced equilibrium analysis for attaining a balance with objectives competing with biofuels for critical resources	To conduct preliminary investigation into how to attain a balance in the food, fuel, feed, and fibre objectives as Nigeria adopts biofuels	Desk review, qualitative method, and descriptive statistics	Nigeria needs to adopt a mix of strategies to attain a balance in food, fuel, feed, and fibre objectives in a biofuels adoption era. Nigeria needs to adopt the integration of production ventures targeting the various objectives.

Paper IV	Using simple tool to advance the inquiry into what factors will shape biofuels consumption and viability of the increasing biofuels investments in Nigeria	To estimate petroleum products consumption as an indicator of biofuels absorption capacity	Econometric analysis, descriptive statistics, correlation analysis	The petroleum products for which blending targets have been set constitute a huge proportion of petroleum product consumption. The interplay between different variables affects the consumption of these products.
Paper V	Theoretical estimation of the land and water footprints, and how much of the existing production will be required to meet biofuels targets.	To assess land, water, and feedstock requirements for meeting Nigeria's biofuels targets	Quantitative analysis, footprints estimation, descriptive statistics	Nigeria can meet the biofuels requirements for 2010 and 2020 targets from domestic production alone. Between 7.5 and 11.5 percent of the resources are needed for meeting ethanol targets in the first phase.

3.1 Research findings

3.1.1 Findings relating to Research Question 1: Does Nigeria have the capacity for producing adequate feedstock for biofuels production?

In line with Weber's theory of industrial location (Weber 1909), the adoption of biofuels and the accompanying investments in plants and plantation must be premised on the existence of adequate capacity. A previous global assessment of biofuels production potential included Nigeria among the countries that meet the criteria to be a promising biofuels producer. Paper 1 and Paper 5 attempt to answer this question more specifically: Tables 3, 4, 5, and 6 present the relevant results. Table 3 shows Nigeria capacity and global ranking in the production of the key feedstocks for ethanol fuel and biodiesel. Promising crops as feedstock are cassava, palm oil and groundnut. Though the results are preliminary to some extents, they nonetheless provide the foundation for deeper assessment of Nigeria's capacity for producing biofuels locally.

Tables 4, 5 and 6 presents results from the land and water footprint estimation for producing the required amount of feedstock crop for meeting the Nigerian biofuels blending targets of 10 and 20 percents. Assuming Nigeria is considering a wide array of feedstock for meeting the ethanol and biodiesel targets, the estimate of possible biofuels yields from the various crops based on the current production figures are presented in tables 4 and 5. The aggregate of the possible biofuels yield for the crops profiled shows, going by the current production level, Nigeria can fully meet the ethanol and biodiesel targets from local production. The six crops, namely cassava, maize, sugarcane, sorghum, potatoes and rice can yield a total of 17.47 million cubic meters of ethanol base on the current production level. The crops profiled for biodiesel can yield a total of 3.3 million cubic meters of the fuel. Table 6 presents the water footprint in cubic kilometer and land footprints in kilometer square required for the production of the gazette volume of biofuels from each of the feedstock crops.

Table 3. Nigeria's Biofuel Crops Production

Crop	2007 Average Yield (MT)	Biofuel Fuel Type Derivation	Derivable Bio-fuel Yield (L/Ha)	Nigeria's Production Rank (Global)
Sesame	100,000	Biodiesels	696	7
Palm oil	1,300,000	Biodiesels	5950	3
Palm Kernel	1,275,000	Biodiesels	5950	3
Ground Nut	3,835,600	Biodiesels	1059	3
Soybean	604,000	Biodiesels	446	11
Coconut	225,500	Bio-ethanol	2689	17
Sugarcane	1, 506,000	Bio-ethanol	6000*	51
Cotton Seed	212,000	Biodiesels	325	16
Cassava	34,410,000	Bio-ethanol	4000*	1
Sweet Corn	6,724,000	Bio-ethanol	172	10

*Data from Leibig (2008); other fuel yield/ha from Mobius LLC (2007)

Source: Abila (2010)

Table 4. Nigeria's Biofuels Production Potential Estimate

Derivable Feedstock	2007 Cultivated Area (Ha)	Biofuel Fuel Type	Biofuel Production Potential Estimate (ML*)
Sesame	196,000	Biodiesels	136.4
Palm oil	3,150,000	Biodiesels	18,742.5
Palm Kernel	3,150,000	Biodiesels	18,742.5
Ground Nut	2,230,000	Biodiesels	2,361.6
Soybean	638,000	Biodiesels	284.5
Coconut	41,000	Bio-ethanol	110.2
Sugarcane	63,000	Bio-ethanol	378.0
Cotton Seed	434,000	Biodiesels	141.1
Cassava	3,875,000	Bio-ethanol	15,500.0
Sweet Corn	3,944,000	Bio-ethanol	678.4

*ML – million litres.

Source: Abila (2010)

Table 5. Estimates of biofuels production and feedstock requirements for the Phase 1 & 2 Targets

Feedstock	Biofuel Yield Per total current production (million m^3)	Estimate on Blending rates (2010) (million m^3)	Estimate on Blending rates (2020) (million m^3)	Feedstock Required for 2010 blending rate (million tonnes)	Feedstock Required for 2020 blending rate (million tonnes)
Bio-ethanol Targets – 2010: 1.3 **2020:** 2.0 (million cubic meters)					
Cassava	9.23	0.690	1.057	3.09	4.76
Maize	2.89	0.220	0.331	0.50	0.77
Sugar-cane	0.01	0.008	0.013	0.09	0.13
Sorghum	3.53	0.260	0.404	0.61	0.93
Potatoes	0.10	0.007	0.011	0.06	0.09
Rice	1.61	0.120	0.184	0.28	0.42
Total	17.47	1.300	2.000	4.63	7.10
Biodiesel Targets – 2010: 0.48 2020: 0.90 (million cubic meters)					
Oil palm	1.790	0.261	0.488	1.22	2.29

Cotton-seed	0.053	0.008	0.015	0.03	0.07
Ground-nut	1.354	0.197	0.369	0.47	0.88
Soybeans	0.099	0.014	0.027	0.08	0.14
Coconut	0.003	0.001	0.001	0.03	0.06
Total	3.303	0.480	0.900	1.83	3.44

Source: Abila (2014b)

Table 6. Estimates of total land and water footprints for biofuels required for the Phase 1 & 2 Targets

Feedstock	Total Water footprint of biofuels 2010 (km^3)	Total Land footprint of biofuels 2010 (km^2)	Total Water footprint of biofuels 2020 (km^3)	Total Land footprint of biofuels 2020 (km^2)
Bio-ethanol				
Cassava	1.70	3, 400	2.62	5,231
Maize	0.52	3, 679	0.79	5,661
Sugarcane	0.02	53	0.03	83
Sorghum	1.79	6,169	2.76	9,491
Potatoes	0.01	238	0.02	367
Rice	0.41	2,229	0.63	3,430
Total	4.45	15,771	6.85	24,264
Biodiesel				
Oil palm	1.30	5,312	2.43	9,961
Cotton seed	0.13	838	0.23	1,571
Groundnut	1.22	3,745	2.30	7, 023

Soybeans	0.16	880	0.30	1,650
Coconut	0.08	64	0.15	121
Total	2.89	10,842	5.41	20,329

Source: Abila (2014b)

3.1.2 Findings relating to Research Question 2: What are the key drivers, including needs, issues, concerns, and factors that exist in Nigeria that will promote biofuels adoption and development?

Owing to the fact that the Nigerian biofuels sector is still young and just developing, to fully understand what drives the adoption of biofuels in Nigeria, a nation that is blessed with the immense oil and gas resources, this research conducted a review and made a synthesis. Paper 2 attempts to answer this research question. The synthesis made led to the development of the conceptual framework as shown in Figure 1.

3.1.3 Findings relating to Research Question 3: What is the historical and existing petroleum products consumption in Nigeria, and how does this form the basis for biofuels adoption?

This question called for an econometric assessment of the factors that drive the consumption of petroleum products for which the Nigerian biofuels policy has proposed blending rates. Paper 4 to some extent answers this question. The econometric analysis gives an overview of the factors that are crucial in the development of the biofuels policy and sector in Nigeria. Table 7 provides the summary of the result of the econometric analysis. The econometric analysis adopted multiple regression analysis with a variety of models including: linear, the double-log, linear-log, log-linear, and lag model specifications. The linear model best fit the data from the econometric estimation. The result shows that the coefficients of consumption of each of the petroleum products and population variable are positive, in line with theoretical expectations. Meanwhile, the coefficients of GDP, electricity generation, and electricity generation capacity are negative, contrary to theoretical expectation. The result of the OLS estimation indicates that the consumption of the key petroleum products for which Nigeria has proposed a blending with biofuels is significant. This implies a unit increase in the consumption of each product implies a corresponding rise in aggregate consumption of petroleum products. By implication, the volume of biofuels required for meeting the targets under the various biofuels regime for Nigeria — E10 for ethanol and between D10 to D20 for biodiesel— will continue to increase, as the overall petroleum product consumption increases in line with increasing population and GDP growth.

Table 7. Summary of the regression analysis – models and parameters estimate for petroleum products' consumption in Nigeria

Model	Equation (1) – Linear-linear	Equation (2) – Log-Linear	Equation (3) – Log-log	Equation (4) – Linear-Log	Equation (5) – Lag
R2	1.00	0.99	0.97	0.98	1.00
Constant	–0.023138 (0.028887)	4.501716[a] (0.021811)	1.110900 (0.660668)	–752.2512[a] (161.5453)	–0.013935 (0.030906)
CONSD (+)	0.999721[a] (0.000361)	0.003298[a] (0.000273)	0.205112[a] (0.053115)	63.06746[a] (12.98750)	0.999855a (0.000394)
CONSJF (+)	0.999299[a] (0.000524)	0.003652[a] (0.000395)	0.044077 (0.017898)	11.27805 (4.376330)	0.999413[a] (0.000543)
CONSK (+)	1.000021[a] (0.000299)	0.003800[a] (0.000226)	0.069646 (0.028064)	17.91508 (6.862203)	1.000074[a] (0.000307)
CONSL (+)	1.004194[a] (0.002183)	0.005486[a] (0.001649)	0.008588 (0.009881)	2.681975 (2.416018)	1.003461[a] (0.002350)
CONSOPP (+)	0.999664[a] (0.000166)	0.003720[a] (0.000125§)	0.112375[a] (0.021798)	29.93691[a] (5.330096)	0.999693[a] (0.000170)
CONSP (+)	0.999543[a] (0.000195)	0.003567[a] (0.000147)	0.297556[a] (0.079534)	78.57941[a] (19.44743)	0.999566[a] (0.000198)
CONSROIL (+)	0.999855[a] (0.000290)	0.003960[a] (0.000219)	0.071939 (0.023036)	18.23783[a] (5.632830)	0.999895[a] (0.000296)
ELEGEN (–)	5.30E-06 (1.03E-05)	1.17E-05 (7.77E-06)	–0.137952 (0.105807)	–47.85750 (25.87177)	7.51E-06 (1.07E-05)
ELINSCAP (–)	1.48E-06 (5.80E-06)	1.46E-05[a] (4.38E-06)	0.096268 (0.098176)	1.569274 (24.00587)	3.06E-06 (6.11E-06)

GDP (+)	–4.66E-06 (4.31E-06)	–2.32E-06 (3.25E-06)	0.102671 (0.111285)	39.16826 (27.21107)	–3.68E-06 (4.48E-06)
POPN (+)	0.000952 (0.000468)	0.000184 (0.000354)	0.140357 (0.148340)	36.38779 (36.27174)	0.000864 (0.000483)
AGCONS(-1)	-	-	-	-	–0.000112 (0.000126)
F-statistic	30083200	781.7181	40.50799	45.72688	27108857
P'| F|	0.000000	0.000000	0.000001	0.000000	0.000000
Akaike info criterion	-6.808157	-7.370136	-4.468581	6.529996	-6.794740
Schwarz criterion	-6.219130	-6.781109	-3.873467	7.125110	-6.156627
Durbin-Watson stat	1.688598	1.621357	1.674514	1.822289	1.772069

Source: Abila (2014)

AGCons = Aggregate consumption of petroleum products (thousand barrels per day); GDP = real gross domestic product, constant prices billion naira; ConsP = Consumption of motor gasoline (Petro) in thousand barrels per day; ConsK = Consumption of kerosene in thousand barrels per day; ConsD = Consumption of distillate (Diesel) in thousand barrels per day; ConsL = Consumption of liquid petroleum gas (LPG) in thousand barrels per day; ConsOpp = Consumption of other petroleum products in thousand barrels per day; ConsRoil = Consumption of residual oils in thousand barrels per day; Popn = Population in millions; Elegen = Electricity generation in megawatt; Elinscap = Electricity installed capacity in megawatt.

Standard errors are in parenthesis. [a] Coefficients have significant t-value (p-value < 0.05).

3.2 Research Findings and Policy Implications

This work on biofuels adoption and development in Nigeria yields findings which have bearing on the existing biofuels policy in Nigeria. The findings from this study may also be useful in guiding further policies that may be proposed with respect to the advancement of biofuels in Nigeria.

These are the key findings relevant to policy.

1) The existing biofuels policy limits the description of feedstock, and in fact identifies only a few crops for biofuels production in Nigeria. This definitely needs to be revised. Expanding this list will allow for enterprises engaged in the production of other crops to benefit from the various incentives, as highlighted by the Nigerian Biofuels Policy and Incentives (NNPC, 2007).

2) The existing biofuels policy does not fully take into consideration the fact that biofuels crops are also food, feed, and in some cases fibre crops. This understanding should be incorporated into subsequent policies, to attain a balance between biofuels development and the food, feed, and fibre objectives.

3) The projection and target setting for blending of biofuels with petroleum fuels should be based on a more reasonable assessment of the current and future consumption of petroleum products. The findings of Paper 4 show that Nigeria's projected blending targets for ethanol and biodiesel production far exceed the blending requirements based on the historical and prevailing consumption.

The projection of blending targets, and the entire biofuels policy, should be premised on the existing and potential capacity for biofuels production in Nigeria. Subsequent biofuels policies should in general be premised on the existing and projected capacity for biofuels production and distribution to attain sustainability.

3.3 The research finding and publications in relation to sustainability

The various papers in this dissertation compilation have explored sustainability themes with respect to biofuels adoption and development in Nigeria. Figure 6 shows the research findings and publications in relation to the widely recognized three pillars of sustainability – although the assessment of sustainability based on just the three pillars is inadequate, as noted by Lozano and Huisingh (2011) and

Lozano (2008). These papers have built a firm foundation for expanding the assessment of biofuels sustainability in Nigeria to other critical themes, particularly as illustrated by Allen (2001).

Paper 3 and Paper 4 explore economic themes as they pertain to biofuels adoption in Nigeria. Paper 3 is largely a review work, setting the stage for further assessment of the economics of biofuels adoption in relation to multiple other objectives. Paper 4 explores aspects of the economics of petroleum product consumption, underlying biofuels adoption and blending targets.

Papers 2, 3, and 4 explore various themes relating to the society. Examination of the biofuels adoption complex in Nigeria brought out core social issues underpinning the promotion of biofuels. Attaining a balance in meeting food, feed, fibre, and fuel needs is an economic as well as social requirement.

Paper 1 and Paper 5 explore aspects of the environment. The introductory assessment of biofuels production capacity is hinged on environmental factors such as rainfall, and also the capacity for the production of feedstock. Paper 5 assesses the water and land footprints for meeting the biofuels targets, also in relation to the environmental sustainability.

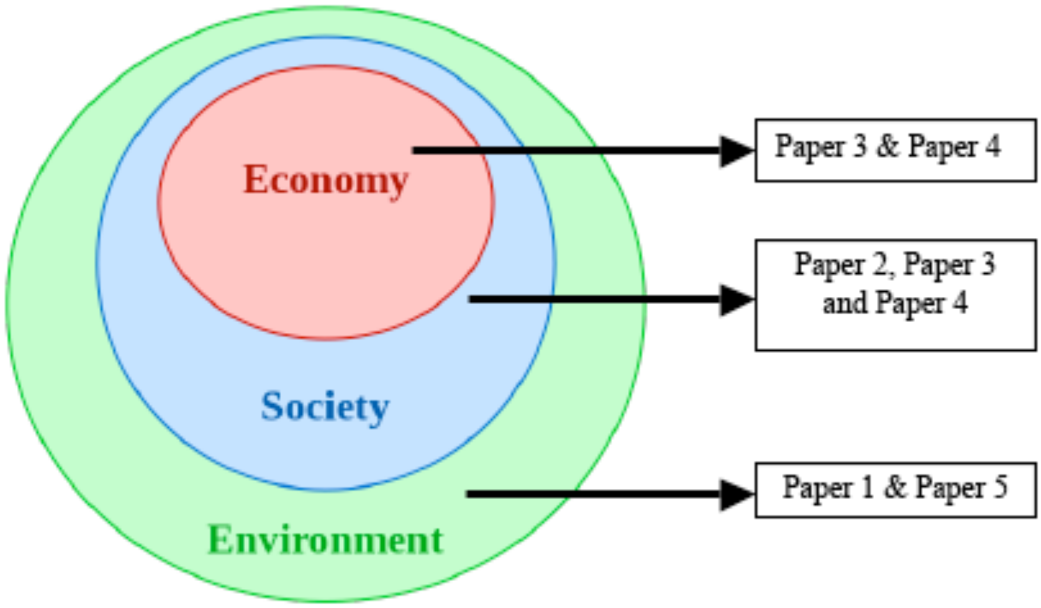

Figure 6. The publications in relation to the exploration of sustainability

Source: Adapted from Scott Cato, M. (2009).

4. CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH

The adoption and development of biofuels in Nigeria is still at the early stage, and this assessment of aspects of sustainability is based on current progress. Assessing sustainability at this early stage is of utmost importance to avoid pitfalls as the biofuels era fully takes root.

The preliminary assessment of the biofuels feedstock production capacity showed that indeed Nigeria has the potential for biofuels production. Further, an assessment of the land and water footprints, and the volume of feedstock required to meet the 2010 and 2020 biofuels targets, showed that Nigeria can rely on local production for meeting these targets. But these assessments of capacity are not sufficient to establish the viability of this young and growing sector. A more comprehensive assessment must take into account these additional factors:

- A critical need is to attain balance among the objectives of food, feed, fibre, and fuel needs, as a foundational concern that may provide the conceptual framework for subsequent research.

- The historical consumption of those petroleum products for which blending targets have been set shows an upward trend, giving impetus to biofuels policy geared toward meeting international agreements and treaties that require cutting down on carbon emission.

- The synthesis of the drivers, enablers, and incentives identifies the various actors, agents, and objectives that must be kept in focus as Nigeria advances with biofuels adoption and development.

Limitations of the Research

This research of course has limitations, especially because the Nigerian biofuels sector is just emerging. First, little data are available from industries just setting up biofuels plants. Second, information and data reported in journal articles are not necessarily valid. (For example, a listing of biofuels industries includes some that do not yet exist.) While the NNPC (the Nigerian government agency managing the nation's automotive biofuels policy) has commissioned a number of studies and assessments for cassava and sugarcane ethanol plants, those reports are still not accessible.

Future Research

It is hoped that more research will be built on this work. Key areas for future research include using advanced econometric analysis and modeling to explore such themes as: forecasting biofuels demand into the future; assessment of the impact of biofuels adoption on the society; and empirical analysis of land, water, and other kinds of footprints. Modeling how to attain a balance in the food, feed, fibre, and fuel objectives is another direction worth exploring, as the scientific work on biofuels development in Nigeria advances.

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Biofuels adoption in Nigeria

A preliminary review of feedstock and fuel production potentials

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Abstract

Purpose – The purpose of this paper is to make a preliminary analysis of the potentials for the adoption of biofuels in Nigeria. This initial analysis aims to capture some of the possibilities in the adoption of biofuel and the promotion of the cultivation of energy crops and processing of biofuels in Nigeria. Taking a step towards biofuel adoption is crucial for Nigeria to remain an important player in the world energy market, as there is a shift in global fossil fuel consumption.
Design/methodology/approach – The study adopted a desk review of existing literatures on global biofuels production potentials. A synthesis of data from the Food and Agriculture Organization(FAO) secondary database on major energy crops production was also conducted, while the GIS map was generated from GIS data sourced from the International Institute of Tropical Agriculture, Ibadan,Nigeria.

Findings – Nigeria has immense potential for energy crops cultivation and the production of bioethanol and biodiesel. The existing database shows that Nigeria ranks very high in terms of production of the major energy crops such as soybean, palm oil, sesame and cassava. The rainfall distribution shows thatmost energy crops can be grown all over Nigeria. Nigeria has the capacity to be a leading exporter of biofuels. The adoption of biofuels can also ease the financial strain relating to the
heavy burden of fossil fuel subsidy and also enhance local livelihoods within the production chains.

Practical implications – With the very high potential for biofuel production, the Government as well as private investors should take steps towards investing in agriculture for the production of energy crops and the establishment of biofuel-processing plants in Nigeria.

Originality/value – The paper is a preliminary analysis of bio-economic and environmental modeling of the adoption of biofuels in the energy sector in Nigeria. This analysis has opened up the
focus of the bigger study, modeling the biological, economic, environmental and other impacts of biofuel adoption.

Keywords Biochemistry, Crops, Energy sources, Nigeria

Paper type Research paper

Introduction

Nigeria is a western African country, with a population of about 150 million based on the 2006 national census estimate (NPC, 2006). Nigeria has a total area of 923,768 sq km consisting of about 1.4 percent water (CIA, 2005). The country is bordered to the west by Benin Republic, to the east by Cameroon and to the north by Niger and Chad Republics. Nigeria is endowed with natural resources consisting of commercial quantities of petroleum, natural gas, bitumen, iron ore and coal. Figure 1 shows the location of Nigeria on the map of Africa.

Nigeria is a major crude oil exporter with equally enormous potentials and capacities for becoming a major player in the global alternative renewable fuels production and trade. Looking at this new direction holds lots of promises for solving current environmental problems relating to the exploitation of fossil fuels in the Niger delta area of Nigeria as well as putting in place a framework for a bottom-up sustainable development. As an agrarian economy, with agriculture employing a huge proportion of the population, particularly those in the rural areas and with agriculture contributing 42.2 percent of the country's GDP in 2007 (CBN, 2008), Nigeria has a unique capacity for the cultivation of the globally accepted biofuel crops as well as putting in place processes and policy framework for the production of and trading in various biofuels with increasing demands internationally. According to Wicke et al. (2008), many industrialized countries are increasing biomass energy import as they increasingly introduced policies towards the use of renewable energy, which have been proven to be more cost-efficient than domestic biomass energy.

The increase in international demand for biofuel is bound to continue unabated as many more industrialized countries introduce and implement policies towards the use of

Figure 1. Map of Africa showing Nigeria

renewable energy (Wicke et al. , 2008). Nigeria has the capacity to become another major player in this emerging energy market. The feedstock and energy crops for producing the traditional primary and secondary biofuel are in abundant. The production of these biofuels can be done in smaller units suitable for small-medium enterprises to spring-up and also allow for community level management and ownership of biofuel production enterprises (CREDC, 2009). von Braun (2007) classified Nigeria as one of the countries with very high potential for energy crops production. This classification of potential was based on the assessed countries' capacity relating to:

- the availability of arable land;
- the availability of water; and
- the level of current food insecurity of the country.

As the global production and demand for energy keep increasing and the quest for energy is directly proportional with technological advancements and economic growth in emerging economies such as China, and many other developing economies that are breaking the barriers of development, the global energy demand is projected to increase (St Clair et al. , 2008). The increasing demand trend for energy gives an endowed country like Nigeria an opportunity to harness it potentials for the production of renewable energy. Harnessing these potentials in Nigeria will imply intensifying the production of energy crops, putting in place essential policies to facilitate the crops cultivation and biofuel production, distribution and export.

The intensification of the energy crops cultivation in Nigeria and biofuel production has the capacity in helping Nigeria meets its international obligation on cutting carbon emission and reaching the seventh Millennium Development Goals (MDG) – ensuring environmental sustainability. Other benefits that are derivable from the investments in energy crop cultivation and biofuels production are a guarantee of the security of supply of fuels and also possible reduction in current the heavy financial burden associated with the fossil fuel. Currently, the government subsidizes all petroleum products consumed locally and there have always been recurrent crises over attempts by government to remove or reduce petroleum subsidy. The production of cheaper and affordable biofuels has a short and long-term impacts including stimulating the economy, increasing employment within the biofuel production chain, as well as the energy crop cultivation and inputs supply chain. This paper presents a synthesis of the potentials for energy crop cultivation and biofuel production. It also provides useful recommendations based on the von Braun (2007) three main domains for ensuring that as agriculture and energy meets, there is little or no negative impact on households, businesses and the private sector of the economy.

Methodology

This study makes a preliminary review of energy crops cultivation and biofuel production potentials of Nigeria. The review is based on existing literatures. The study also compiled and analyzed FAO secondary data on major energy crops productions. Weather element data and GIS database were sourced from the International Institute of Tropical Agriculture, Ibadan, Nigeria.

Nigeria's biofuel crops production

FAO statistics on crop production show Nigeria is among the top producing countries for the promising energy crops (FAO, 2009). Table I shows these crops and Nigeria's global ranking in terms of output. Though Nigeria is among the highest producers of crops with high biofuel yield, it is surprising that the country is yet to start harnessing these potentials and participating in biofuel production and trading, in spite of the increasing global demand. The prevailing cultural practices for the production of some of these crops still portray less intensive and non-chemical dependent production. This prevailing production condition has been described as organic by default and can be maintained to ensure less environmental impact on the soil, water and air quality as Nigeria progress towards market volume production of energy crops targeted towards feeding biofuel processing plants.

Major energy crops with high biofuel yield for feedstock include sugarcane, sugar beet, maize, wheat, rapeseed, palm oil, jatropha, switch grass, and willow (FAO, 2008). Of these crops, Nigeria is a major producer of palm oil, maize and jatropha. Nigeria has been a leading producer of cassava and ground nut, which also have very high biofuel yielding potentials.

Biofuel production

Biofuels are liquid or gaseous form of fuels processed from biomass sources, which can replace fossil fuels of petrol, diesel and other transport fuels used for running various automotive and mechanical machines. Biofuels are derivable from many sources including agricultural crops, forest biomass and bio-wastes (Keam and McCormick, 2008). The various forms of biofuels are bioethanol, biodiesel, and biogas (FAO, 2000). Peskett et al. (2007) defined biofuels as organic primary and/or secondary biomass derived fuels, which can be used for generating thermal energy by combustion or by other technology. This definition includes purpose-grown energy crops, multipurpose plantations and agricultural and non-agric by-products (FAO, 2000). These fuels are classified as primary and secondary biofuels depending on their form. FAO (2000) made this distinction clearer describing primary biofuels as the unprocessed fuels such as firewood, wood chips and pellets which are used in their natural form while the secondary are processed

Table 1. Nigeria's Biofuel Crops Production

Crop	2007 Average Yield (MT)	Biofuel Fuel Type Derivation	Derivable Biofuel Yield (L/Ha)	Nigeria's Production Rank (Global)
Sesame	100,000	Biodiesels	696	7
Palm oil	1,300,000	Biodiesels	5950	3
Palm Kernel	1,275,000	Biodiesels	5950	3
Ground Nut	3,835,600	Biodiesels	1059	3
Soybean	604,000	Biodiesels	446	11
Coconut	225,500	Bio-ethanol	2689	17
Sugarcane	1, 506,000	Bio-ethanol	6000*	51
Cotton Seed	212,000	Biodiesels	325	16
Cassava	34,410,000	Bio-ethanol	4000*	1
Sweet Corn	6,724,000	Bio-ethanol	172	10

Sources: Leibig (2008); Mobius LLC (2007); FAO (2009)

fuels use through a combustion process for generating heating or electricity. Primary and secondary biofuels are dominant form of energy in most households in Nigeria, particularly those in the rural and peril-urban areas that are not connected to the national grid. The low level of power generation and poor supply electricity has also confined populations in the urban areas to the use of biofuels such as charcoal.

Bio-ethanol

Bioethanol is a biologically produced alcohol derivable from a wide sugar or starch crops including sugarcane, sweet corn, coconut and cassava. The local production of ethanol from maize, guinea corn, millet, and other starchy substrates and cellulose is as old as Nigeria (ICP, 2005). Local ethanol production from palm wine is yet another common livelihood in the southwest and south-south part of Nigeria. The capacity for producing ethanol from cassava is huge and harnessing this potential will help in cutting waste of cassava crops, a prevailing phenomenon during gluts. This will also give priority to this long neglected important crop (Lipton, 1988).

Biodiesel

Biodiesel is a renewable fuel, gaining increasing acceptance globally. It is achieved by blending it with the conventional diesel. Higher biodiesel yields are derived from crops feedstock such as soybean and rapeseed in Europe while Asian countries are also exploring the less attractive biodiesel feedstock from non-edible seed oils like jatropha (Sarin et al., 2007). Nigeria rank third in the production of oil palm and groundnut based on the FAO 2007 world ranking of commodity production figures. These crops have very high biodiesel yields 5950 l/ha and 1059 l/ha respectively (Table I). There is also a high potential for producing non-edible oils that are suitable for the processing biodiesel.

Biophysical capacity for energy crops production

Nigeria has a highly varied landscape and biophysical conditions that reflect a total contrast between the far south and the far north. This geographical diversity portends rich biophysical endowments and agro ecological diversity. Nigeria lies between 10o North and 8o East, covers a 910,768 sq km of land and 13,000 sq km of water with climate ranging from equatorial condition in the south to the arid condition in the north (CIA, 2005). The country currently uses only 36.16 percent of the land area for agricultural purpose. The average annual rainfall ranges between 300mm in the far north to 2850mm in the far south. Its total renewable water resources are estimated to be 286.2 cu km. The ultraviolet light intensity and duration of sunshine across the country is suitable for most energy crops cultivation irrigated or rain fed. Energy crops require the availability of appropriate environmental conditions. These conditions include adequate water supply and the availability of suitable land (Yang et al., 2009;O ¨ zdemir et al., 2009). The high water and land requirement form part of the major concern for energy crops cultivation and biofuels production.

Energy crops such as sugarcane require a large volume of water for their cultivation and subsequent processing of their feedstock. Sugarcane cultivation is suitable across a wide range of the Nigerian landscape from the very deep forest mangroves in the Niger Delta to Guinea savanna that is suitable for the cultivation of grasses. High crop yield and productivity for sugarcane production is attainable across Nigeria, but the cultivation of this crop has been limited, due to utilization in unprocessed (primary) or semi-processed form for human consumption, particularly in Northern Nigeria. The quest to invest in the production of this energy crop implies the need to resuscitate moribund sugarcane plantations in Numan (North East), Jebba (North Central), Papaalanto (South West) and many other plantations that stopped operation with the influx of cheaper refined sugar.

The perennial energy crops such as the oil palm and jatropha are posited to have more benign environmental impact on the soil quality considering the lower level of inorganic chemical requirement for their cultivation (Peskett et al., 2007). Since Malaysia and Indonesia took the lead in the production of palm oil, the production of the crop in Nigeria has been limited to small non-commercial scale production. Most plantations in Eastern and Western part of country are old and less productive, requiring a replacement of the crops and rehabilitation of the processing plants, as well as the integration of biodiesel feedstock processing accessories.

Jatropha is yet to be seen as a viable economic crop in Nigeria. The cultivation of jatropha is still limited to its use as a hedge crops in rural communities or as mere ornamental plant. Jatropha gossipifolia, jatropha multifida, and jatropha podagrica are grown widely as ornamental plants, while jatropha curcas is most common and grown as hedge. The rainfall requirement of jatropha is not heavy, which makes it to thrive even in average annual rainfall of about 250 mm. The Nigeria rainfall distribution (Figure 2) shows jatropha can be grown in all ecological zones in Nigeria. The production advantage lies in the ability of the plant to survive in marginal lands, thereby reducing the competition for arable land with food and other cash crops.

Though there exist concerns on the environmental impact of the cultivation of jatropha such as effects on soil quality, caustic effluents from the processing of jatropha oil, and the toxicity of the seeds and extracted oil and cake, the costs and benefit of the investments in biodiesels production from jatropha is worth assessing. Gu¨bitz et al. (1999) detailed some of the toxicity concerns of jatropha seeds, the oil and cake. As envisaged with every innovation, the negative impact of this technological feat must be well managed to ensure that the benefits far outweigh the cost – both economically, socially, and environmentally. The concerns on the impact of the jatropha cultivation were doused on the discovery that the cultivation of jatropha is a very viable option for remediation process for metal contaminated soils/land (Kumar et al., 2008). This result from Kumar et al. (2008) study opens a vista for assessing the remediation potentials of jatropha in the contaminated soils in the Niger region of Nigeria following petroleum exploitation and spillages from petroleum transportation and products distribution.

Current biofuels use in Nigeria

Biofuels use in Nigeria currently includes the use of the primary biofuels such fuel wood, briquettes, charcoal as well as bioethanol and biodiesel. Bio-ethanol production has been ongoing in most part of southern Nigeria, particularly in the Niger Delta region where saps from palms are tapped and distilled into ethanol. The ethanol produced from scattered small-scale distilleries are consumed as liquor and used in local industrial processes. There are also pockets of small-scale ongoing bioethanol production for biofuel fossil blending research projects. These include the Nigeria National Petroleum Corporation (NNPC), states' governments and private funded bio-ethanol production from cassava and sweet sorghum and biodiesel from oil feed stocks.

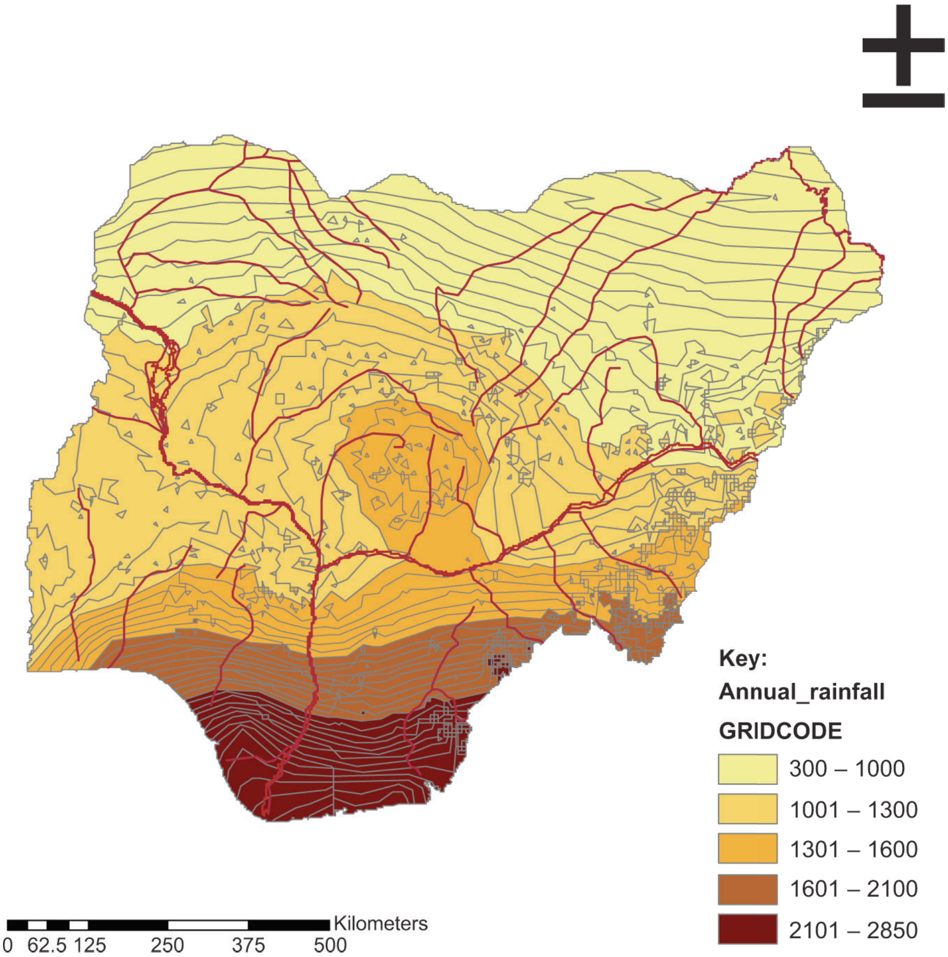

Figure 2. Annual average rainfall distribution across Nigeria

With the current low level (30 percent) operation of the 445,000 barrels per day (70,700m3 /d) of the running refineries in Nigeria, meeting the required daily petroleum products demand is sustained by the import of over 70 percent of the required refined petroleum products consumed in Nigeria. Some of these imported refined products are already blended to the E10 standard adopted by Nigeria. Biofuels adoption and the diversification of energy supply which will pave way for small-scale decentralization of fuel production and distribution has the capacity to ease the already stretched and strained fossil fuel supply infrastructure in Nigeria. The framework envisaged for promoting biofuels production also has the promise of ensuring the supply of fuel to the remote rural areas, which are hitherto not reached by the existing fuel supply infrastructure as well as other energy infrastructure particularly national grid electricity supply. Table II shows the estimates of potential biofuels derivable from the various feedstocks cultivated in Nigeria in 2007 based on the FAO (2009) crops production data. Though these estimates did not consider the competition between food and fuel, it however affirms the availability of the potential for biofuels production, which the

Table 2. Nigeria's biofuels production potential estimate

Derivable Feedstock	2007 Cultivated Area (Ha)	Biofuel Fuel Type	Biofuel Production Potential Estimate (ML)
Sesame	196,000	Biodiesels	136.4
Palm oil	3,150,000	Biodiesels	18,742.5
Palm Kernel	3,150,000	Biodiesels	18,742.5
Ground Nut	2,230,000	Biodiesels	2,361.6
Soybean	638,000	Biodiesels	284.5
Coconut	41,000	Bio-ethanol	110.2
Sugarcane	63,000	Bio-ethanol	378.0
Cotton Seed	434,000	Biodiesels	141.1
Cassava	3,875,000	Bio-ethanol	15,500.0
Sweet Corn	3,944,000	Bio-ethanol	678.4

Note: ML = million litres

country's renewable energy strategy must aim towards harnessing. Palm oil and palm kernel have the highest biofuel (biodiesel) potential for Nigeria. The country ranks third globally in the production of these feedstocks in 2007 (FAO, 2009), despite the declining yield per hectare associated with the several years of neglect of the sector, the non replacements of the aging existing palms in plantations and very low level of investments and incentive in by government. Apart from the capacity to solve the current supply crises affecting both the urban and rural areas of Nigeria, the biofuel production and processing chain has the capacity to generate employment in rural areas. The employment generation, the attraction of foreign investments and agricultural and rural development form the pivot of the gazette Nigeria's biofuel policy (Achimugu, 2008). As Nigeria's various rural development policies and strategies highlighted the need for rapid infrastructure, decentralized biofuels production and supply for powering information and communications technologies (ICT) and other related developments are very important to ensure access in remote and disconnected rural communities.

Implication for policy

Further assessment and review of Nigeria's energy crop production and processing of biofuel is premised on von Braun's (2007) three thematic domains on which biofuel feedstock and biofuel production impact:
(1) economic change;
(2) environmental change; and
(3) political and social change.

Economic change

The existing informal market situation needs to be improved to ensure the reduction of risks in the production of biofuel feedstock and processing of biofuels. Specialized regulatory frameworks tailored towards energy crop production, processing and trading in the biofuels needs to be put in place. There is need to also improve on the declining agricultural and technological research to ensure a broad base focus on both food and fuel crops production and processing. Current economic development frameworks of NEEDS and Vision 2020 plans will need to be improved on to capture the emerging global shift in energy consumption, as evidenced in the declining revenue accruing to the federation accounts from petroleum export (CBN, 2007). It is also pertinent that as the country drives towards the deregulation of the petroleum downstream sector and the reduction in fossil fuels subsidy, increasing the investments for enhancing biofuel production will create necessary stimulus for the low-income strata of the population, particularly farmers and others within the agricultural production and processing chain.

Environmental change

The existing environmental problems including erosions, flooding affecting rural and urban communities across the country, desertification, prolonged drought and water and land pollution from oil spills in the Niger Delta and along petroleum and petroleum products delivery pipelines crossing the country affects crop production all over Nigeria. Previously, arable lands have turned to marginal lands, with little or no suitability for profitable food production agricultural venture. The designing and implementation of a strategy for energy crop production and harnessing the broad-spectrum biomass, as well as bioenergy potentials of Nigeria, holds the key to solving some of the existing environmental challenges. Most marginal lands resulting from persisting environmental problems can be rehabilitated for producing non-edible biofuels feedstocks. Water availability may not be a problem, but managing the effluents from biofuel processing will be an issue requiring sound and strict regulatory framework. Nigeria will also need to build up the right capacity and technology for assessing gains and benefits of adopting biofuels, in terms of carbon sequestration.

Political and social change

The process for environmental governance, which will translate into positive social changes, requires setting clear goals, designing and implementing achievable frameworks. Issues relating to the environment have many stakeholders. There is therefore the need for policies, structures and processes which will enable control and coordination of stakeholders' decision making and facilitate the development of a set of shared values concerning the issue in question (Stewart and Jones, 2003), in this case biofuels adoption and harnessing of existing production potentials. The successful adoption of biofuels in Nigeria will depend largely on a participatory decision making process, designing and implementation policies and regulations focused on harnessing the obvious biofuels potentials of Nigeria. This is necessary to ensure the benefits trickle down to farmers and others at the lower level of the supply chain of biofuels production and processing. It is also important for a participatory mitigation of negative impacts. The effort to harness biofuels production potentials as an alternative livelihood in volatile regions like the Niger Delta region requires the consolidation of peace and security in these communities.

Conclusion

This paper has provided a preliminary assessment of the biofuel feedstocks and fuel production potentials of Nigeria. This initial review illustrates the existence of huge energy crops production capacity and the availability of general biophysical characteristics in terms of soil type, availability of land for arable and permanent crops production, water availability and the ample water supply for crop cultivation, which furthers confirms von Braun (2007) description of Nigeria as among nations with high and promising biofuel production capacity. Considering the global drive for and adoption of biofuels, Nigeria will of necessity need to put in place a workable framework for biofuels adoption, production, processing and distribution. As the nation envisages in the near future fully independent and secured supply of refined petroleum products, which meets the international regulations, and as government's effort to curb persistent scarcity is being pursued, there is definitely a need to set the pace for biofuels adoption. The availability of biofuel production potential, the need to guarantee fuel supply security and promote rural economy growth is essential premises for the adoption of, and mainstreaming the processing of biofuels into the energy sector in Nigeria. There is bound to be environmental, economic and social related gains derivable from the adoption of biofuels in Nigeria. As this review is preliminary, a comprehensive analysis of bio-economic and environmental capacities for biofuels adoption is recommended. Further studies, which brings into fore existing consumption capacity, the economic capacity for biofuel-fossil substitution as well as willingness to adopt biofuels by the major energy dependent sectors is necessary.

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Biofuels development and adoption in Nigeria: Synthesis of drivers, incentives and enablers

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ABSTRACT

Biofuels development and adoption in Nigeria has progressed significantly since the inception of the country's biofuel program in 2007. The rapid growth of the biofuels subsector in Nigeria inspired this review which aims at identifying the key drivers, agents, enablers, incentives and objectives driving the development. From the upstream to the downstream sub-sectors, there is an increasing entry of players and participants (private and public investors). This paper aims to explore the underlining drivers, enablers and incentives promoting the investments and participations in biofuels development, adoption and utilization in Nigeria. The research sourced data from basically secondary sources and undertook desk review of available information. The drivers identified are classified into the endogenous and exogenous categories. From the review, the paper presents a multi-components conceptual framework that captures key elements of the biofuel development in Nigeria.

1. Introduction

Biofuels adoption in Nigeria encompasses the different phases in the development of the biofuels subsectors of the country's economy. The prompting directive which evolved into the biofuels development was issued by the Federal Government of Nigeria (FGN) in 2005, mandating the Nigeria National Petroleum Corporation (NNPC) to initiate and create the environment for the take-off of the Automotive Biomass Programme for Nigeria (NNPC, 2007). The directive and subsequent initiatives by the NNPC culminated in the kick-start of activities within the biofuels industry in Nigeria. The adoption of biofuels in Nigeria is confirmed and highlighted by the commencement of the Biofuels Programme which was categorized into the first and second phase of the promotion and utilization of biofuels in Nigeria. NNPC (2007) delineated the first phase as the period for the implementation of the 10 percent fuel ethanol blending rate (E10), which is been achieved by penetrating the market with ethanol imported from Brazil (NNPC, 2007; Ohimain, 2010). The second phase of the biofuels development in Nigeria which also affirmed the extent of adoption of biofuels is the promotion and implementation of the domestic biofuel production in Nigeria. There has been a leap in the progress of the biofuels development in Nigeria. Ohimain (2010) reported the current level of biofuels development indicated by the massive investments in the biofuels, particularly the ethanol subsector estimated at about $3.86 billion. The progress in biofuels development and adoption is also evidenced by the different biofuels production factories and refineries at various stages of development in Nigeria. The upstream segment of the biofuels industry is also witnessing appreciable development with the NNPC promotion of the out grower schemes for feedstock production. Various out grower schemes for cassava, jatropha, and sugar cane utilization as biofuels feedstock are being undertaken across Nigeria. Other private and public initiatives mobilizing investments and establishing plantations based on the geophysical suitability for growing different feedstocks including cassava, sweet sorghum, green maize, jatropha, oil palm and sesame across the country are also advancing the biofuels development.

The adoption of biofuels holds a diversity of opportunities and potentials for the Nigerian economy. Some of these opportunities are key socio-economic drivers promoting investments in the biofuels subsector. The importance placed on transforming the drivers to avenues for socio-economic development led the FGN to put in place incentives for biofuels industries, facilitating access to and harnessing the enablers for promoting the development and increasing the adoption of biofuels in Nigeria. From the upstream to the downstream sub-sectors, there is an increasing entry of players and participants.

Nigeria is a major oil producing country with crude oil reserve estimated at 37.2 billion barrels, a daily production capacity estimated at 2.2 million bpd and 47 years R/P (reserves/production) ratio as at 2008 (WEC, 2010). Despite the huge fossil fuel production capacity, Nigeria has joined other nations in the quest

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for harnessing the biofuels production potentials by promoting and implementing the biofuels development and adoption program. The objectives for adopting biofuels include the need to reduce Nigeria's dependence on imported refined petroleum products and curbing environmental pollution, which has been one major criticism levelled against petroleum exploration and production. The FGN quest to diversity the Nigerian economy and create other commercially viable sectors is yet another underlining motive for the adoption and implementation of biofuels program (NNPC, 2007).

The surge in the global demand for renewable and alternative energy sources combined with the potentials for large scale production of biofuels enabled Nigeria's entry into the biofuels era. Though Nigeria is a major petroleum exporting country the drivers for promoting biofuels adoption are deeply connected with the roots of the many problems impeding the growth and development of the nation's economy (Abila, 2010; Sambo, 2009). There is a preponderance of rural communities and populations with a default energy reliance sourced mainly from renewable sources and primary biofuels such as fuelwood, charcoal, palm kernel shells, palm-oil wastes (shaft and slurry), sawmill waste, cow dung among others. Though there is also a rapid growth of urban centers across Nigeria, majority of the population in urban areas still depend on these renewable sources because of the very low rate of access to electricity, natural gas or other improved or cleaner energy sources. The poor state and reach of infrastructure and mechanism for these energy generation and distribution have been major factors limiting access.

Different authors have attempted to identify the drivers of renewable energy development around in world. Rourke et al. (2009) identified major drivers for the deployment of renewable energy technologies in Ireland to include among others security of supply, environmental concern, high and fluctuating prices of fossil fuels as well as technology, agricultural, rural and social related policies. Peters and Thielmann (2008) identified preferential taxation, rural development and energy supply diversification as major drivers promoting biofuels in developing countries. Other drivers identified as promoting biofuels development include biofuel policy, biophysical potentials, various socio-economic factors, climate change threats, emission reduction targets, promotion of employment in agriculture, energy insecurity, resource potential, among others (Charles et al., 2007; Schut et al., 2010).

Generally, the clear delineation and typology of drivers of biofuels development is still far-fetched, hence this paper attempts to bring to fore the thematic factors which have become crucial in the development of the biofuels sub-sector in Nigeria. An understanding of the various factors and their delineation into related components will help in the implementation of biofuel policies and providing focus to the various elements in the biofuels development phases.

This paper aims to explore the underlining drivers, enablers and incentives promoting the investments and participations in biofuels development, adoption and utilization in Nigeria. The paper categorizes the drivers into exogenous and endogenous inducements. From the analysis, the paper presents the multi-component conceptual framework of biofuels development and adoption in Nigeria.

2. Methodology

This research undertakes a review of the socio-economic, environmental and other factors underpinning the development and adoption of biofuels in Nigeria. The review research involved an extensive desk review of available literatures, information and secondary data, which were sourced from the internet, consultation of gazetted documents and published database and information by the Nigeria Bureau of Statistics, Nigerian National Petroleum Corporation (NNPC) and other available secondary sources including previous publications and report from the International Energy Agency, Food and Agriculture Organisation, World Energy Council and other international organizations. Considering the fact that the biofuels sub-sector is still emerging in Nigeria with few in-depth exploration and analysis, this research attempts a synthesis of factors, drivers, enablers and incentives to help construct and propose a conceptual framework for the biofuel development and adoption. Quantitative analysis of sourced secondary data was done using descriptive statistics such as percentages and ranking. Though the proposed conceptual framework does not necessarily reflect empirical correlation and causation relationship between drivers, agents, actors, incentives, enablers and objectives, the synthesis is aimed at grouping issues and factors that would be useful for further empirical work as the biofuels industry in Nigeria gets fully established.

3. Biofuels development in Nigeria

Though the traditional energy sources in Nigeria are predominantly combustible renewable primary fuels (IEA, 2007), there is an increasing shift and adoption of the first and second generation biofuels. The first generation biofuels which include biodiesel, bioethanol and biogas (Naik et al., 2010) are sourced mainly from edible sources or current food material such as maize, soybean, oil palm, sugar-cane and cassava for ethanol or biodiesel production. The second generation biofuels are fuels sourced from mainly non-edible sources such as jatropha, algae (Naik et al., 2010). The crude ethanol or edible oil for the range of first generation biofuels are already being produced at non-commercial and commercial scales in Nigeria. Ethanol production is part of the traditional livelihood systems in the Niger Delta area and extending to some part of the south western States of Nigeria. Edible oil production from soybean, ground nut, oil palm fruits, oil palm kernel, sesame seed, melon seed, cotton seed, shea nut and cashew nut has been thriving aspects of the agricultural subsector.

Beyond the traditional small scale and the medium scale production of oil and crude ethanol in Nigeria, there is a growing response to the market demand for these products for the production of biofuels. Various private and public investment projects in first generation biofuels are starting up in various parts of Nigeria. These biofuels investment projects are at various stages of implementation ranging from feasibility studies to refinery plant installation. Ohimain (2010) posited that the market demand for ethanol in Nigeria is estimated to be 5.14 billion litres per annum. The demand for biodiesel on the other hand is estimated at 480 million litres per annum (NNPC, 2007). An increase in the demand for bioethanol, biodiesel, and biogas is envisaged as the urban and middle class population in Nigeria increases.

The response to the existing and future demand is reflected in the growing number and value of investments in fuel ethanol and biodiesel production. Ethanol production in Nigeria to meet the prevailing demand is reported to be about 134 million litres per annum from five major commercial scale ethanol distilleries located in Lagos, Sango–Ota and Bacita (Ohimain, 2010). Various biodiesel production projects are at various stages of implementation. The biodiesel projects include the Biodiesel Nigeria Limited's biodiesel initiative in Lagos State, Aura Bio-Corporation's Tolao Biodiesel project in Cross River State and the Shashwat Jatrophal Biodiesel Limited's biodiesel project in Kebbi State.

These biodiesel production projects which are been implemented through private public partnership (PPP) arrangements target jatropha and soybean as the major source of feedstock. Alamu et al. (2007, 2008) reported the successful production of biodiesel from palm kernel in a research trial in Nigeria. There are also ongoing research profiling and testing a wide array of other edible and non-edible feedstocks for biodiesel production at the University of Agriculture and the Benue State University, Makurdi in Benue State, Nigeria. In the same vein, potential feedstocks profiling is ongoing at the Energy Institute, University of Vaasa, Finland. The feedstocks sourced from Nigeria, been profiled and assessed include shea nut, sesame, yellow oleander, jatropha, tiger nut, wild pear, castor and fluted pumpkin seed.

Progress have been reported in the designing of biogas plants at the Usman Danfodiyo University where a biogas digester with 425l capacity adequate for household cooking energy need has been developed (Akinbami et al., 2001). Other experimental efforts are also ongoing at the University of Nigeria, Nsukka and at the Global Network for Environment and Economic Development Research (GNEEDER) in Ibadan for developing appropriate technological innovations for harnessing existing potentials for producing biogas, particularly for household use.

The implementation of the Seeding phase of the biofuel development in Nigeria been implemented by the NNPC entails the introduction of fuel ethanol, the creation of biofuels market in Nigeria and facilitating the development of the necessary infrastructure to support the introduction and marketing of biofuels in Nigeria. Since Nigeria currently import most of the refined petroleum products to meet the daily consumption estimated 4.5 t of motor gasoline in 2008 (IEA, 2008), the NNPC is undertaking several initiatives including the modification of the Pipelines and Product Marketing Company limited (PPMC) facilities at the Altas Cove, Mosimi Depot and other PPMC facilities across the country to handle fuel ethanol blending according to the E10 specifications. The PPMC is a subsidiary of the NNPC responsible for sourcing and distributing petroleum products across Nigeria.

4. Drivers, enablers and incentives of biofuels adoption

4.1. Nigerian biofuel policy and incentives

In promoting biofuels, the FGN in 2005 gave NNPC the directive to initiative Automotive Biomass Program for Nigeria. The directive was aimed at facilitating the development and adoption of biofuels as well as promoting investment in the subsector (NNPC, 2007). This led to the birth of the Nigerian biofuel policy and incentives, a government whitepaper for promoting biofuels in Nigeria. The white paper provides a broad policy platform for promoting the development and adoption of biofuels as well as fast tracking the investment in biofuels value chain from feedstock production to biofuel refining and distribution. The policy set a target of 10 years for attaining full E10 blending of gasoline and by implication BD10 for biodiesel blending. Though the whitepaper identified very few source of biofuels feedstock in Nigeria particularly for producing first generation biofuels, Nigeria has the potential for producing feedstocks for second generation biofuels including sweet sorghum, sweet corn, jatropha, algae and water hyacinth. The feedstock cultivation will harness currently underutilised arable and marginal lands in Nigeria. The promotion of feedstock production for boosting agricultural productivity is also expected to pose no threat to the food security situation or negatively impact the environment.

The underlining objectives for government interest in a national biofuel promotion are among other revenue diversification, job creation, improving agricultural productivity, meeting energy needs as well as deriving environmental benefits. Vermeulen et al. (2009) hinted that the growth in the demand for biofuel particularly for transport fuel is driven by policy. The federal and state governments are the main agents promoting biofuels development in Nigeria. The actions and initiatives of governments are focused on putting in place policies as a key driver, outlining incentives and also providing support for accessing existing enablers. Though Nigeria practices a free market economy, government role remains crucial in providing the foundation and support for the development and thriving of various sectors. Table 1 delineates and outlines the key components and incentives of the Nigerian Biofuel Policy and the respective agencies of government that are saddled with the mandate of facilitating the deployments of the incentives and access to enablers.

The biofuel policy consists of a number of tools projected for incentivising the take-off and development of the biofuels industry in Nigeria. Notable is the economic and financial framework which include the pioneer status providing income tax relief for a period of 10 years, import and custom duties waiver for the importation of fuel ethanol to meet the E10 blending regime at the onset of the policy implementation and importation of machineries and materials necessary for establishing feedstock plantation and biofuels plants. Other important incentive is the provision of the preferential long term loans to actors within the

Table 1
Components and incentives of the Nigerian biofuel policy and implementing agencies.

Policy frameworks	Components and incentives	Implementing/responsible agencies
Regulatory/legislative	Biofuel policy and acts,	Ministry of Petroleum/NNPC
	biofuels plants	NNPC/DPR
	integrated plantations, out grower schemes,	Ministry of Agriculture & Ministry of Commerce and Industry
	biofuels energy commission,	Ministry of Petroleum/NNPC
	biofuels research agency,	Ministry of Petroleum/ Ministry of Agriculture
	research and development funding	Federal Government/Central Bank of Nigeria
Economic/Financial	Pioneer Status – Income tax relief	Ministry of Finance
	Withholding tax on interest & dividends	Ministry of Finance/Inland Revenue Office
	Import and Customs duties waver	Ministry of Finance/Custom
	Value Added Tax exemption	Inland Revenue Office /Ministry of Finance
	Long Term preferential loan	Central Bank of Nigeria
	Preferential Insurances and guarantees	Central Bank of Nigeria
	Biofuel blending and off-take guarantees	NNPC
Environmental	Qualification for CDM and other protocols or carbon credit or emission benefits	Ministry of Environment

Table 2
International agreements and treaties relating to biofuels.

Agreement or treaties	Elements WRT biofuels	Date of ratification	Coordinating agency	References
United Nations Framework Convention on Climate Change (UNFCCC)	Climate change, Greenhouse gases emission, desertification , drought	29 August 1994	Federal Ministry of Environment	(UNFCCC, 2011)
Kyoto Protocol	Climate change,Greenhouse gases emission, desertification, drought	10 March 2005	Federal Ministry of Environment	(UNFCCC, 2011)
Convention on Biological Diversity	Species, ecosystem, water, land	29 August 1994	Federal Ministry of Environment	(CBD, 2011)
Cartagena Protocol	Biosafety	13 November 2003	Federal Ministry of Environment	(CBD, 2011)
Ramsar Convention[a]	Wetland, species, ecosystems	02 February 2001	Federal Ministry of Environment	(Ramsar, 2011)

[a] Nigeria has about 1.1 million Ha of wetlands (Ramsar, 2011). WRT=with respect to.

upstream and downstream subsectors of the biofuels industry who qualify for the pioneer status. To qualify for a pioneer status, an investor must have invested in and be implementing a project in the upstream or downstream sub-sector of the biofuels industry. The biofuel policy and its implementation have played a major role in the rapid development of the biofuels subsector, particularly in the number and worth of investment into the biofuels industry in Nigeria. The policy document constitutes a prime driver for the adoption of biofuels and the growth of the biofuels industry. The rapid pace of development of biofuel in Brazil, France, Germany and USA has been ascribed largely to the policies put in place by governments in these countries (IEA, 2006; Peters and Thielmann, 2008; Sorda et al., 2010). Peters and Thielmann (2008) debated the justification for promoting biofuels in Brazil even when the delivery cost far outweighs the cost of fossil alternative. The validity of the arguments for promoting biofuels use based on other highly prioritized objectives such as reducing greenhouse gases emission, ensuring security of supply, job creation and economic diversification for long term gain vary from country to country. The policies for promoting biofuels always entails the proclivity towards the more highly prioritize short or long term objectives.

4.2. International and regional conventions

Nigeria is a party to a number of regional and international conventions whose ratification, implementation and domestication pertain directly or indirectly to the development, adoption and utilization of biofuels. Nigeria's growing presence and participation in the global biofuel trade has been asserted with the increase in investments and implementation of biofuels projects (Abila, 2010; Ohimain, 2010). There is a link between the biofuels development in Nigeria and the many conventions whose ratifications have to do with the sustainable production of biofuels. Wetlands (2011) listed the global agreements and treaties which are considered of high importance in supporting the biofuels as well as being critical criteria for assessing biofuel sustainability. Some of these conventions specifically mentioned that biofuels such as the ethanol made from sugarcane or biodiesels variants from palm oil are examples of renewable energy sources.

Though these conventions do not focus primarily on biofuels, the increasing global discussions and the frequency of mention of biofuels and renewable energies in the recurring meetings of parties can be said to be promoting biofuel. Nigeria has ratified and is implementing a number of these treaties. The country's quest to implement some of the ratified conventions is tied to curbing desertification, drought, loss of wetlands, ensuring biosafety and biodiversity conservation. Curbing the prevailing livelihoods, particularly in the rural areas that cause deforestation and destruction of the wetlands and other ecosystems has been a priority for government. Rural livelihoods such as uncontrolled logging, charcoal production, and uncontrolled hunting are still rampant. These account for bush burning and rapid loss of forests, fragile ecosystems and biodiversity in Nigeria.

Providing alternatives to these unsustainable rural livelihoods through the promotion of sustainable biofuel production and utilization of non-productive arable land fall within the federal government biofuel policy. Various government agencies are mandated to implement and report progress of the domestication of these treaties in Nigeria. It is noteworthy that the implementation of these treaties also entails inter-agency as well as inter-ministerial cooperation on issues relating to Nigeria's participation in these conventions and treaties. Table 2 lists the various international agreements relating to biofuels and biofuels production which Nigeria is already a party to.

A number of agencies in Nigeria are already promoting projects towards benefiting from the international carbon trading. The international greenhouse gases accounting and reporting rules have been said to make biofuel a more attractive alternative to the fossil fuels (Wetlands, 2011). The availability of the essential and potential natural resources for biofuels production, the possible gains from participating in the clean development mechanism (CDM) and biodiversity conservation are objectives for translating the environmental and exogenous drivers (including regional and international cooperation) into promoting biofuels development and adoption in Nigeria.

4.3. International fossil fuels and biofuels demand

Nigeria's current dependence on imported refined petroleum products for much of the local consumption requirements has created the insecurity of supply, scarcity, exerted pressure on the distribution infrastructure and depletes revenues from the crude oil export. The implementation of renewable energy policies in various countries across the world promoting renewable energy from local sources, particularly biofuels is a potential threat to the revenue generation from crude oil export for Nigeria. Some of Nigeria's main crude petroleum trading partners including US, Brazil, France, India, and Netherlands are already implementing a vigorous renewable energy programmes which may result in the cut in the existing import from Nigeria. The implementation of the European Union's renewable energy directive (EC, 2008) and other biofuels promoting mandates in countries across the world are bound to create ripples. UNCTAD (2009) posited that the implementation of mandatory blending targets will impact the feedstock, the biofuels and transport fuel markets. The impact of the various mandates and directives promoting biofuel will be either negative or positive. This will affect fossil fuels and biofuels endowed countries and those that are not.

The international pressure on the global fossil fuels and biofuels markets is linked directly or indirectly with the capacity to ensure security of supply, stabilize fuel pump price and to manage fuel related subsidies within national boundaries.

The trends in the international market and regulations for fossil or bio fuels could not be ignored even by a country rich in fossil fuel deposit, but depends entirely on the international market for meeting the daily domestic fuel consumption requirement. This trend is stimulating the effort to harness in-country capacities for producing biofuels. Abila (2010) affirmed that Nigeria falls within the region of the world that meets the von Braun (2007) criteria for sustainable biofuels production. These criteria are the availability of arable land and water as well as the current level of food security. Wetlands (2008) had earlier reported that Nigeria is one of the major possible biofuels exporting countries in Africa considering the biofuels' production potentials that can be harnessed.

WEC (2010) reported an increase in the production of biomass feedstock and processed bioenergy carriers including bioethanol and biodiesel in 2010. The increasing demand for biofuels which hinges on cost effectiveness and GHG emission reduction have been major drivers of the international trade in biofuel. The instability and increases in the price of crude oil in the international market sometimes makes biofuels cheaper (UNCTAD, 2009). The possibility of having alternative fuels whose pump price is cheaper is driving biofuels development and adoption in Nigeria. This holds an enormous cost saving prospects for Nigeria, particularly in cutting down on the huge expenditure for subsidizing petroleum products consumed locally.

4.4. Default dependence on renewable biomass fuels

Report estimates of International Energy Agency (IEA, 2007) put the total energy consumption for Nigeria at 107,000 kt of oil equivalent. This IEA estimate shows that combustible renewable primary fuels provide 80.2 percent of the total energy need in Nigeria. According to the IEA report, the highest contribution for renewable biomass fuels serves the energy requirements for heating and cooking needs particularly in the rural areas where access to the national grid is currently not available or still a dream in the pipeline. A previous national survey of the National Bureau of Statistics (NBS) in 2005 which profiled the poverty level in Nigeria provided national estimate of the sources of fuels for cooking as shown in Fig. 1. Firewood contributed nearly 70 percent based on this estimate (NBS, 2005). In 2007, an economic survey by the NBS shows there has been a gradual climb in the proportion of the population of Nigeria who depend on fuelwood for cooking. NBS estimates put the proportion at 74.1 percent. Previous study by Akinbami et al. (2001) also reported the energy source survey of 1991, in which fuelwood contributes about 66 percent. The electricity supply and sources survey for the same year 2007 also indicated that only about 47 percent of the population access electricity from the main national grid, while considerable proportion (41 percent) do not have access to any form of electricity supply. IEA data for 2008 indicated that electrification rate for Nigeria was 47 percent for the entire country. In urban areas, 69 percent of the population had access to electricity compared to rural areas where electrification rates were 26 percent. Approximately 81 million people do not have access to electricity in Nigeria.

The low level of access to electricity and cleaner sources of energy implies majority of the population with no access depend on primary sources of energy such as fuelwood, charcoal, palm kernel shells among others. According to Sambo (2009), Nigeria consumes over 50 million metric tonnes of fuelwood annually which contributes greatly to the rate of deforestration of the nation's primary forest resources which replenishment cannot be attain going by the current level of afforestation. The combination of these problems constitute major environmental and energy concern which must be addressed by promoting and providing access to cheaper, cleaner, environment friendly and sustainable fuels. Though the FGN has been implementing integrated power projects for improving electricity generation, transmission and distribution in the last ten years, there has not been any significant change in the level of access. Biofuels may provide a solution to the lack of access to cleaner energy by the poor and middle class urban and rural population. The current level of dependence on fuelwood for cooking and small to medium scale processing such as in bakery and confectionary industries is not sustainable.

4.5. Poverty

The poverty level in Nigeria and the declining capacity for electricity generation has deeply entrenched the dependence on

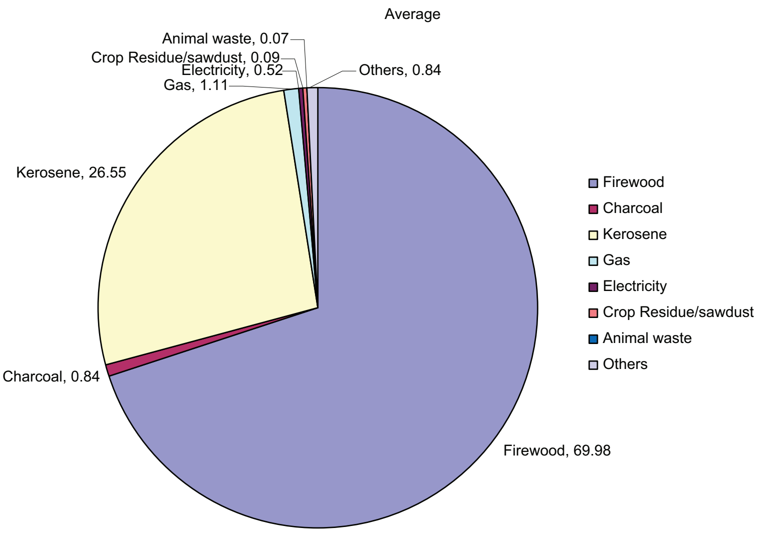

Fig. 1. Energy consumption by source in Nigeria.
Source: NBS, 2007.

renewable biomass fuels. The current level of poverty and the default reliance on energy from renewable source are important drivers, pushing government to explore the opportunities for making a transition into improved technologies and techniques in the use of the traditional biofuels and biomass. Though the use of traditionally produced fuels of kernel oil or other oil as lighting reduced over the years, there is an opportunity to stimulate the local production of biodiesel for powering homes and appliances that are far from the national electricity grid infrastructure. Harnessing biofuel and biomass resources for off-grid electricity generation is a viable option for villages and telecommunication infrastructures in remote locations. Table 3 below shows the increasing poverty rate and incidence in Nigeria between 1980 and 2004. The increasing poverty level is an indicator of the lack of access to improved energy sources. This makes the existing need and potential demand for alternatives such as biofuels evermore crucial. The need to create new opportunities for employment within the biofuels value chain and in the allied sectors ranks among the main objectives of government for promoting biofuels development (Azih, 2007). For some developing countries, promoting biofuels has been described as a 'pathway out of poverty' (Schut et al., 2010). Differing opinions abound on the impact of biofuels in alleviating or exacerbating poverty (Habib-Mintz, 2010), but the implementation of sustainable biofuels programmes remain a valid option for alleviating poverty in most biofuels endowed countries.

4.6. Potential demand for biofuels

The Nigerian Biofuel Policy and incentive gave an estimate of fuel ethanol requirement at 10 percent blending rate to be about 1.3 billion litres per annum with projected increase to 2 billion litres by 2020. This estimate gives the worth of the bio-ethanol market to be $391 million annually. Table 4 shows the various substitution capacity for biofuels based on the 2008 average consumption for petrol, household kerosene and diesel. A combined capacity for the major fuels consumption at the blending rate E10 and BD10 proposed by the Nigerian biofuels policy gives a demand of about 3011 mt of biofuels.

4.7. Feedstocks production and capacity for productivity improvement

Nigeria falls with the region of the world rated to have high potential for biofuel production based on the three-criteria of the level of water availability, level of available arable land and the state of food insecurity (von Braun, 2007). This high potential is further buttressed by the current production capacity for the basic feedstocks for first generation biofuels. Abila (2010) posited that the level of productivity of crops with very high potentials and demand for biofuel production can be improved. The improvement in the productivity level per hectare allotted for the production of these crops will help to create a balance between the food and fuel objectives. Table 5 shows the major biofuel crops for which Nigeria ranks between 1st and 20th position in terms of nominal production globally. The ranking of the productivity per hectare cultivated for this crops shows Nigeria has much room for improving on the production efficiency of these crops. Based on these FAO data, Nigeria leads in the production of cassava globally, but ranks 13th globally in terms of productivity per hectare cultivated. This underpins one of the underlining objectives for promoting investment in first generation biofuels in Nigeria. The Nigerian biofuels policy classifies investments within the biofuels value chain as an agro-allied. This helps such investments to benefit from various incentives such as government guaranteed insurance, long term loans, value added tax waiver and custom duties waiver in attempt to stimulate biofuels production for achieving multiple objectives.

Table 3
Trends in poverty levels between 1980 and 2004.
Data sourced from the National Bureau of Statistics (NBS), 2005 and 2007.

Year	Population estimate (million)	Poverty incidence (%)	Rate of poverty increase (%)	Rate of population growth (%)
1980	65	28.1	0	0
1985	75	46.3	64.8	15.4
1992	91.5	42.7	−7.8	22.0
1996	102.3	65.6	53.6	11.8
2004	126.3	54.4	−17.1	23.5

Note: the rates are in comparison to the previous year.

Table 4
Nigeria's biofuel substitution capacity on 5, 10, percent fuels blending rates (000 mt).
Data sourced from the NNPC Annual Statistical Bulletin (2008).

Fuel types	Yearly average consumption ('000 mt)	Biofuels substitution capacity for blending rates ('000 mt)	
		5 (%)	**10 (%)**
PMS	20,822.45	1041.12	2082.25
HHK	3,766.13	188.31	376.61
AGO	5,524.94	276.25	552.49

PMS – Premium Motor Spirit (Petrol), HHK – Household Kerosene, AGO – Automotive Gas Oil (Diesel).

Table 5
Nigeria's production, productivity and cultivated area ranking for edible feedstocks.
Data sourced from Food and Agriculture Organisation (FAO), Statistics (2008).

Crop	2008 Average yield (MT)	Nigeria's nominal production rank (Global)	Nigeria's yield land productivity rank (Global)	Nigeria's cultivated area (Ha) rank
Sesame	110,000	7th	13th	6th
Palm fruits	8500,000	4th	20th	3rd
Ground Nut	3900,000	3rd	6th	3rd
Soybean	591,000	13th	20th	10th
Coconut	234,000	19th	10th	17th
Cotton Seed	492,000	12th	18th	9th
Cassava	44,582,000	1st	13th	1st
Maize	7525,000	14th	17th	7th
Green Maize	5709,000	3rd	17th	2nd

5. Conceptual framework for biofuels development and adoption in Nigeria

The review of available literature, analysis of the various government policies and investments and the various factors based on the available socio-economic data brought to the fore the various components of the biofuel development in Nigeria. These include key drivers, the agents, the different tools and elements for incentivising investments and participations in biofuel development. Other components are the diversity of actors and stakeholders as well as the key objectives for promoting biofuels development and adoption in Nigeria. The review culminated in proposing the conceptual framework detailed in

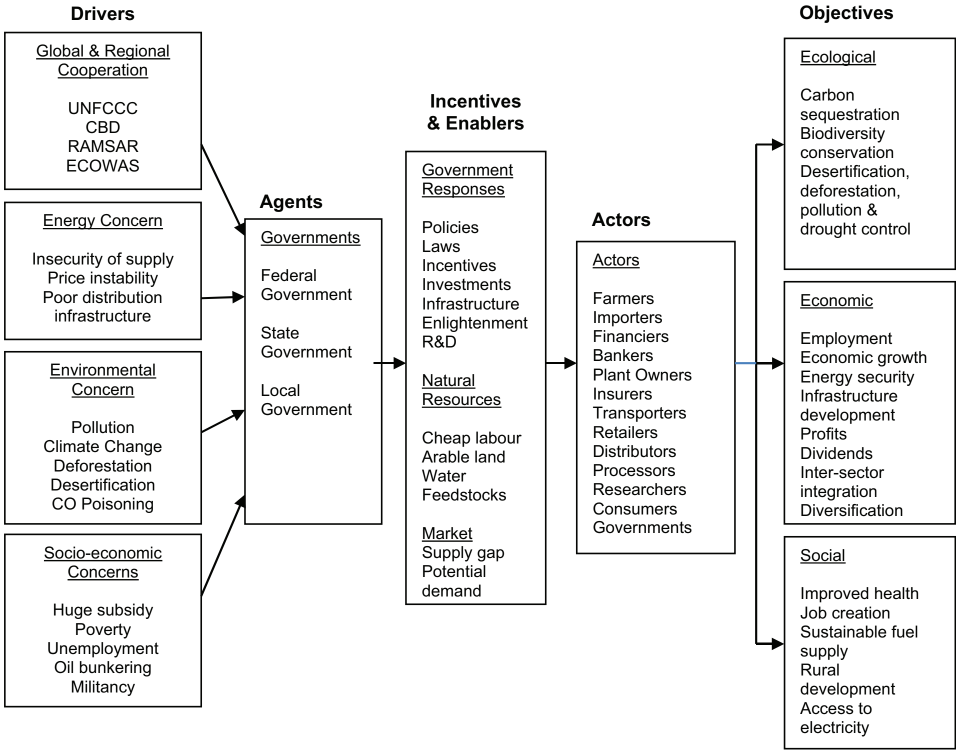

Fig. 2. Conceptual Framework of biofuels development and adoption in Nigeria.

Fig. 2. This conceptual framework shows that there are various components including drivers, agents, incentives, enablers, actors, and objectives that feature in the biofuel development in Nigeria.

The drivers can be grouped into exogenous and endogenous categories based on the sources of such pressures exerted on the agents. The exogenous include various global and regional cooperation such as treaties and conventions to which Nigeria subscribes. Others in this category include international trade, prices and demands for fossil and bio fuels which exert pressure on the local energy market situations. The endogenous category of drivers includes variables from within the country that exert pressures on the agents. These include various socio-economic, environmental and energy related challenges. The endogenous drivers are problems and issues which affect economic growth and the attainment of others socio-economic indicators. The various components of the exogenous and endogenous drivers constitute the forces propelling the federal, state and local governments to initiate the processes and create the environment for biofuels development.

Nigeria's participation in many international treaties and protocols promoting sustainable development places upon the country the burden of implementing agendas, targets and projects that are proposed from such cooperation. Wetlands (2008) report on the global biofuel situation alluded to the possibility of Nigeria and other countries in Africa participating in the global biofuel trade. Nigeria's participation in the international biofuels trade will become a driving factor for the expansion of the biofuel sub-sector once the targets specified in the first and second phase of the biofuel growth in Nigeria has been attained. There is no doubt that considering the potentials for feedstock production for solid, liquid or gaseous biofuels, Nigeria may become a key player in the international biofuels trade.

The four categories of global cooperation, energy concerns, environmental concerns, and socio-economic concerns constitute the drivers for biofuels adoption in Nigeria. The exogenous and endogenous inducements and pressure on governments brought about the development of the biofuel policy and incentives. The biofuel policy is incentivising investments and allocation of funds for driving the national Automotive Biomass Programme for Nigeria. The various incentives are targeted at the different actors including farmers, importers, and processors, among others. The objectives for incentivising the biofuel developments and adoption include various elements within ecological, economic and social categories.

Governments at the various levels are the main promoters of biofuels in Nigeria. The biofuels development and adoption in Nigeria is highly incentivised. Apart from the incentives put forward by the governments, there are also key enablers that facilitative the entry of actors to harness the incentives provided by the governments. There are two categories of enablers. These are the natural resources that can sustain feedstock production and the existing supply gap and potential demand for biofuels. The domestic market potential for biofuels blending with fossil fuels and direct utilization is a key enabler. Nigeria is the second largest economy in the Africa and the progress in economic and infrastructural development will continue to expand the fuel demand for transport and other sectors in the next decades. The enablers are crucial for biofuels development and adoption. The natural resources are important for efficient production of feedstock, while the existence of a guaranteed market ensures the sustainability of entire biofuels value chain.

The progress into the second phase of biofuel development and adoption in Nigeria highlights the existences of many actors.

The actors range from participants in the upstream to downstream sub-sectors of the biofuels industry. The designing and implementation of the various biofuel projects in Nigeria reported by Ohimain (2010) shows an interaction between various actors and the implementation of public private partnership (PPP) approach in fostering the development and adoption of biofuels in Nigeria.

The actors outlined in Fig. 2 have sets of motives and objectives for participating in the biofuels development and adoption in Nigeria. The conceptual framework categorizes the objectives within the sustainability tripod of ecological, social, and economic. The various objectives are cut across various actors within the biofuel industry. The sustainability of the biofuels industry will depend on the balancing of the various objectives as the biofuel industry in Nigeria progresses through the second to the third phase. The main objectives for the promotion of biofuel development and adoption in Nigeria by the governments have been posited to include among others creating a multiplier on employment generation and bringing about more agricultural opportunities (Azih, 2007).

6. Conclusion

This paper outlined the key components of the biofuel development and adoption in Nigeria. Biofuels development and adoption in Nigeria is at the second phase. This phase encompasses the development of the domestic capacity for meeting the E10 or BD10 blending regime. The progress attained so far in the growth of the biofuels sub-sector is driven by the government which serves as the key agent for promoting biofuel development and adoption in Nigeria. Government responses to the highlighted drivers including the exogenous and endogenous components have led to various initiatives for incentivising the biofuels development and adoption process. Some of the drivers, including the predominant default dependence on primary biomass fuels, poverty level, unemployment and the current low level of access to improve energy sources confirm the existence of gaps in energy supply. The gaps provide strong inducements for attracting investment into the biofuel production value chain considering the enabling environment and incentives created by the government.

The multi-component conceptual framework on biofuels development and adoption outlined the key drivers, agents, incentives, enablers, actors and the underlining motivations and objectives. The drivers which constitute major concerns and commitment are stimulating government responses and actions towards developing Nigeria's capacity to become a major player in the increasing global biofuels market. The components of the conceptual framework outlined are variables to put into consideration in ensuring the sustainability of the biofuels development and adoption in Nigeria. The drivers and objectives components of the conceptual framework indicate problems and prospects requiring medium and long term policy interventions from government to ensure an efficient transition into a bioenergy driven economy. The drivers, incentives and enablers present areas of interest for investors and other actors who would need to come up with sound strategies as players in the emerging biofuels economy in Nigeria.

The objectives component of the conceptual framework highlighted ecological, economic, and social elements which are crucial for attaining sustainability. These various elements of sustainability of biofuel development in Nigeria are in line with the IEA (2009) prescribed 'three Es' of sound energy policy – energy security, economic growth, and environmental protection. It is crucial that governments work towards maintaining and implementing sound energy policies in their investment drive. There is also the need to back the various policies with a proactive monitoring and evaluation strategy. The implementation of policies and investments should also focus on capacity building and research and development in the bioenergy subsector. Research mandate should focus on exploring and identifying feedstocks which are not already listed among the priority feedstock but hold good potential for biofuel production.

The conceptual framework provides a pillar for further analysis of the relationship between actors, the drivers and motivations for biofuels adoption in Nigeria. Future reviews, designing and implementation of biofuels policy and the channeling of the domestic biofuel production programmes should take into cognizance the key drivers and enablers. This is to ensure the attainment of the multiple-goals and a win–win situation for the many actors within the biofuels subsectors in Nigeria. The drivers and enablers identified in this article are factors considered of importance for consolidating the gains and progress already achieved in biofuels development in Nigeria.

Acknowledgment

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Biofuels adoption in Nigeria: Attaining a balance in the food, fuel, feed and fibre objectives

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ABSTRACT

The drive towards economic development in Nigeria brings about the pursuit of many competing objectives whose attainments depend on limited resources. Biofuels adoption has been set as an important path, among other options, for pursuing economic growth and development for the country. The Federal Government of Nigeria (FGN) is currently promoting the production, processing and utilization of biofuels in the transport and energy sectors. The article examines biofuels adoption in Nigeria vis-à-vis the attainment of a balance in the food, fuel, feed and fibre objectives. Crops already profiled as preferred sources of feedstock for the primary biofuels production are also crucial for food, feed and fibre. The resources needed for producing these crops are limited, hence the need for a balance. This paper derived data from secondary sources including the Food and Agriculture Organization (FAO). The paper explores some aspects of biofuels sustainability and present recommendations for attaining a balance in the multiple objectives for attaining socioeconomic development.

Contents

1. Introduction

Energy is a critical factor in the pursuits of socioeconomic growth and development objectives of any nation. Energy is required for driving activities in the various sectors of the economy. There is also a linkage between energy supply and consumption, and meeting the food, fuel, feed, and fibre targets which in turn determine the aggregate contribution of agriculture and other sectors to the national gross domestic product (GDP). Various studies have attested to the strong link between energy consumption and socioeconomic development. Kebede et al. [1] posited that there is a direct relationship between energy use and technological development on one hand and economic growth on the other. Yildirim et al. [2] established the link between economic

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growth and energy consumption in the USA. The economic growth and development witnessed in China, India, Austria, Japan, and the United Kingdom have also been reported to lead to increase in energy consumption [3–5].

Karekezi [6] quoting an earlier report indicated that the rationing of electricity in Ethiopia, Kenya, Malawi, Nigeria and Tanzania impacted adversely these economies. The low energy consumption in Sub-Saharan Africa (SSA) accounts largely for why the GDP in these countries are among the lowest in the world [6]. The energy consumption and economic growth linkage re-enforces the need to gear up energy generation and consumption in an economy like Nigeria struggling to take off. Esso's [7] study of seven African countries including Nigeria re-enacted the fact that energy consumption and economic growth are co-integrated. This implies, to ensure the growth of the Nigerian economy is not impeded, concerted effort in policy and investment must be channelled towards ensuring stable energy consumption.

Access to energy at both the urban and rural sector of the Nigerian economy has been a recurring issue. Nigeria still depends on imported refined petroleum products for meeting the local consumption for transport, electricity generation and powering other activities. The decline in the local refining capacity as the nation's refineries age has led to the dependence on import for over 70% of the refined petroleum products consumed in Nigeria [8]. Recent industrial and civil crisis relating to the hike in prices of petroleum products, resulting from the removal of subsidies on imported refined petroleum products is an indicator of how dire the energy situation is in Nigeria [9]. The energy related crisis also is also telling on the nation's revenue profile as the financial burden of subsiding petroleum products increase every year. With the decline in industrial and agricultural production, partly accounted for by the energy shortage, Nigeria now depend largely on import for meeting food, feed, and fibre demands. Like in other countries with food security concern in West Africa, Nigeria import food to meet the shortfall in demand that local production cannot fulfil [10]. The trend in imports has been on the increase, making Nigeria a net importer of food and other products.

The overall impact of unstable supply of imported petroleum products, unstable prices tied to prices of crude oil internationally constitute further constraint on an economy with increasing unemployment, poverty rate, among other socio-economic indicators. The introduction of the biofuel policy in 2007 was set to provide an alternative path through agriculture to solving energy and related socioeconomic problems. Facing the obvious energy challenges, Nigeria, which is endowed with the conventional and renewable energy resources, must harness these resources to meet the fuel requirement for socioeconomic growth and development.

As the Federal Government of Nigeria (FGN) pushes the agenda of growing the economy through biofuels adoption, this paper explores some aspects of biofuels sustainability and how to attain a balance in and securing the supply of food, fuel, feed and fibre. The paper offers interpretations on the link between the objectives and how the advancement of biofuels can help in attaining the needed balance.

The data used in this paper were mainly derived from the Food and Agriculture Organisation (FAO) crop production and food balance sheet database. Data on water footprints for biofuels crops production, water footprint per energy and per litre of biofuel were sourced from Mekonnen and Hoekstra [11]. The paper is based on basic statistical analysis of secondary data on the crop production and land use.

2. Situating the food, feed, fuel and fibre objectives in the Nigerian biofuel policy

The advancement in the biofuel development and adoption in Nigeria is hinged on the directive – Automotive Biomass Programme for Nigeria – and the subsequent Nigerian Biofuel Policy and Incentives [12]. The directive and policy were put in place to promote biofuel utilization through seeding of the market through importation of refined ethanol from Brazil and promoting local production [13,14]. So far, no study exists showing there is a strategy in place to attain a synergy between food, feed, fuel and fibre objectives in Nigeria.

The biofuel policy identify and classified biomass as renewable raw materials from agriculture including trees, crops, plants, fibre, cellulose based materials, industrial wastes and biodegradable municipal solid wastes [12]. A further description of biofuel feedstock in the policy document include cassava, sugarcane, oil palm, jatropha, cellulose based materials and other crops as may be approved by a commission governing biofuel utilization in Nigeria. This broad categorization includes the sources of food, feed, fuel and fibre (for textile). Since the crops classified and being promoted for biofuel production are also used as food, feed or fibre, it is expected that the use of these crops for biofuel does not affect the attainment of other equally important objectives. In this scenario, there is bound to be conflict between food, fuel, fibre and feed, as these compete for the utilization of land, water, labour and other factors of production. Ohimain [15] had pointed out the obvious gap in the Nigerian biofuel policy and incentives of 2007 as it failed to address the potential food versus fuel conflicts. There is also the possibility of feed versus fuel, fibre versus fuel conflicts.

As the biofuels subsector in Nigeria evolves, it is crucial that the omitted goal of attaining a balance in the food, feed, fuel and fibre objective be included in the subsequent review of the Nigerian Biofuel Policy and other legislations that will be put in place to promote biofuel development and utilization. Though the current biofuels policy recognized that some food, feed, and fibre crops are biofuels feedstock, the policy was designed as mainly pursuing biofuels development goal in isolation to other objectives. The reworking of the biofuel policy must extend equally important incentives such as tax relief and import duty waiver; meant for facilitating the production of the crops classified as biomass or feedstock to crops devoted to other objectives.

3. Making biofuels sustainable in Nigeria

The advancements in biofuels adoption are not without fervent debates on the sustainability of fuels sourced from biomass. Amigun et al. [16] appraised the sustainability of biofuels in Africa on the premise of food versus fuel, land use and tenure security, climate change and environment, poverty impact and gender equality. The paper drew a conclusion on the need to adopt along with biofuels development, practices, process and technologies that can improve efficiency, reduce energy and water requirements for biofuels production. Janssen and Rutz [17] assessing biofuels development in Latin America vis-à-vis risks and opportunities concluded that environmental and social aspects are crucial for sustainability.

Specific issues about biofuels sustainability have also been assessed by other authors. Yang et al. [18] examined the land and water requirements for biofuel production in China and concluded that the pursuit of the current biofuel development path for the country will impact significantly food supply, trade and the environment. Owing to the link between fuel, food, feed and fibre, the production of one may influence the price of the other. Zhang et al. [19] identified a potential influence on the short-run prices of agricultural commodity as the global production of ethanol increased.

In summing the arguments on biofuels sustainability, von Braun [20] proposed a conceptual framework bordering on political, economic and environment as essential domains for assessing biofuels.

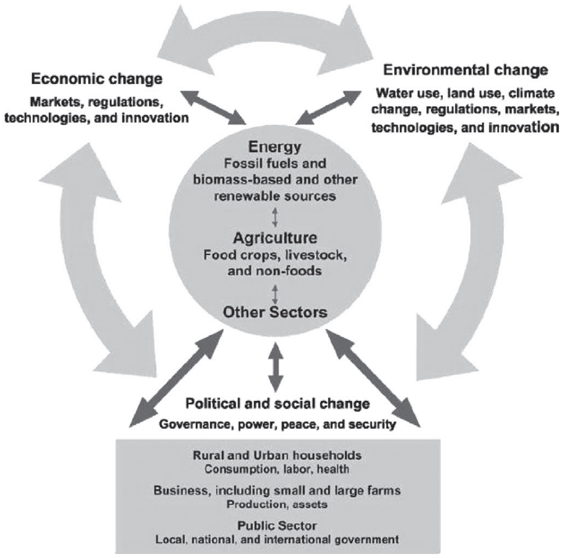

Fig. 1. Conceptual framework for assessing biofuels sustainability.
Source: von Braun [20].

Fig. 1 details the elements of von Braun's conceptual framework for assessing biofuel sustainability. This proposition argued for considering broader perspectives in assessing biofuels' issues rather than the use of simple yardstick of trade-offs between food and fuel. von Braun's proposition is hinged on the existence of an interaction between the three domains when agriculture and energy are linked through biofuels.

Biofuels adoption, promotion and utilization in Nigeria does not necessarily lead to, and should not be about trade-offs between fuel and food, or between other objectives such as fibre, feed, ecosystem preservation or biodiversity conservation. The primary biofuels, including fuelwood, charcoal, palm kernel shells, palm-oil wastes, sawmill wastes and cow dung still constitute a large proportion of energy source for cooking in Nigeria [14]. The adoption of first and second generations' biofuels provide solutions to environmental, economic and social problems such as deforestation, pollution and health risks associated with the use of the primary forms of biofuel, which are predominant in Nigeria.

Considering biofuels sustainability in Nigeria, the scientific arguments – environmental, technological, political, social and economic are no longer about if biofuels are acceptable but on how to guarantee and stabilize gains from the adoption of biofuels; maximize biofuels output per investment in feedstocks, processing technologies and distribution networks; optimize natural resource use in a biofuels' revolution; minimize environmental, social and economic impacts and develop efficient frameworks for meeting biofuels targets. The increasing adoption, promotion and investment into biofuels development have become irreversible owing to political, economic, environmental and social factors driving the biofuels revolution [14,21–23]. Based on these factors, it is obvious that the real concern is to ensure a sustainable biofuels' era.

As much as the three main domains proposed by von Braun [20] for assessing biofuels sustainability are tenable, the policy formulations and discussions about biofuels in Nigeria must transcend the meeting points between agriculture and energy on the political, economic and environmental domains. The emerging pivot for pushing for sustainable biofuels utilization is allowing for a balance in the pursuits of the multiple, competing and or complementing objectives. The pursuit of the food, fuel, feed and fibre objective can be seen beyond the competition for available arable lands, water resources, labour and capital. In avoiding conflict in the pursuits of these multiple goals, interlinking between the objectives through a lateral integration that allows for by-products from one enterprise to be transferred to another will enhance productivity. A good example is ensuring that the by-products from cassava production and processing that have for some time been considered as waste and disposed of, constituting environmental pollution and ecosystem destruction can be channelled into feed for livestock in an integrated production system. The interlink between agriculture and new energy sources – biofuels necessitates ensuring optimal sharing and allocation of the limited resources such as arable land and water. There is also the need to ensure the transfer of by-products from one enterprise to the other. This is the required paradigm shift to ensure biofuels sustainability.

3.1. Social concern

The social concerns within the tripod for sustainability regarding biofuels adoption in Nigeria is to ensure the attainment of the full range of social objectives as listed by Abila [14], including poverty reduction, employment creation, ensuring access to fuel, electricity and engendering rural development. The five decades of the exploration of petroleum can be adjudged to have failed in the social angle; hence, the emergence of a thriving biofuels subsector must ensure the non-repetition of such a trend. Decentralizing the entire value chain of biofuels production and allowing a fair participation of even the small scale farmers is a crucial policy for ensuring social sustainability. In this regard, the push for the maximization of the production of feedstocks must not lead to the takeover of small farm holdings by the bigger large-scale investors. The out-grower scheme listed in the biofuels policy for Nigeria, which is to facilitate arrangement between farmers and biofuels mill companies in the cultivation of feedstocks must be revised to ensure small scale and female farmers are not disenfranchised. Cooperative farming arrangements that will allow the farmers with small landholdings to pool and annex their farmlands to meet the basic farm size requirement for qualification under the out grower scheme must be put in place.

3.2. Economic concern

Making economic growth resulting from the emerging biofuels' subsector stable and efficient is crucial for sustainability. Though the Automotive Biomass Programme for Nigeria [12] was set out to facilitate the advancement of biofuels, the implementation of the policy needs to incorporate building and maintaining the natural and man-made assets for driving the biofuel revolution. Ensuring economic sustainability of the biofuel development in Nigeria necessitate allowing for critical resources such as land, labour, capital to be available for other important sectors. The growth of the biofuel economy must not be at the expense of manufacturing, transport, health, or other sectors of the economy. The growth of the biofuels sector must equally stimulate progress in other related sectors. Harnessing the default linkage between biofuels production and other sectors is necessary. The biofuels developments interventions and incentives must be well situated within the bigger economic development plans relating to other sectors.

3.3. Ecological concern

The possible threat to ecosystem, biodiversity and biological resources has been a main issue in the contention over biofuels sustainability. Nigeria's primary forest resources and fragile ecosystems need not be further threatened by biofuels development. The opportunity for the full utilization of the existing underutilized agricultural lands and curbing major ecological challenges such as charcoal production and deforestation should be an intrinsic aspect of the biofuels development policy. The provisioning of biofuels as alternatives for livelihoods and meeting the basic energy requirement – lighting and cooking is pivotal as the Nigerian economy enters into a green energy era.

4. Trends in food, fuel, feed and fibre situation in Nigeria

Nigeria has been a net importer of processed and unprocessed foods since the discovery of petroleum led to prioritizing oil and gas as the major revenue source and mainstay of the economy to the detriment of agriculture and agro-allied productions and processing. FAO [24] reported that wheat and milled rice top Nigeria's staple food import apart from other processed products such as tallow, palm oil, milk, malt and margarine. The value of Nigeria's top twenty import agricultural commodities stood at $3.7 billion for 2009. This is an indication of the inability to meet consumption of key staples from domestic production. Efforts in the last decades have been on increasing local production of staple crops such as rice; accounting for the highest foreign exchange utilization and a huge drain on the foreign reserve, and tilting the trade balance towards the negative.

von Braun [25] analysis of the global food situation showed that there was marked increase in the food consumption in a number of developing countries from 1990 to 2005. Within the same period, Nigeria did not witness any marked changed in the consumption of high valued food products such as meat, milk, fish, fruits and vegetables as reported by the same study. Nigeria continues to struggle with the food crisis, chief among which is high inflation on food prices. The prevailing food concern in Nigeria has been a symptom of the declining local production, which is exacerbated by the energy crisis facing the country. Curbing the spiralling inflation on food prices requires ensuring affordable and profitable local production and an efficient cheaper distribution of the imported and locally produced food products. The cost of distribution of food products between the originating points to the consumption points depends largely on fuel prices.

The tie between food and fuel prices has increasingly become entrenched with Nigeria's dependence on imports for meeting local fuel consumption. Hike in the price of crude oil internationally translate into an increase in the cost of everything, particularly food with no visible safety net such as subsidizing the transport and haulage for food products. The lack of cheaper alternative fuelling options for heavy-duty transport, other than expensive diesel, makes the drive towards developing locally produced biodiesel a priority for curbing food crisis. The entire value chain of food production through processing to distribution requires diesel, the most expensive petroleum product in Nigeria. Maconachie et al. [26] reported that the prices per litre of diesel for the years 2006, 2007 and 2008 were $0.92, $0.95, and $0.94 respectively. In the same period, the price of petrol was reported to be $0.63, $0.61, and $0.60, while the price of kerosene was reported to be $0.75, $0.78, and $0.77. These figures shows the prices of diesel far outshot other petroleum products.

The fuel consumption in Nigeria has also been import dependent. Jesuleye et al. [27] indicated an increasing importation of refined petroleum products as the refining capacity of the local refineries declined. This indicates the petroleum products supply for meeting local fuel consumption for transport, cooking, lighting and electricity generation, which represent the topmost demand for petroleum products – diesel, petrol, and kerosene – increasingly depend on import. Apart from the shortfall in refined conventional fuels, Nigeria is also about 5 billion l per annum short of the ethanol required for meeting the current mandatory E10 petrol blending [13]. The fuel situation is further compounded by the persisting inability of the country to generate electricity for household and industrial need. With the current rate of electricity generation in Nigeria hovering around 4000 MW, the inadequacy of this generation capacity get more glaring as the population increases. Abila [14] highlighted the dependence on primary biomass for basic energy requirements such as cooking on the account of the lack of the conventional and cleaner alternative. IEA [28] shows that electrification rate for Nigeria only covers about 47% of the country. This data only relates to the electrification infrastructure and does not provide the frequency and quality of the supply of electricity, which has been on the decline even in areas with installed transmission infrastructures. Most homes, businesses, public and private institutions have to resort to standalone electricity generation running on diesel or petrol.

The feed concern is also captured by the current shortfall in meeting animal protein requirement for the country. FAO [24] data shows Nigeria still depend on import for meeting the requirement for meat, eggs, milk and other animal products. This indicates the inability of the country to meet the demand for animal products, particularly dairy products such as milk, and cheese from the local production.

Nigeria has the appropriate climatic, geological and hydrological conditions for the production of most fibres crops, but cotton has been the dominant crop. Bamboo, jute, hemp and other fibre crops grow very well in Nigeria, but these are not being produced at a commercial scale, nor has there been an obvious concerted effort devoted to their production at a large scale for deriving fibre raw-materials for meeting the local manufacturing demand or for export. Cotton, which has dominated the fibre sub-sector in Nigeria has witnessed spiral trend in the production since 1960. The five decades data for cotton production in Nigeria shows an up and down trend within each decade with the 1980s showing the lowest production of cotton lint when the country produced a mere 10,524 ton. Since the lowest record of 1985, cotton lint production has witnessed an unsteady growth. According to FAO [29], the cotton production in Nigeria peaked with 0.197 million - tons of cotton lint in 2006. The sharp drop in the production between 1992 and 1993 is in sync with the price of cotton lint that fell to about $873/ton in 1992 from the previous year value of $1680/ton. The production also rose as the price picked up until the drop in export volume from 2007 which was exacerbates by the absence of local absorption for the lint produced with the near collapse of the textile industries in Nigeria. Fig. 2 shows the unstable production of major crops over five decades. Abila [14] compared the ranking of Nigeria on productivity per hectare devoted to the production of major biofuels crops. For most of these crops, Nigeria ranked lower in productivity as compared to the country's higher rank in terms of the nominal output and land area cultivated. For cotton, Nigeria ranked ninth in terms of land area cultivated, but ranked eighteenth in terms of productivity per land use when compared to other major producers globally. Increasing the productivity per land, labour, capital and other resources devoted to the production of cotton lint and by implication, cotton seed, is an essential goal that must come along with the pursuits of increasing nominal output.

The Federal Government of Nigeria (FGN) has set forth a target of tripling the current production level for cotton lint and cotton seed by 2015. This target aims to engender local production of cotton lint and cotton seed for the purposes of reviving the nearly extinct textile industry, and stimulating production of allied industries such as the vegetable oil production. The drive for revamping the local cotton production is towards increasing the contribution of the fibre sub-sector to the agricultural component of the GDP which has been low for some time.

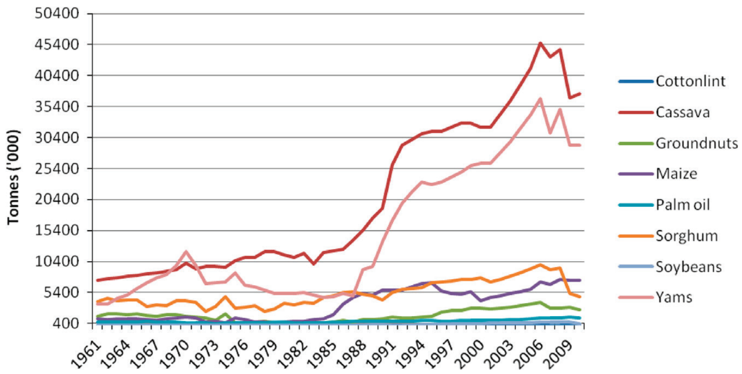

Fig. 2. Five decade trend in major crops production (tons) in Nigeria.
Data source: FAO [29].

Table 1
Nigeria's average production and productivity of major crops essential for meeting the four objectives from 2000 to 2009.
Source: adapted from FAOStat database on world crop production [24].

Crop	Average production (ton)	Average area cultivated (ha)	Productivity per hectare (ton)	Global productivity per hectare	Target productivity increase to meet global average
Cassava	3,854,293	3,547,851	10.86	11.41	0.55
Maize	5,900,784	3,529,086	1.67	4.75	3.08
Green maize	658,793	199,815	3.29	8.09	4.80
Cotton seed	472,948	549,680	0.86	1.94	1.08
Sesame	93,602	211,959	0.44	0.48	0.04
Groundnut	3,071,837	2,121,135	1.45	1.55	0.10
Soyabean	526,586	578,753	0.91	2.31	1.40
Coconut	195,686	38,700	5.06	5.04	−0.02[a]
Sugarcane	1,002,275	47,095	21.28	65.65	44.37
Oil palm	8,485,200	3,203,500	2.65	13.38	10.73
Rice	3,380,459	2,289,920	1.48	4.08	2.60
Millet	6,738,989	4,707,960	1.43	0.85	−0.58[a]
Sorghum	8,161,079	6,889,473	1.19	1.37	0.18
Cashew	581,160	298,500	1.95	0.62	−1.33[a]
Karite nuts	417,498	251,932	1.66	1.84	0.18
Mellon	416,643	638,754	0.65	0.65	0.0
S. potatoes	2,853,182	957,679	2.98	13.61	10.63
Potatoes	753,478	243,700	3.09	16.91	13.82
Yam	30,778,200	2,871,901	10.72	10.28	−0.44[a]

S. potatoes – sweet potatoes.
[a] The Nigerian productivity exceed the global rate.

5. Situation of the major crops between 2000 and 2009

The pursuit of a balance in the food, feed, fuel and fibre objectives must rest on ensuring a stable and efficient production of the major essential crops. Though there is enough land and rainfall for the production of most of these crops, the productivity per hectare and other resource devoted the production of these crops is still currently low. Table 1 shows the average production and productivity per land area devoted to the cultivation of some of the major crops in Nigeria, in comparison to the global productivity. The figures in the table are estimated ten years average; from year 2000 to 2009. For much of these crops, it is obvious that Nigeria still lags behind the global productivity per hectare cultivated. For all the 19 crops profiled, only coconut, millet and cashew are currently produced with productivity per hectare above the global average. Of the three crops that can be considered as faring well in terms of productivity, only millet is produced largely for its commercial or subsistence purpose. Coconut and cashew are currently grown as marginal crops, not consciously cultivated for the purpose of deriving subsistence or sale for income. Increasing the productivity per hectare in order to attain a balance in the food, feed, fuel and fibre will also require addressing issues that currently account for the low productivity such as decreasing soil fertility and the low use of innovations and inputs for soil improvement. Promoting and implementing land management practices that will sustain soil fertility as well as increasing access to affordable technology for the production of these crops should feature in the policy and incentives already in place for encouraging production.

The current agricultural production policy must also provide a target in productivity per land and other resources devoted to the production of these crops, beyond stating a target for increasing nominal production rate. From Table 1, the wide margin between the productivity per hectare for Nigeria and the global rate is obvious for sugarcane, oil palm, sweet potatoes and potatoes. The wide margins can be explained in that these crops are not produced as main commercial or subsistent commodities. Most farmers grow these crops as marginal crops for secondary purpose of additional income or subsistence. The increasing relevance of these crops for food, feed and fuel should stimulate the intensification of the production towards enhancing productivity. The trend is changing for oil palm as the global demand is on the increase and subsequently changing the fortunes of the crop. Most oil palm plantations that gave Nigeria the top position in the production of the crop in the sixties that have gone moribund are being revitalized.

6. Current utilization balance sheet for the major crops

An individual crop item can be used for more than one purpose. Different parts and products derivable from a crop can serve differing purposes. A good example is the cotton which is produced mainly for the lint but the seeds extracted from the lint are further used for oil extraction for food or fuel, while the residual cake from the oil extraction is a component for producing feed concentrates for livestock. In this scenario, the pursuits of increasing the production of a particularly crop by default will lead to increasing the supply of raw materials for meeting a combination of two or more of the food, feed, fuel, fibre or other objectives. Table 2 shows the current utilization balance of the major crops produced in Nigeria. The figures in the table depict the average estimate for 10 years – between 2000 and 2009. From the table, it is obvious that even with the demand for the products and parts of a crop in meeting different needs, some of the products are still wasted due to the inability to absorb these for the required needs, the occasional glut situation, the logistics and distribution impediments – particularly in situations where crop products and parts are produced but there are no sufficient haulage facilities to convey them to the market or point of demand. In the face of an increasing expansion of the utilization of some of these crops for more than the current utilizations, to include biofuels production and as industrial raw materials, government policy on biofuel production and related interventions must ensure a near total utilization of the crops produced. Ensuring that there is a market for current production is crucial for stabilizing production overtime and to avoid occasional scarcity that follows periodic gluts.

The current scenario of the utilizations of crops such as cassava, millet, maize, groundnut and sorghum with huge proportion of the production still wasted yearly gives credence to the timeliness and usefulness of the policy of the Federal Government of Nigeria promoting biofuels production, processing and utilization across the country. The biofuel policy, if fully implemented will provide for the full absorption of the yearly production of these crops. Along with other policy interventions such as mopping excess production of crops for stocking Federal Government silos and food reserve banks, facilitating the utilization of these crops for other equally essential objectives will serve the purpose of stabilizing prices both in and out of the production season. There is a recurrent scenario where prices shot up during the out of season, but the prices fall far below the point where farmers can breakeven during the in-season. The strong link between the absorption of the production and price stability is crucial for ensuring sustainable production at the medium and long term. By extension, one can posit that this is also pivotal for the success of policy interventions aimed at increasing nominal production, productivity of resource use and the adoption of best practices, innovation and technologies.

Table 2
Major crop's utilization balance sheet for Nigeria – average from 2000 to 2009.
Source: adapted from FAOStat database on world crop production [24].

Crop	Products/ parts	Current major utilization	Average production (ton)	Average utilization as food (ton)	Average utilization as feed (ton)	Average utilization as other (ton)	Average waste (ton)	Percentage of waste to production (%)
Cassava	Roots	Food+Feed+Other	38,542,930	15,982,413	18,042,446	186	4,511,437	11.70
Maize	Seed	Feed+Food+Other	5,900,784	3,212,408	1,794,162	19,730	666,438	11.29
Cotton	Lint	Fibre	171,000	–	–	158,866	–	–
	Seed	Food+Feed	255,782	–	–	90,287	13,165	5.15
	Seed cake	Feed	57,105	–	48,743	–	–	–
	Seed oil	Food	20,557	20,980	–	–	–	–
Sesame	Seed	Food	92,631	2260	–	–	11,549	12.47
	Seed cake	Feed	9180	–	9180	–	–	–
	Seed oil	Food	6120	6117	–	–	–	–
Groundnut	Cake	Feed+Food	686,100	–	686,393	–	–	–
	Oil	Food	566,800	563,229	–	–	–	–
	In shell	Food+Other	3,071,837	426,243	–	501,429	210,081	6.84
	Shelled	Food+Other	2,150,286	298,370	–	351,000	147,056	6.84
Soyabean	Cake	Feed	10,400	–	33,589	–	–	–
	Oil	Food	2340	3418		–	–	–
	Seed	Food+Feed	526,586	385,013	53,203	–	53,203	10.10
Coconut	Seed	Food+Feed	199,920	88,507	6559	–	13,995	7.00
Sugarcane	Stem	Food	1,003,107	136,651	–	273,000	–	–
Oil palm	Palm oil	Food+Other	1,135,500	735,500	–	635,912	42,513	3.74
	Kernel cake	Feed	538,573	–	459,633	–	–	–
	Kernel oil	Other	495,487	495,901	–	–	–	–
	Kernels	Feed+Other	1,083,079	–	–	–	–	–
Rice	Milled	Food	2,254,766	2,992,802	–	–	241,952	10.73
	Paddy	Food	3,380,459	4,486,959	–	–	362,746	10.73
Millet	Seed	Food+Other	6,738,989	4,815,277	1,047,868	–	796,850	11.82
Sorghum	Seed	Food+Other	8,161,079	5,648,612	1,271,321	–	962,825	11.80

7. Resource requirements for attaining food, fuel, feed and fibre objectives

The food, fuel (biofuel), feed and fibre are agriculture related objectives which require access to land and water for their production. Spiertz and Ewert [30] highlighted the dependence of production of food, feed and fuel objectives on the critical resources of land, freshwater, and biodiversity. von Braun [20] also outlined the resources critical for a nation to have the potential for biofuel production to include availability of water resources and availability of arable land. The global profiling of countries with high and promising biofuel production capacity based on the availability of water and arable land include Nigeria [31]. Table 3 presents water and land use situation of major biofuels crops which are also cultivated for food, feed, and fibre. The water footprints for the biofuels crops production and the respective water footprints for energy and biofuels production are based on the estimates made by Mekonnen and Hoekstra [11].

The water footprint concept was introduced initially by Hoeskstra [32]. It has been deployed for assessing biofuels production water footprint for various countries and region to help analyse human water consumption in relation to the available global freshwater [18,33]. Hoekstra et al. [34] defined water footprint as the total volume of freshwater that is used in the production of a product. The figures for the water footprints are the aggregates for the blue, green and grey water footprints in cubic metre per ton of crop produced. The blue water footprint is the surface and ground water consumed during production of a good, the green is the rainwater used in the production of a product while the grey refers to the volume of freshwater needed to absorb the pollutant with respect to existing water quality [11].

From Table 3, cashew and sesame have the highest water footprint per ton of the crops produced. The crops being promoted for biofuels production in Nigeria, namely: cassava and sugarcane have water footprints that are not so high, 564 m^3/ton and 210 m^3/ton respectively. Though, the percentage water footprints of each biofuel crop to the national water footprint for crop production for Nigeria are so insignificant, considering the very low values, there may be an increase in the values as the demand for crops for biofuels production increase. The water footprint of the possible crops that can be cultivated towards biofuel production in Nigeria has implication for the Nigerian biofuel policy. As Nigeria strives towards local production of biofuels needed to meet the E10 blending rate for ethanol and D10 blending rate for biodiesel, emphasis must be on the crops with low water footprint per ton of crop produced and litre of biofuel produced.

The table also shows percentage land use for each crop to the total national arable and permanent land use for crop production in Nigeria. Sorghum has the highest value (20.1%), followed by millet (15.0%). Cassava and sugarcane currently occupies 9.8% and 0.1% of the arable and permanent land use in Nigeria. The expansion of land cultivation for meeting the biofuels requirements must take cognizance of the current level of land use of the crops of interest in relation to other crops for meeting the requirements for food, feed and fibre.

8. The linkage between biofuels adoption and the four objectives

The entire value-chains from the farm production to processing of the food, fuel, feed and fibre products require energy. The production of biofuels particularly at the farm level provides an alternative fuelling option for farm operations. Enhancing energy self-sufficiency for farms, particularly fuel for tractor operations, haulage, running generators for electricity used in processing and refrigeration will be a good cost saving option, for increasing productivity, increasing profit and reducing farm level emissions.

Though there might be a competition between food, fuel, feed and fibre objectives, it is expected that an efficient allocation of the required resources and designing an appropriate plan for implementing lateral integration of production will help in increasing

Table 3
The water and land use situation of major biofuels crops produced in Nigeria.
Source: Mekonnen and Hoekstra [11].

Crop	Biofuel yield (l/ton)[a]	Crop water footprint (m^3/ton)[b]	Total water footprint per unit of energy (m^3 per GJ of biofuel)[b]	Water footprint per litre of biofuels (litre of water per litre of biofuel)[b]	Percentage of hectarage to the total arable and permanent crop land use (%)	Possible combination of objective use
Ethanol crops						
Cassava	222	564	109	2538	9.8	Food+Fuel+Feed
Maize	428	1222	121	2855	11.6	Food+Fuel+Feed
Sugarcane	99	210	91	2107	0.1	Fuel+Food+Feed
Millet	–	4478	–	–	15.0	Food+Feed+Fuel
Sorghum	434	3048	300	7023	20.1	Food+Feed+Fuel
Potatoes	131	287	94	2192	0.5	Food+Feed+Fuel
Rice	434	1673	165	3855	6.4	Food+Fuel+Feed
Biodiesel crops						
Oil palm	213	1098	156	5166	9.3	Food+Fuel+Feed
Cotton seed	222	4029	547	18,134	1.6	Fibre+Food+Feed+Fuel
Sesame	–	9371	–		0.5	Food+Fuel+Feed
Groundnut	421	2782	200	6607	6.2	Food+Fuel+Feed
Soybeans	188	2145	343	11,397	1.6	Food+Fuel+Feed
Coconut	17	2687	4751	157,617	0.1	Food+Fuel+Fibre+Feed
Cashew	–	14,218	–	–	0.8	Food+Fuel+Feed
Mellon	–	5184	–	–	1.5	Food+Fuel+Feed

Water footprint for crop production for Nigeria (1996–2005) is 192 Gm^3/yr (Mekonnen and Hoekstra [11]).
CW=crop water.

[a] As reported by Mekonnen and Hoekstra [11], based on the density 0.789 kg/l for ethanol and 0.88 kg/l estimated by Alptekin and Canakci [35].
[b] Figures based the average data for crop production from 1996 to 2005.

productivity per resource utilized. This paper is premised on the assumption that based on the current concerns for food, fuel, feed, and fibre, the adoption and development of biofuels in Nigeria creates a unique avenue for creating a linkage for attaining balance between the objectives. This will help in attaining desired growth in each sub-sector and the required minimum contribution to
GDP, which will better reflect evenly distributed economic growth rather than a skewed growth accounted for by a few promising sectors.

Attaining a balance in the multiple objectives, which are as equally complementing and competing, can be achieved through integration, by channelling by-products or hitherto unutilized wastes from one objectives venture into another. By-products such as waste and compost will contribute to increasing the attainment of other objective ventures by improving the utility of constraint resources such as land and labour and offsetting the cost of capital such as fertilizer. In the scenarios where the objectives ventures cannot be paired or co-produced simultaneously, an arrangement for consecutive production planning bringing in additional resources at lower cost may be appropriate. A typical example can be producing food crops when they are better produced optimally rain fed, and switching to biofuel crops during the dry season or seasons of low rainfall for crops with low water footprint (less demand for rainfall). The scenario may have to be varied from the low rainfall regions of northern agro ecological zone to the high rainfall humid southern region.

The existing biofuel incentives and policies must go a little further to adjust the existing plans for the biofuel programs of the Federal Government and various other private and public entities to take cognizance of the need to attain balance in the multiple objectives. The growing population of Nigeria is a unique incentive as well as caution for taking a more analytical path which considers the element of growth in the population, and the attendant increase in the demand for the various objective ventures of food, feed, fibre, as well as the increasing constraints and possible conflicts between the objectives for the limited resources.

Fig. 3 shows a conceptual integration pathway for integrating biofuel production with the production of crops meant for meeting the food, feed, fuel and fibre objectives. The figure shows by-products and resource contribution that can flow from biofuels production to other enterprises as well as an offshoot of a possible link to the production of livestock products such as meat, egg and hide. It is worth noting that Fig. 3 does not show the complete list of external and internal inputs that can possibly feature in the link between biofuels production process and the production of food, fuel, feed and fibre crops.

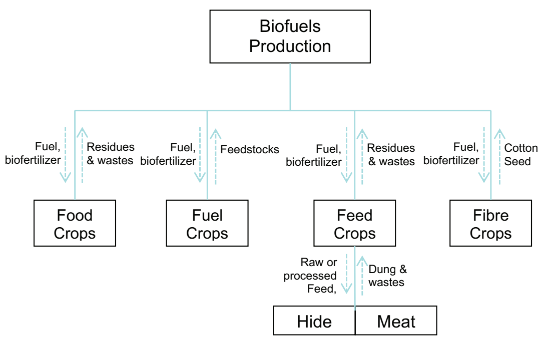

Fig. 3. Conceptual integration pathway between biofuels, food, fuel, feed and fibre crops production.

9. Conclusion

This paper attempted to explore issues that are necessary for ensuring the sustainability of the growing biofuels sector in Nigeria. The paper proposed a conceptual framework for integrating the food, fuel, feed and fibre objectives. The article explores the possibility of balancing the local production of the food, feed, fuel and fibre objectives through a more efficient use of the currently underutilized resources of land and water. Though it is expected that there might be a competition between objectives, it is anticipated that an efficient allocation of the required resources, designing an appropriate plan for implementing integration of production will help in increasing productivity per resource utilized. This paper is premised on the assumption that going by the current concerns for food, fuel, feed, and fibre, the adoption and development of biofuels in Nigeria creates a unique avenue for creating a link for balance between the objectives and attaining desired growth in each sub-sectors and increasing the contribution of agriculture to GDP, which will better reflect evenly distributed economic growth rather than a skewed growth accounted for by a few promising sub-sectors.

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Econometric estimation of the petroleum products consumption in Nigeria: Assessing the premise for biofuels adoption

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A B S T R A C T

The promotion and adoption of biofuels in Nigeria must be predicated on sufficient capacity for absorbing biofuels produced from the increasing investments in biofuels plantations, plants and processing facilities. This paper assesses the socioeconomic and related premises for biofuels development in Nigeria by conducting an econometric estimation of the petroleum products consumption. The paper first estimates aggregated petroleum product consumption, and then assess the response to specific petroleum products in terms of consumption, market (population), electricity generation, installed electricity generation capacity, and GDP. The result shows that all the petroleum products contribute significantly and about equally to aggregate petroleum consumption. The high proportion of petrol (about 44 percent) as a percentage of the aggregate petroleum product consumption validates the push for implementing the E10 petrol-ethanol blending for Nigeria. The consumption of diesel is also significant. Diesel is another petroleum product for which D20 biofuel blending policy has been proposed. The increase in population and GDP, coupled with the poor electricity situation, will keep driving the consumption of petroleum products. As the population increases, and the country continues to struggle to match electricity generation with population growth, the petrol-ethanol and diesel-biodiesel blending policy must be pursued tenaciously to ensure a reduction in carbon emission in Nigeria.

1. Introduction

Nigeria is a petroleum-endowed country with myriad energy challenges. Though the country is among the top ten exporters of crude oil globally, with a vast natural gas reserve, it still faces several crises related to the consumption of petroleum products. The challenges include the scarcity in supply of refined products, dependence on imports, the huge yearly subsidy budget which has been spiraling out of control, and increasing pollution, along with other socioeconomic burdens. Nigeria continues to struggle with meeting the energy demands of its growing economy. Per capita energy consumption in Nigeria is among the lowest in the world — and even in Africa, considering population size and the global ranking of the economy. A World Bank [1] report estimated the annual total energy consumption per capita at 713.6 kg of oil equivalent, lagging behind that of South Africa and Libya with smaller populations. The evident low level of penetration of energy consumption goes along with the inability to meet the demand for petroleum products through local refining.

Burdened with these challenges, Nigeria joined other nations in promoting the adoption and utilization of biofuels. The country in 2007 commenced the implementation of the automotive biofuels development and adoption program. The biofuels program aims (among other goals) to reduce the import of refine petroleum products, conserve oil reserves, improve the agricultural and allied sectors, create a biofuels economy and stimulate overall economic growth [2–4]. The Nigerian biofuels development program is currently at the second phase, which encompasses the development of domestic capacity for meeting targets of 10% ethanol in gasoline blends and between 10% and 20% biodiesel (in petroleum diesel blends) [3,5].

During the first phase, involving the seeding of the biofuels market, Nigeria relied on Brazil as the main supplier of the bioethanol required for attaining the E10 blending target [2]. To facilitate the domestic production of ethanol and biodiesel, the Nigerian biofuels policy included a number of incentives to attract investors into the sector, such as import waivers, tax incentives, and guaranteed loans. To be economically viable, biofuels production

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must be related to the consumption capacity for gasoline, diesel and other petroleum products. Some of these products are consumed as complementary goods, while others are petroleum substitutes in the transport, energy, manufacturing, and processing sectors.

Entering into the second phase, the Nigerian biofuels program still seems to be struggling to fully takeoff [3,6]. While biofuels adoption and promotion represent a laudable step toward solving the many energy-related challenges facing Nigeria, the promotion of these new fuels must be based on a clear analysis/assessment of the existing demand for fossil fuels.

This paper attempts to estimate the consumption of petroleum products, including some of which blending targets have been set, through an econometric estimation based on historical data and trends of petroleum products consumption. The aim is to better understand the relationship between aggregate and individual petroleum products consumption, in the context of socio-economic and other factors. This paper assesses the empirical argument for promoting investment in both the upstream and downstream sectors of biofuels in Nigeria.

2. Petroleum consumption as a premise for biofuels adoption

Biofuels production, and particularly ethanol, is not a new technology. However, the promotion of these alternative fuels gained global momentum only after governmental interventions started to drive intensive development and adoption. Various countries have promoted biofuels by enacting a compulsory blending rate with gasoline or diesel, and regional bodies around the world have also promoted their use. In EU, the renewable energy directive of 2008, published by the European Commission, proposed a mandatory target of 20 percent EU energy from renewable sources [7]. Toke [8] hinted that the directive to adopt the 20 percent renewable energy (which also includes transport fuels) was driven by pressure from the renewable energy industry as well as the European Parliament. Sorda et al. [9] provided an overview of government policies from across the world which energized the promotion of biofuels. In the United States, the July 2010 Renewable Fuel standard (RFS2) replaced an earlier policy document, the Energy Independence and Security Act of 2007. In 2007, Nigeria drafted the Biofuels Policy and Incentive, designed to ensure the implementation of biofuels utilization in transport and other sectors.

Some national biofuels policies have been questioned, based on several arguments: biofuels impact the availability of crops meant for food; biofuels production are not profitable; they impact the environment negatively, yielding little or no benefit to curbing climate change, etc. [9–12]. Nevertheless, the promotion and utilization of these fuels continue to advance around the world.

The factors driving the development and promotion of biofuels as reliable alternatives to petroleum products vary, but they include economic, ecological, and social drivers. Not every country faces the same energy challenge, particularly in relation to the supply and consumption of petroleum products. While some of the key challenges are global in nature, including pollution and emission of greenhouse gases (GHGs), each country also has specific challenges that give impetus to their biofuels policies, laws and regulations. However, there is an overarching theme — a global challenge regarding the supply and utilization of fossil fuels. The most fundamental case for biofuels adoption is the fact that fossil fuel resources are finite, with limited recovery time frame, even when the cost of petroleum prospecting is decreasing. By the current estimate of the World Energy Council [13], global petroleum reserves stand at 223,454 metric tons of crude oil, with an overall R/P ratio of barely 56 years.

Nigeria is a petroleum resource-rich nation with recoverable crude oil and natural gas deposits of about 37,200 million barrels and an R/P ratio of 42 years [13]. However, such huge petroleum resources do not translate into availability, affordability, and accessibility of refined petroleum products to meet the criteria for Nigerian energy security. Due to the poor performance of its four refineries [14], Nigeria relies on import for much of the refined petroleum products consumed in the country. The need to solve the challenge of energy security led to the drafting of the Nigeria automotive biofuel program, which later resulted in the Nigerian Biofuel Policy and Incentives. Nigeria is pursuing biofuel development and adoption as a means of solving the energy crisis, boosting its agricultural sector, and addressing its socio-economic challenges [4]. Adopting biofuels may also allow Nigeria to pursue green economic growth.

3. Review of historical consumption trends for the various petroleum products

Nigeria is a major exporter of crude oil and a minor consumer of refined petroleum products. From the available historical data, it is clear that consumption of petroleum products has not matched the pace of population growth, in spite of the relevant economic goals and policies of administrations over the last five decades. A series of development plans, agendas, and programs have been put in place, designed to open up the economy and increase the consumption of key petroleum products, targeted particularly to those whose limited consumption reflects substandard living conditions. Since 1960, when data on energy consumption started being recorded for Nigeria, the consumption of petroleum products such as liquid petroleum gas (LPG) has remained very low; a high proportion of the population depends on primary biomass, such as fuel wood, charcoal, agricultural waste, and even dung, for cooking, lighting, and food processing [5].

The consumption of petroleum products varies from state to state across Nigeria. While Lagos, Oyo, Ogun, Kaduna, Edo, Rivers, Delta, Kano, Abuja, and Imo have been leading consumers of gasoline [15], other states with limited commercial activities still have very low consumption. Low penetration and variable consumption apply to virtually all petroleum products. Kerosene and LNG, which ought to be basic household commodities, still record very low consumption in most states, where the alternative primary energy options are preferred and more affordable.

The historical trends for petroleum products consumption in Nigeria are shown in Fig. 1. The products include kerosene, diesel, motor gasoline (petrol), jet-fuel (aviation fuel), liquid petroleum gas (LPG), residual fuel oil (heavy oils), and other refined petroleum products. Total petroleum products consumption increased over the two decades, with drops in 1987, 1990, and 1998. From 2001 to 2004, the country experienced an average drop of 3.73% in total petroleum product consumption.

Iwayemi et al. [16] posited that the trend in total petroleum product consumption can be explained in terms of real per capita national income (PCI) as well as the introduction of the structural adjustment program (SAP) in 1986. However, GDP (a proxy for PCI) only shows a drop in 1987, and not in other years when aggregated petroleum products consumption show negative growth. The historical data for prices of petroleum products over the period also indicate that the change in prices of key petroleum products (gasoline, distillate, and kerosene) did not correspond with the drop in consumption. These periodic drops in consumption can be explained by the supply constraints as the nation increasingly depended on import of refined products as the local refining capacity declined [14]. The increasing dependence on import of refined products leads to occasional supply chain and

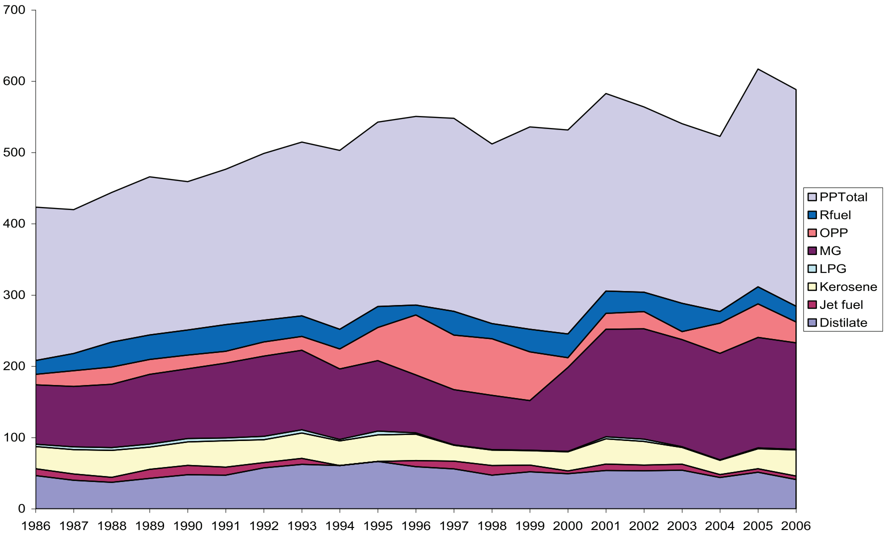

Fig. 1. Petroleum Products Consumption, 1986–2006 (thousand barrels/day). Source: Computed from data from US Energy Information Administration [18]. Key: PPTotal = aggregate petroleum products consumption, Rfuel = residual fuel, OPP = other petroleum products, MG = motor gasoline (petrol), LPG = liquid petroleum gas.

logistic constraints. There is an obvious inadequacy and inefficiency of the supply infrastructures for receiving imported products at the terminals such as the Atlas Cove storage jetty and distributing the products through the depots across the country. Note that the petroleum sector in Nigeria is still largely price-regulated, with the Federal Government subsidizing petroleum products to keep prices down. The subsidy regimes also create supply constraints. This occurs when a backlog of subsidy payment to the importers have not been paid, hampering their ability to bring in new cargoes. These related supply constraints sometimes lead to protracted shortages which affect overall consumption for the year.

Interestingly, from 1986 to 2006 kerosene experienced a 17.84% growth in consumption, while gasoline consumption increased by 79.67% percent over the same period. The rapidly increasing consumption of gasoline underlies the government policy to implement local production of biofuels as a strategy for economic growth. However, the quantity of ethanol required for meeting the E10 blending rate, for 110 thousand barrels per day of gasoline, makes this a daunting project: Ohimain [17] estimates that Nigeria requires 5.14 billion liters of bio-ethanol yearly to meet the set blending target for petrol.

The fluctuation in petroleum products consumption may reflect the developing nature of the Nigerian economy. Much of the economy is still largely in the informal sector. As the formal sector increases, the growth in GDP and population are likely to result in an increase in activities in sectors with high petroleum demand, and eventually petroleum consumption trends will stabilize overtime.

4. Methodology

4.1. Model

Studies of how aggregate petroleum products consumption responds to key variables have been undertaken for various countries. Rao and Parikh [19] analyzed the demand for petroleum products in India; Zaman et al. [20] assessed the factors affecting the commercial consumption of petroleum products in Pakistan; and Pirlogea and Cicea [21] assessed petroleum products consumption and economic growth in the European Union. These studies applied econometric analysis to assess the response of petroleum product consumption to key socio-economic factors. For Nigeria, there is little literature on the empirical estimation of petroleum consumption based on historical data. Iwayemi et al. [16] applied error correction modeling to estimate aggregate petroleum demand, using a series of four simultaneous equations. Iwayemi et al. [16] estimated petroleum product demand elasticities for petrol, diesel, and kerosene, focusing on how the independent variables (GDP, prices, and a lag of consumption quantity) integrate to affect the long-run demand equilibrium for individual products as well as aggregate petroleum products.

This paper rather attempts to estimate how aggregate petroleum product consumption responds to key socio-economic variables including GDP, population, electricity generation, electricity generation capacity, and the consumption of individual petroleum products. In estimating aggregate petroleum product consumption, the following multiple linear regression model was used:

$$\begin{aligned} \text{AGCons}_t = {} & \beta_1 + \beta_2\text{GDP}_t + \beta_3\text{ConsP}_t + \beta_4\text{ConsK}_t + \beta_5\text{ConsD}_t \\ & + \beta_6\text{ConsL}_t + \beta_7\text{ConsOppr}_t + \beta_8\text{ConsRoil}_t \\ & + \beta_9\text{ConsJf}_t + \beta_{10}\text{Popn}_t + \beta_{11}\text{Elegen}_t \\ & + \beta_{12}\text{Elinscap}_t + \varepsilon_t \end{aligned} \quad (1)$$

where:

AGCons = aggregate consumption of petroleum products (thousands barrel per day)

GDP = real gross domestic product, constant prices in billion naira

ConsP = consumption of motor gasoline (petrol) in thousand barrels per day

ConsK = consumption of kerosene in thousand barrels per day

ConsD = consumption of distillate (diesel) in thousand barrels per day

ConsL = consumption of liquid petroleum gas (LPG) in thousand barrels per day

ConsOpp = consumption of other petroleum products in thousand barrels per day

ConsRoil = consumption of residual oils in thousands barrel per day

ConsJf = consumption of jet fuel in thousands barrel per day

Popn = population in millions

Elegen = electricity generation in megawatts

Elinscap = electricity installed capacity in megawatt

$\mathcal{E}$ = estimated residual t = time span of available data (1986–2009)

Variants of the above multiple regression model were run to determine the best equation for estimating aggregate petroleum product consumption. The variants of the equation are: Linear-Log, Log-Linear, Log–Log, and Lag models. The variables included in the models by theoretical expectation should influence petroleum products consumption. In addition to GDP and population, two additional variables: Elegen, the electricity generation in Nigeria; and Elinscap, the existing capacity for electricity generation are included. These variables, directly and indirectly affects petroleum products consumption. The inability to meet the electricity demand of the growing population has led to an escalation in the use of stand-alone power generators of varying capacities across Nigeria, which run on petroleum products, particularly diesel and petrol.

According to theoretical expectation, the signs for β_2, β_3, β_4, β_5, β_6, β_7, β_8, β_9 and β_{10} ought to be positive, while the signs for β_{11} and β_{12} should be negative. A growing GDP, increasing population, and an increase in the consumption of individual petroleum products can be expected to lead to an increase in aggregate petroleum product consumption, assuming petroleum products behave like other goods. The increase in electricity generation capacity and actual electricity generation ought to translate into a decrease in the aggregate consumption of petroleum products and of individual petroleum products whose consumption is tied to the lack of electricity. Prices of the petroleum products are not included in the models, since price regulation is still being implemented for nearly all of the products, particularly petrol, kerosene, and diesel, through the Nigerian fossil subsidy regime which keeps prices low and regulated [15].

4.2. Data

The data used in this econometric analysis span the 30 years from 1980 to 2009. Data on petroleum product consumption and aggregate consumption was sourced from the United States Energy Information Administration (US-EIA). The population data for the period was collected from the Nigerian Bureau of Statistics (NBS), while the Gross Domestic Product (Real GDP) data were sourced from the International Monetary Fund (IMF) world economic outlook data for April 2011 (expressed in constant prices in billions of naira) [22]. The data on the electricity generation and installed capacity are as reported by Oseni [23].

4.3. Estimation process

To determine the equation with the best fit, based on the statistical tests as well as theoretical expectations, the paper estimated four variations of the original model specified in (1), which are given as follows:

$$\begin{aligned}\text{LogAGCons}_t = {} & \beta_1 + \beta_2\text{GDP}_t + \beta_3\text{ConsP}_t + \beta_4\text{ConsK}_t \\ & + \beta_5\text{ConsD}_t + \beta_6\text{ConsL}_t + \beta_7\text{ConsOpp}_t \\ & + \beta_8\text{ConsRoil}_t + \beta_9\text{ConsJf}_t + \beta_{10}\text{Popn}_t \\ & + \beta_{11}\text{Elegen}_t + \beta_{12}\text{Elinscap}_t + \varepsilon_t \end{aligned} \quad (2)$$

$$\begin{aligned}\text{LogAGCons}_t = {} & \beta_1 + \beta_2\,\text{LogGDP}_t + \beta_3\,\text{LogConsP}_t \\ & + \beta_4\,\text{LogConsK}_t + \beta_5\,\text{LogConsD}_t \\ & + \beta_6\,\text{LogConsL}_t + \beta_7\,\text{LogConsOpp}_t \\ & + \beta_8\,\text{LogConsRoil}_t + \beta_9\,\text{LogConsJf}_t \\ & + \beta_{10}\,\text{LogPopn}_t + \beta_{11}\,\text{LogElegen}_t \\ & + \beta_{12}\,\text{LogElinscap}_t + \varepsilon_t \end{aligned} \quad (3)$$

$$\begin{aligned}\text{AGCons}_t = {} & \beta_1 + \beta_2\,\text{LogGDP}_t + \beta_3\,\text{LogConsP}_t + \beta_4\,\text{LogConsK}_t \\ & + \beta_5\,\text{LogConsD}_t + \beta_6\,\text{LogConsL}_t + \beta_7\,\text{LogConsOpp}_t \\ & + \beta_8\,\text{LogConsRoil}_t + \beta_9\,\text{LogConsJf}_t + \beta_{10}\,\text{LogPopn}_t \\ & + \beta_{11}\,\text{LogElegen}_t + \beta_{12}\,\text{LogElinscap}_t + \varepsilon_t \end{aligned} \quad (4)$$

$$\begin{aligned}\text{AGCons}_t = {} & \beta_1 + \beta_2\text{GDP}_t + \beta_3\text{ConsP}_t + \beta_4\text{ConsK}_t + \beta_5\text{ConsD}_t \\ & + \beta_6\text{ConsL}_t + \beta_7\text{ConsOpp}_t + \beta_8\text{ConsRoil}_t \\ & + \beta_9\text{ConsJf}_t + \beta_{10}\text{Popn}_t + \beta_{11}\text{Elegen}_t \\ & + \beta_{12}\text{Elinscap}_t + \text{AGCons}_{(t-1)} + \varepsilon_t \end{aligned} \quad (5)$$

Equation (2) is a log-linear form of the original model; equation (3) is a double log equation; equation (4) is a linear log; and equation (5) is the lag model. The equation with the best fit gives a more reliable estimation of aggregate petroleum consumption. Following the estimation exercise, autocorrelation test were also conducted.

5. Estimation results

5.1. Summary of descriptive statistics

The summary of the descriptive statistics for the parameters is presented in Table 1. Within the three-decade period, the population has more than doubled (min: 80.69 million, max: 151.9 million), while aggregate petroleum product consumption has only grown around 50% (min: 208.30 tbd, max: 311.6 tbd). The consumption of kerosene more than tripled over the period (min: 12.14 tbd, max: 37.88 tbd), while the consumption of petrol doubled (min: 69.81 tbd, max: 163.80 tbd). GDP, too, more than tripled over the period (from 3038.04 naira to 10240.48 naira). Unlike aggregate petroleum product consumption, then, the consumption of kerosene, diesel, jet fuel, and petrol has kept pace with the growth of population and GDP.

Fig. 2 shows the trends of the variables during the same period. Population shows consistent linear growth, while GDP shows almost exponential growth. The consumption of each petroleum product shows a fluctuating pattern, while aggregate petroleum product consumption shows consistent linear growth until 1992 and then fluctuates. The electricity generation capacity remains nearly stagnant for most of the period, while electricity generation shows limited growth. While it is expected that population increase should produce a rise in petroleum product consumption, the reverse holds for Nigeria. Maconachie et al. [24] studied fuel

Table 1
Summary of statistics of the variables used in the regression analysis.

	ConsD	ConsJf	ConsK	ConsL	ConsOpp	ConsP	ConsRoil	Elegen	Elinscap	GDP	AGCons	Popn
Mean	48.58	8.36	29.78	2.36	32.79	115.91	27.16	1819.51	5705.71	5420.31	264.93	113.04
Median	48.64	8.47	32.62	1.89	23.79	108.46	28.26	1679.60	5888.00	4399.06	266.83	111.16
Maximum	66.45	18.10	37.88	5.31	84.15	163.80	39.73	2645.00	6210.00	10240.48	311.63	151.87
Minimum	23.88	0.00	12.14	0.03	8.31	69.81	13.94	1227.50	4574.00	3038.04	208.30	80.69
Std. Dev.	10.11	4.30	7.53	1.69	22.58	31.93	7.37	450.37	482.65	2207.14	26.17	21.75
Skewness	−0.51	0.00	−0.80	0.23	1.22	0.20	−0.17	0.69	−1.78	0.93	−0.20	0.21
Kurtosis	3.09	2.98	2.44	1.49	3.16	1.51	1.90	2.18	4.45	2.44	2.65	1.85
Jarque-Bera	1.04	0.00	2.85	2.49	6.00	2.38	1.32	2.56	14.72	3.77	0.28	1.49
Probability	0.60	1.00	0.24	0.29	0.05	0.30	0.52	0.28	0.00	0.15	0.87	0.48
Observations	24	24	24	24	24	24	24	24	24	24	24	24

consumption in households in Kano, Nigeria, reporting a drop in the consumption of kerosene even with population growth.

5.2. Correlation analysis of the variables

The correlation analysis of the variables used in the regression analysis is designed to illuminate the relationship between the variables, laying the foundation for the multiple regression analysis. Table 2 presents the correlation coefficients of the variables. The correlation analysis shows a negative relationship between the consumption of diesel and the other variables: consumption of jet fuel and petrol, electricity generation, GDP, and population. The correlation analysis shows a positive relationship between aggregate petroleum product consumption and the variables of electricity generation (r ~ 0.6), electricity installed capacity (r ~ 0.6), and population (r ~ 0.5). This means that aggregate petroleum product consumption may rise as the population, electricity generation, and electricity installed capacity increase. The correlation coefficient between aggregate petroleum product consumption and GDP, though positive, is very low (r ~ 0.39); indeed, the correlation of GDP with most petroleum products is negative. However, the correlation coefficient between petrol (gasoline) consumption (ConsP) and GDP is positive and high (r ~ 0.84), and gasoline constitutes, on average, 44 percent of the aggregate petroleum products consumed in Nigeria [16]. Jaja [15] indicates that gasoline consumption in Nigeria is positively correlated with economic growth. Similarly, other studies find that energy consumption increases with GDP growth [25–29].

The correlation analysis shows the peculiarity of the Nigerian economy, as the data do not conform to the theoretical expectation

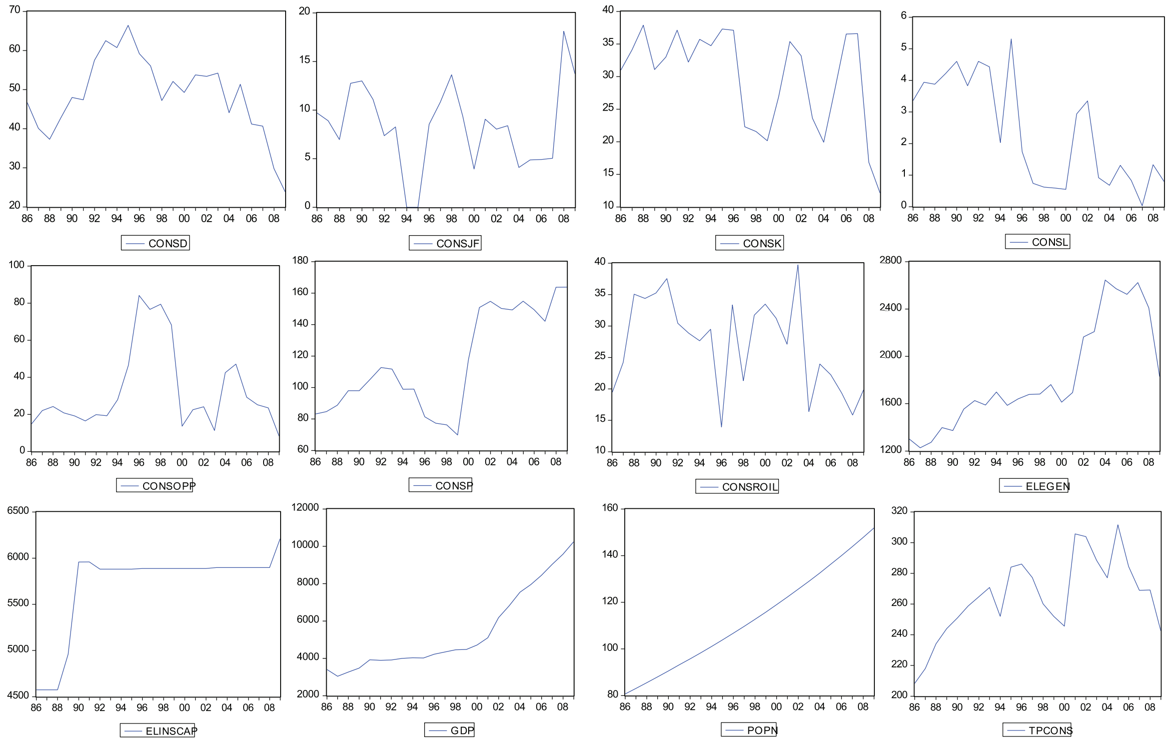

Fig. 2. Graphical descriptions of the variables used in the regression analysis.

Table 2
Correlation analysis matrix of the variables use in the regression analysis.

	ConsD	ConsJF	ConsK	ConsL	ConsOpp	ConsP	ConsRoil	Elegen	Elinscap	GDP	AGCons	Popn
ConsD	1	−0.52	0.44	0.30	0.34	−0.35	0.32	−0.19	0.22	−0.54	0.40	−0.36
ConsJf		1	−0.47	−0.02	−0.02	−0.01	−0.05	−0.17	−0.05	0.11	−0.22	0.03
ConsK			1	0.59	−0.15	−0.24	0.22	−0.29	−0.29	−0.49	0.06	−0.52
ConsL				1	−0.34	−0.29	0.37	−0.63	−0.40	−0.63	−0.20	−0.73
ConsOpp					1	−0.47	−0.27	0.06	0.20	−0.15	0.28	0.03
ConsP						1	−0.23	0.75	0.43	0.84	0.53	0.79
ConsRoil							1	−0.42	−0.05	−0.49	−0.03	−0.42
Elegen								1	0.51	0.85	0.62	0.86
Elinscap									1	0.49	0.65	0.63
GDP										1	0.39	0.95
AGCons											1	0.54
Popn												1

of a positive relationship between GDP and all petroleum product consumption, which is negative in the case of diesel, kerosene, LPG, other petroleum products, and residual oil. Although the relationship between petrol consumption (ConsP) and GDP is strongly positive, GDP is negatively correlated with kerosene consumption (ConsK) (r ~ −0.49) and diesel consumption (ConsD) (r ~ −0.54).

Similarly, electricity generation shows a negative correlation with all petroleum products except for petrol (r ~ 0.75). It has a very slightly positive correlation with “other petroleum products (r ~ 0.06).) Even the positive relationship between petrol consumption and electricity generation falls short of the expected trend. Low electricity generation necessitates dependence on standalone electricity generators that run mainly on petrol. A similar dynamic holds for diesel, another fuel used in electricity generating sets, and also for kerosene, which is used for lighting in rural and peri-urban Nigeria. Jaja [15] posited that the use of generators for power supply is one factor contributing significantly to increasing the consumption of petroleum products in Nigeria.

The relationship between population and petroleum product consumption is negative for diesel (r ~ −0.36), kerosene (r ~ −0.52), LPG (r ~ −0.73), and residual oils (r ~ −0.42). The correlation with population is strongly positive, however, for petrol (r ~ 0.79), and slightly positive for jet fuel (r ~ 0.03) and other petroleum products (r ~ 0.03). This conforms to the theoretical expectation that as population grows, gasoline consumption also rises.

5.3. Multiple regression analysis

The models represented by equation (2) through (5) were estimated using OLS to determine the equation with the best fit to give a reliable estimate of the aggregate petroleum product consumption as influenced by the specified regressors. The linear model fit the data better than the double-log, linear-log, log-linear, or the lag model specifications. For each petroleum product's consumption and population results, the coefficients are positive, in line with theoretical expectations. However, for GDP, electricity generation, and electricity generation capacity, the coefficients are negative, contrary to theoretical expectation.

The result of the regression analysis is summarized in Table 3, showing the parameter estimates, the standard errors and the coefficient of determination, F-statistics, and other measures of the fitness of the models.

The linear model result shows that nearly 100% of the variation in aggregate petroleum product consumption is explained by the variables specified. The models were submitted to residual tests for autocorrelation, using the Breusch Godfrey Serial Correlation LM

Table 3
Summary of the regression analysis — models and parameters estimate for petroleum products' consumption in Nigeria.

Model	Equation (1) Linear–linear	Equation (2) Log-linear	Equation (3) Log–log	Equation (4) Linear-log	Equation (5) Lag
R2	1.00	0.99	0.97	0.98	1.00
Constant	−0.023138 (0.028887)	4.501716[a] (0.021811)	1.110900 (0.660668)	−752.2512[a] (161.5453)	−0.013935 (0.030906)
ConsD (+)	0.999721[a] (0.000361)	0.003298[a] (0.000273)	0.205112[a] (0.053115)	63.06746[a] (12.98750)	0.999855a (0.000394)
ConsJf (+)	0.999299[a] (0.000524)	0.003652[a] (0.000395)	0.044077 (0.017898)	11.27805 (4.376330)	0.999413[a] (0.000543)
(+)	1.000021[a] (0.000299)	0.003800[a] (0.000226)	0.069646 (0.028064)	17.91508 (6.862203)	1.000074[a] (0.000307)
ConsL (+)	1.004194[a] (0.002183)	0.005486[a] (0.001649)	0.008588 (0.009881)	2.681975 (2.416018)	1.003461[a] (0.002350)
ConsOpp (+)	0.999664[a] (0.000166)	0.003720[a] (0.000125§)	0.112375[a] (0.021798)	29.93691[a] (5.330096)	0.999693[a] (0.000170)
ConsP (+)	0.999543[a] (0.000195)	0.003567[a] (0.000147)	0.297556[a] (0.079534)	78.57941[a] (19.44743)	0.999566[a] (0.000198)
ConsRoil (+)	0.999855[a] (0.000290)	0.003960[a] (0.000219)	0.071939 (0.023036)	18.23783[a] (5.632830)	0.999895[a] (0.000296)
Elegen (−)	5.30E-06 (1.03E-05)	1.17E-05 (7.77E-06)	−0.137952 (0.105807)	−47.85750 (25.87177)	7.51E-06 (1.07E-05)
Elinscap (−)	1.48E-06 (5.80E-06)	1.46E-05[a] (4.38E-06)	0.096268 (0.098176)	1.569274 (24.00587)	3.06E-06 (6.11E-06)
GDP (+)	−4.66E-06 (4.31E-06)	−2.32E-06 (3.25E-06)	0.102671 (0.111285)	39.16826 (27.21107)	−3.68E-06 (4.48E-06)
Popn (+)	0.000952 (0.000468)	0.000184 (0.000354)	0.140357 (0.148340)	36.38779 (36.27174)	0.000864 (0.000483)
AGCons (−1)	–	–	–	–	−0.000112 (0.000126)
F-statistic	30083200	781.7181	40.50799	45.72688	27108857
P'|F|	0.000000	0.000000	0.000001	0.000000	0.000000
Akaike info criterion	−6.808157	−7.370136	−4.468581	6.529996	−6.794740
Schwarz criterion	−6.219130	−6.781109	−3.873467	7.125110	−6.156627
Durbin–Watson stat	1.688598	1.621357	1.674514	1.822289	1.772069

AGCons = Aggregate consumption of petroleum products (thousand barrels per day); GDP = real gross domestic product, constant prices billion naira; ConsP = Consumption of motor gasoline (Petro) in thousand barrels per day; ConsK = Consumption of kerosene in thousand barrels per day; ConsD = Consumption of distillate (Diesel) in thousand barrels per day; ConsL = Consumption of liquid petroleum gas (LPG) in thousand barrels per day; ConsOpp = Consumption of other petroleum products in thousand barrels per day; ConsRoil = Consumption of residual oils in thousand barrels per day; Popn = Population in millions; Elegen = Electricity generation in megawatt; Elinscap = Electricity installed capacity in megawatt.
Standard errors are in parenthesis. [a]Coefficients have significant t-value (p-value < 0.05).

Test and correlogram of residuals squared. The linear model shows that there is no serial autocorrelation, while the correlogram of residuals squared shows that all the variables fall within the band limit for autocorrelation and partial correlation.

The coefficients of ConsD, ConsJF, ConsK, ConsL, ConsOpp, ConsP, and ConsRoil are all statistically significant (p-value < 0.05). Based on the OLS regression estimates for the significant coefficients, this implies, holding everything else constant, that a unit increase in the consumption of diesel, jet fuel, kerosene, LPG, other petroleum products, petrol, or residual oil will yield approximately a one-barrel increase in the aggregate consumption of petroleum product.

The coefficient of population is positive, confirming the theoretical expectation that an increase in population results in an increase in petroleum product consumptions. For GDP, however, while the coefficient is expected to be positive, in the linear, log-linear, and lag models the GDP coefficients are negative, reflecting the fact that GDP does not adequately account for aggregate petroleum product consumption in the case of Nigeria. Since the bulk of petroleum product consumption occurs in the informal (unreported) segment of the economy, this divergence from theoretical expectation is understandable. Similarly, although electricity generation and electricity generation capacity would be expected to have negative coefficients, the models return positive signs.

6. Implications for biofuels adoption and development in Nigeria

The historic trend of the aggregated consumption of petroleum products showed an overall increase with periodic drops (Fig. 1). The trend for petrol (gasoline) consumption also shows growth since its lowest consumption level in 1999 (Fig. 2). The correlation and regression results highlight the significance of petrol, diesel, and kerosene in contributing to the aggregate consumption of petroleum products. Forecasts for both population and GDP predict growth into the next decades for Nigeria [22], with continuing dominance of petrol (over 44 percent of the aggregate) as the most important petroleum product consumed in Nigeria [16].

The total carbon dioxide emission associated with consumption of energy has been rising, along with the aggregate petroleum product consumption. The increase in consumption of petroleum products contributes to increased emission from various sectors in Nigeria. The country's emission of greenhouse gases, particularly carbon, has been on the increase in recent years. The sectoral emission is estimated to have jumped from 6 million tonnes in 1971 to 51 million tonnes in 2007 [30]. Meanwhile, there is little growth in consumption of LNG, which presents a cleaner alternative to gasoline, diesel, and kerosene.

These factors all highlight the need for biofuels adoption in Nigeria. The adoption of biofuels is critical for meeting the carbon sequestration target for Nigeria, as the country has signed several treaties for cutting down on carbon emission [5].

The result of the OLS estimation shows the significance of the key petroleum products for which Nigeria has proposed a blending with biofuels: a unit increase in the consumption of each product implies a corresponding rise in aggregate consumption of petroleum products. The biofuels requirement for meeting the targets for the current biofuels development phase in Nigeria — E10 for ethanol, and between D10 to D20 for biodiesel —will continue to increase, as overall petroleum product consumption increases in line with increasing population and GDP growth.

Moreover, the historical trends in petroleum product consumption and the result of the econometric analysis are in tune with the bases for promoting biofuels adoption in Nigeria. The growing consumption of petroleum products and the significance of each specific product in contributing to the aggregate consumption indicate a strong case for biofuels adoption, particularly if local production can be geared toward meeting the country's blending targets for petrol and diesel. With the country's dependence on foreign import of refined petroleum products, the local production of biofuels to meet the blending targets will help to reduce imports of fuel consumption in the transport, energy, and manufacturing sectors. In addition, the promotion of local production of biofuels to meet the targets will translate into improving agricultural and allied sectors, which will help create and sustain a biofuels economy.

Different drivers drive the adoption of biofuels around the world. Sorda et al. (2010) outlined various reasons why countries around the world promote biofuels, including reducing the dependency on imported oil, and increasing the share of renewable energies to help to support declining farm income. In the case of Nigeria, several factors are relevant: reduction in subsidy on fossil fuels, reducing carbon emission, and deriving other ecological, economic and social benefits [5]. Nigeria currently pays about 1 trillion naira annually to subsidize the prices of petroleum products. The local production of biofuels to meet the E10 and D20 targets will help transfer much of the finances devoted to subsidizing imported products into the local economy.

7. Conclusion

The transition from being a major petroleum-exporting country to a biofuels economy for Nigeria must start with creating demand for the new fuels. Increasing depth of penetration of petroleum products consumption will support arguments in favor of biofuels. On the other hand, the current low level of penetration means that cleaner forms of bioenergies, as compared to the primary forms such as fuel wood and charcoal, will have benefits for the environment and human health.

Arguments for biofuels adoption must begin with an estimate of the response of aggregate consumption of petroleum products to the consumption of specific petroleum products, as well as to the variables of population growth, GDP growth, and the electricity generation index. Econometric estimates can also validate the significance of various factors highlighted as key drivers for biofuels adoption. The historical trends, the correlation analysis, and the OLS estimates show that all petroleum products significantly contribute to aggregate consumption of petroleum products in Nigeria. However, the econometric analysis shows that not all the models confirm theoretical expectations, in terms of the signs and magnitude of coefficients, regarding aggregate petroleum products consumption.

The growth in population and the dire situation of electricity generation in Nigeria mean that the consumption of petrol, diesel, and kerosene will increase, along with GDP. The analysis shows the need for adoption of biofuels, as well as increasing LPG consumption and other carbon reduction strategies. With petrol remaining dominant in consumption of petroleum products, Nigeria must strongly pursue the E10 blending target to be able to meet emission reduction commitments under the various treaties to which the country is signatory. The significant contribution of petrol in aggregate consumption of petroleum products also means that investment in the upstream and downstream biofuels subsector will remain promising, as Nigeria replaces biofuels imports from Brazil with locally produced biofuels.

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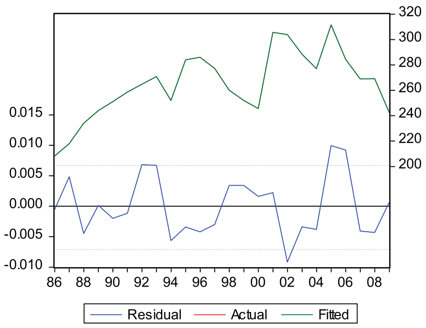
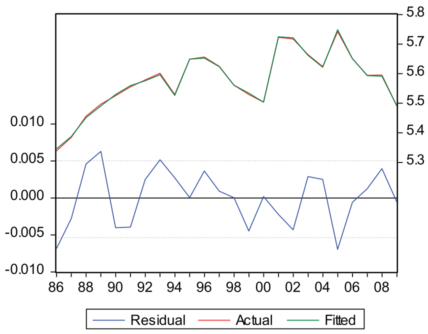
Appendix

Residual Graphs of Models

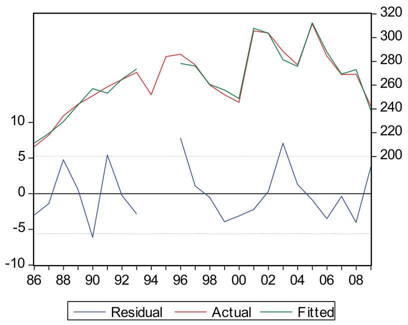


Model 1



Model 2

Model 3



Model 4

Model 5

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Assessing land and water requirements for meeting biofuels targets in Nigeria

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ABSTRACT

Nigeria has set forth ethanol (E10) and biodiesel (D20) blending targets under the automotive biofuels programme being implemented in the country. The domestic production of biofuels to meet the set blending targets for ethanol and biodiesel requires adequate land, water and other resources. This paper attempts to estimate the land and water footprints for meeting the set targets. The result of the analysis shows that for the crops profiled, Nigeria can meet the biofuels requirements for 2010 and 2020 targets from domestic production alone. Going by the current production levels for the feedstock profiled, only 7.4 percent of the feedstock produced and land area are required for meeting the 2010 target for ethanol, while 11.5 percent of the feedstock and land-area are required for meeting the 2020 target for ethanol. The biodiesel target for 2010 and 2020 will require devoting 14.5 and 27.2 percents of the feedstock and land area of the current production levels of the profiled biodiesel-crops. To ease the competition for food, feed and other utilizations to which the biofuels-crops are devoted, Nigeria may need to explore more viable biofuels-crops. The country also needs to work towards increasing the yield per hectare of arable land and other resources devoted to the production of biofuels-crops. The alternatives for Nigeria also include expanding the mix of bio-energies, such as the utilization of agricultural and municipal wastes for meeting the country's renewable energy targets.

Keywords: Biofuel, water footprint, land footprint, feedstock, policy, Nigeria

1. Introduction

Land and water resources are critical for the production of biofuels. The land and water footprints resulting from biofuels production are good measures of their sustainability. The levels of availability of these resources are also at the heart of the consideration of a nation to be a potential biofuels producing economy [1]. The various discussions and arguments on the sustainability of bioenergies, biofuels and the whole lists of renewable energies are linked with the use of land and water resources. Sustainability also extends to how the conversion of these resources to fuel affects the production of other essentials such as food and feed. Wu et al. [2] simulated the impact of future biofuels production in the United States and concluded that the production of the various biofuels feedstock will significantly affect the availability of fresh water. Still in the United States, Venteris et al. [3] assessed land availability under the algae to biofuels production scenario and concluded that the nature of the feedstock has less competition for land.

The possible feedstock (crops) for biofuels production obviously have diverse intensity of demand for land and water resources. While some are land and water resource intensive in their production, others are bound to be less land and water demanding. Beyond the direct impact on the availability of land and water resources, there are the indirect impacts of appropriating these resources for the production of biofuels in a large commercial scale. Wu et al. [2] also highlighted the fact that the concentrated use of water resource in the manner for biofuels production will affect soil nutrient, leading to an increase in the concentration of key nutrients such as nitrogen and phosphorous, which have adverse effects.

The land and water concerns for biofuels production go beyond the availability of these resources, to the consideration of the ripples that are bound to be created as these resources are appropriated for biofuels production. It is obvious that these resources have default competing demands which includes sustaining biodiversity, food crops production, industrial and domestic use, among others. The development of biofuels in Nigeria is still at the early stages, but the concern for sustainability of the new fuels will be hinged on the availability of land and fresh water resources to support the emergence of the country as a strong biofuels producing nation. von Braun [1] categorizes Nigeria among the countries of the world with great potentials for biofuels production.

Nigeria has commenced and is advancing into the second phase of the Automotive Biofuel Programme (ABP) which focuses on local production of biofuels to meet the approved blending targets of E10 for ethanol and D20 for biodiesel. Various investment projects for biofuels production and processing are already on-going in Nigeria, one already producing ethanol, while others are at various stages of development and completion [4, 5].

The adoption and promotion of biofuels in Nigeria is bound to have direct and indirect impacts on natural resources utilized for biofuels production, processing and distribution. As Nigeria advances into the biofuels era, the competition for land, water, and other resources crucial for biofuels production will increase. Even if the current level of utilization of the resources shows no competition, there is bound to be competition as more are appropriated for biofuels production. Of obvious concerns are the expected water and land footprints for producing the huge volume of biofuels required to meet the Nigerian yearly demand without resorting to import.

The Nigerian biofuel programme set the targets for biofuels during the first phase to 1.3 million and 0.48 million cubic meters per annum for ethanol and biodiesel respectively [6]. The targets for the second phase are far higher at 2 million and 0.9 million cubic meter of ethanol and biodiesel per annum, starting from the year 2020 [6]. These targets exceeded the estimated biofuels requirements for Nigeria using the E10 for ethanol and D20 for biodiesel based on the current petrol and diesel consumption in the country. In 2010, the estimates for the consumption of petrol and diesel in Nigeria are 135,050 and 20,270 barrels per day respectively [7]. Based on these estimates, the ethanol and biodiesel required to meet the E10 and D20 targets are 0.783 million and 0.238 million cubic meters of ethanol and biodiesel respectively. Obvious reason for setting such high biofuels production target includes export and trade possibilities. The federal government aims to make Nigeria a major biofuels producer.

Despite the advancements in technology which has led to higher biofuels yield per unit of feedstock and resources, Nigeria will still require a considerable amount of land and water for meeting these targets. This paper estimates the water and land footprints required for meeting the biofuels targets set by the Nigerian biofuels programme.

2. The development of the Nigerian biofuel policy

In 2005, the Federal Government of Nigeria (FGN) gave the Nigerian National Petroleum Corporation (NNPC) the directive to set in motion strategies and tools for evolving a biofuel economy in Nigeria [6]. This directive, tagged Nigerian automotive biofuels programme, led to the development of the current Nigerian biofuels policy and incentives. The directive and policy sets the ball rolling for the implementation of the various biofuels projects which are springing up across the country. This also led to the many lines of researches into estimating the potentials for biofuels feedstock production, estimation of the biofuels yields for many biofuels-crops as well as other researches aimed at setting Nigeria on the path for the dawn of the biofuels era [8, 9, 10]. The NNPC is the main government agency saddled with task of implementing the automotive biofuels programme alongside other government agencies and private sectors. Ohimain [11] detailed the roles of the various players in contributing to the development of biofuels in Nigeria. NNPC has also undertaken various feasibility studies for the establishment of the ethanol producing plants and feedstock plantations, particularly for cassava and sugarcane across the country [9].

The Nigerian biofuels policy and incentives streamlined the development of biofuels in the country into two phases. The first phase involves seeding the marketing through import of ethanol from Brazil to meet the E10 blending target. This phase was set to allow the country to develop the capacity and capability for large scale production of the feedstock, processing plants and other necessary infrastructure for an efficient biofuels distribution [5]. The second phase involves putting into place the core infrastructure for the upstream and downstream segments of the Nigerian biofuels sub-sector. Having implemented the biofuels policy for some years, assessing the progress so far is necessary. Surprisingly, the assessments of the progress of the biofuels development in Nigeria returned verdicts of very little progress [5, 8]. Many of the planned biofuels plants are yet to take off while others that have been under construction for some years now are yet to reach completion, to commence production to help the country meet the biofuels targets. In addition to the slow pace in the biofuels development in Nigeria is the growing concern for the country's ability to meet the biofuels targets from local production and processing of ethanol and biodiesel. The concerns also extend to the direct and indirect impact on land, water, other sources as well as meeting food, feed and fiber requirements from the same crops that have been projected as biofuels feedstock.

3. Methodology

The production of biofuels in Nigeria to meet the required volume for ethanol and biodiesel requires water and land. Biofuel production in the country still focuses on the first generation fuels. Adeoti [9] had assessed the water requirement for meeting 5 percent ethanol volume for blending with gasoline for Nigeria. To estimate the land and water footprints, this paper adopts composite methodologies already advanced and implemented by other authors. This paper followed adjusted version of the methods and sequence of steps used by Gerbens-Leenes at al. [12] and Yang et al. [13]. The steps involve selecting the scenario and biofuels targets for Nigeria, determining the types of feedstock for producing the required ethanol and biodiesel, determining the crops water requirement, then the water and land footprints. Figure 1 detailed the steps for estimating the water and land footprints for local production of biofuels in Nigeria.

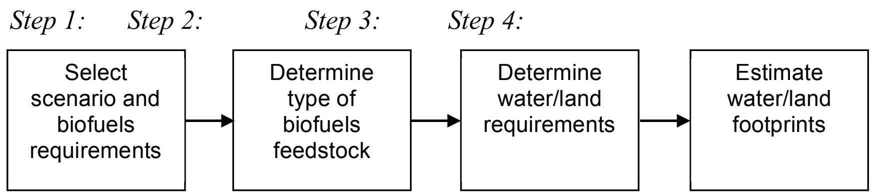

Fig 1. Steps for estimating land and water footprints for biofuels in Nigeria

Source: Adapted from Gerbens-Leenes et al. [12].

After determining the biofuels requirements and following the steps through to step 3, the paper used an adaptation of Yang et al. [13] methodology for determining the land footprint for the volume of biofuels needed for meeting the targets set under the Nigeria automobile biofuels programme. The estimation of the water footprints for meeting the Nigerian biofuels targets is based on the Mekonnen and Hoekstra [14] baseline water footprint per liter of biofuels that can be produced from the profiled crops. Figure 2 is a modified version of the flowchart by Gerbens-Leenes et al. [12]. The figure shows the processes for biofuels processing to ethanol and biodiesels for the feedstock selected in the case of Nigeria. There are already biofuels processing plants and plantations for the production of the feedstock for the two fuels types across Nigeria [4], though the focus is still on a few of these crops.

The water footprints concept was developed by Hoekstra and Chapagain [15]. The measure of water footprint helps to estimate the freshwater requirement for producing a unit of products, as this has an influence on the availability of freshwater for other uses. The water footprint for biofuels and biomass crops production have been undertaken in the past for various countries, regions and the world in general [12, 13, 16].

This paper attempts to determine the water and land footprint using composite methods used by Yang et al., 2009. The methodology for estimating water footprint for biofuels crops has been described by Mekonnen and Hoekstra [14]. This includes first determining the crop evapotranspiration (ET in mm per day), crop water requirement (m^3/tonnes), specified in the formula:

$$CWR = \frac{ET}{Y} \quad (1)$$

Where CWR is water requirement (m^3) for producing a tonne of biofuels crops, ET is the seasonal evapotranspiration of surface water (m^3/km^2) for the crop production period, Y is the crops yield (kg/km^2).

Yang et al. [13] specified the formula for estimating water footprint estimation as follows:

$$WF_b = \rho \times C \times CWR \quad (2)$$

Where WF_b represents the water footprint given in m^3/L, ρ represents the density of specific biofuels (kg/L), with varied fuel types. The densities for biofuels are specified by Alptekin and Canakci [17] as follows: 0.789 kg/L for ethanol and 0.88 kg/L for biodiesel. C represents the feedstock to biofuels conversion ratio (L/tonne).

To determine the land footprint, the following formula was used:

$$LF_b = \frac{Lc}{C\ X \rho\ X\ Tc}\ X\ 10{,}000 \quad (3)$$

Where LF_b *r*epresents the land footprint of biofuels (m^2/L); like in the case of Yang et al. [13], equation (3) is multiplied 10,000 to convert the result from hectare to meter-square. Lc represent land use for the crop production in hectare, Tc represent volume of crop produced in tonnes. Based on the paucity of data for estimating the crop water requirement, which should be based on evapotranspiration data for various stations across Nigeria and in respect of the various crops of concern, this paper adopts the average global figure for water footprint for biofuels-crops estimated by Mekonnen and Hoekstra [14]. The water footprints used for each crop in this paper are the green and blue water footprints. While the blue water footprint represents the quantity of surface and ground water consumed in the production of the crop, the green water footprints stand for the amount of rain water consumed for the production of a crop.

The biofuels yields per crop are based on the estimates by Mekonnen and Hoekstra [14] for the respective crops. Data on land use, production and yield per hectare for the biofuel crops are from the Food and Agriculture Organization [18] and represent an average over ten years from 2002 to 2011.

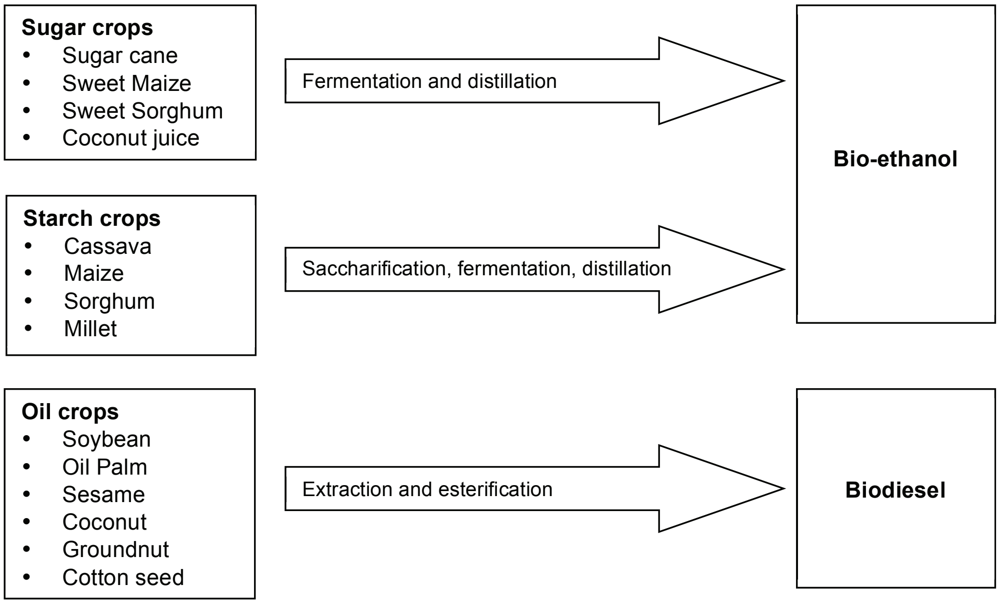

Fig 2. Crops and conversion path to biofuels

Source: Adapted from Gerbens-Leenes et al. [12]

4. Baseline data for estimating land and water footprints of biofuels crops for Nigeria

In estimating the land and water footprints, this paper focuses on crops which are potential and viable options for biofuels production in the case of Nigeria. Of all the crops, only cassava and sugarcane have been highlighted by the Nigerian biofuel policy and incentive as biofuel crops. The crops assessed for land and water footprints are cassava, maize, sugarcane, sorghum, rice and potatoes for ethanol production. Crops profiled for biodiesel production are oil palm, cotton seed, groundnut, soybeans and coconut. Other potential biofuels crops are also grown in Nigeria but are not listed in this paper's estimation for land and water footprints. These other crops include green maize, sweet potatoes, cashew, sesame, melon, millet, and karite nut, which Nigeria is among the leading producers in the world.

Table 1 provides the overview of the water and land footprints of key biofuels crops in Nigeria. The crop yield is based on the average estimate over ten years – from 2002 to 2011. For ethanol, maize, rice and sorghum have the highest biofuel yields per ton of crop harvested. For biodiesel, groundnut has the highest biofuel yield per ton of crop produced. While the Nigerian biofuels programme currently prioritized cassava and sugarcane for ethanol production, the potential biofuels yields reported in the table gives hint as to what other crops the country may have to explore and devote attention to. The potential yields for groundnut is the highest among the crops profiled for biodiesel. The utilization of groundnut for biofuels production will be a good incentive for boosting the production of the crop and bringing back the long disappeared 'groundnut pyramids' that adorned the landscape in the northern part of the country before the oil boom. Cotton also has a high biofuels yield per ton of feedstock. With Nigeria prioritizing cotton as a potential biofuels crop, the drive towards improving and increasing the cultivation will serve much more purposes beyond the utilization of the lint for reviving the comatose textile industry. Intensifying the production of cotton particularly in the northern region of the country with the climatic, geological and hydrological advantage for producing the crop can help Nigeria gain a higher position in the global cotton production. The position of Nigeria in the global cottonseed production from 1960 through to 2010 has floundered between fourteenth and nineteenth. Nigeria's position in the global production of other crops too has always fluctuated, even for cassava.

In the ethanol crops, sugarcane yields the highest tonnage of feedstock, but has the lowest feedstock to biofuel yield. The water footprint per liter is highest for sorghum, while the land footprint for potato is the highest among the ethanol crops category. Coconut takes the lead in terms of water and land footprints for the biodiesel crops category. The figures for the crops yield and land footprint are based on the current low level of productivity for the crops. In terms of crop yield per hectare, water, and other resources devoted to their production, Nigeria still lags behind other major producers of the crops. This means there is room for Nigeria to catch up with other top producers in terms of improving crop productivity, on the path to becoming a biofuel nation. Increasing productivity per unit of resources devoted to the production of the biofuels crops is going to be crucial in ensuring the fuels so produced are profitable in Nigeria. The economic profitability of biofuels remains a major concern in the assessment of sustainability. Sorda et al. [19] argued that external incentives are required for achieving biofuels targets as production still remains unprofitable except in the case of ethanol from sugarcane in Brazil. The low productivity concern and profitability will remain a yardstick in addition to land and water footprints on how sustainable the Nigerian biofuels targets will be.

Table 1: Biofuels yield, crop yield, water and land footprints of biofuels feedstock

Biofuels Type	Feedstock	Feedstock biofuels yield ($L\ t^{-1}$)	Crop Yield ($t\ ha^{-1}\ y^{-1}$)	Water footprint of biofuels ($m^3\ L^{-1}$)	Land footprint of biofuels ($m^2\ L^{-1}$)
Bioethanol	Cassava	222	11.5	2.5	5.0
Bioethanol	Maize	428	1.7	2.4	17.1
Bioethanol	Sugarcane	99	20.1	2.0	6.4
Bioethanol	Sorghum	434	1.2	6.8	23.5
Bioethanol	Potatoes	131	3.0	1.7	32.2
Bioethanol	Rice	434	1.6	3.4	18.6
Biodiesel	Oil palm	213	2.6	5.0	20.4
Biodiesel	Cotton seed	222	0.9	16.1	108.1
Biodiesel	Groundnut	421	1.4	6.2	19.0
Biodiesel	Soybeans	188	1.0	11.2	61.2
Biodiesel	Coconut	17	5.2	156.7	127.7

Sources: Feedstock biofuels yields obtained from Mekonnen and Hoekstra [14], Crop yield based on FAO average data for crop production from 2002 to 2011[18], Water footprint of biofuels is based on the global average reported by Mekonnen and Hoekstra [14] for blue and green water.

5. Land and feedstock requirements for meeting 2010 and 2020 biofuels targets

Having identified the scenarios, the biofuels quantity and types of feedstock for Nigeria, this paper estimates the land and feedstock requirements for meeting the targets. Based on the Nigerian biofuel policy, the paper estimates the volume of biofuels that each crop should be able to contribute to meeting the set targets, according to the current production capacity. Based on the proportion of yield derivable from the crops, the paper arrives at the volume of ethanol that Nigeria should work towards producing from each crop. Table 2 presents the estimate of the possible biofuel yields obtainable from the current level of production, minimum biofuel yields to be expected from each of the crops, and quantity of feedstock that is needed towards producing the estimated biofuels quotas for 2010 and 2020.

The aggregate of the possible biofuels yield for the crops profiled shows, going by the current production level, Nigeria can fully meet the ethanol and biodiesel targets from local production. The six crops, namely cassava, maize, sugarcane, sorghum, potatoes and rice can yield a total of 17.47 million cubic meters of ethanol base on the current production level. The crops profiled for biodiesel can yield a total of 3.3 million cubic meters of the fuel. As the crops profiled are equally used for food, feed and other purposes in the country; the entire production cannot be channeled into biofuels production. For ethanol, the highest quota goes to cassava, followed by sorghum, maize and rice in that order. The quantum of the entire production that is required for producing the ethanol from each crop is about 7.4 percent of the annual production for the 2010 target and 11.5 percent for the 2020 target. For the crop requirement for biodiesel production, 14.5 percent and 27.2 percent of the current production of the crops must be devoted to the production of biofuels to meet the 2010 and 2020 targets.

The volume of crops that is needed for producing biofuels will curb the yearly waste recorded for each crop. FAO [19] commodity balance for the crops primary equivalent reports the percentages of the entire annual production that is wasted in Nigeria. Based on the ten years average estimates from the FAO data, the following proportion of wastes (percentages) are reported for the crops – cassava (11.7), maize (11.3), potato (10), sorghum (11.8), soybean (10.1), rice (10.7), palm oil (3.7), coconut (7), cottonseed (5.1), and groundnut (6.8). The wastes reported for cassava, maize and sorghum far exceeded the proportion of the crops that are needed for meeting the quota for biofuels production for 2010 and 2020 targets. Though the proportion of wastes reported for rice, palm oil, cottonseed, groundnut, soybean and coconut fall below the proportions of the crops required for biofuels, the intensification of the production should provide sufficient supply of the needed feedstock. It should be noted that utilizing the proportion of the currently wasted crop towards meeting the volume of feedstock required for biofuels production is not necessarily sustainable. There are bounds to be years when the crop produced are completely utilized or insufficient as the demand for such crops increase. Hence, effort must be geared towards ensuring that the production of the crops can sufficiently meet the various needs, including biofuels, food, feed, fibre and other productions.

As Nigeria advances into the biofuels era, the options should remain as wide as possible to ensure that crop utilization does not hamper the fulfillment of the food, feed and other requirements. The cellulose based biofuels, as well as fuels from non-food sources should be incorporated into the Nigerian biofuels strategy. In the direction of exploring alternatives to food component of crops for biofuels for Nigeria, Iye and Bilsborrow [20, 21] assessed the availability agricultural residue for large scale bioenergy production. Deploying agricultural, sawmill and other wastes for energy generation is certainly an option the country must explore. The list of possible biofuels crops that can be grown in Nigeria is far longer than those considered in the paper. A possible strategy will be to increase the list of biofuels crops that Nigeria will devote resources towards their production for meeting the set targets for the first and second biofuels phases.

Table 2: Estimates of biofuels production and feedstock requirements for the phase 1 & 2 Targets

Feedstock	Biofuel Yield Per total current production (million m³)	Estimate on Blending rates (2010) (million m³)	Estimate on Blending rates (2020) (million m³)	Feedstock Required for 2010 blending rate (million tonnes)	Feedstock Required for 2020 blending rate (million tonnes)
Bio-ethanol – Targets 2010: 1.3 **2020:** 2.0 (million cubic meters)					
Cassava	9.23	0.690	1.057	3.09	4.76
Maize	2.89	0.220	0.331	0.50	0.77
Sugarcane	0.01	0.008	0.013	0.09	0.13
Sorghum	3.53	0.260	0.404	0.61	0.93
Potatoes	0.10	0.007	0.011	0.06	0.09
Rice	1.61	0.120	0.184	0.28	0.42
Total	**17.47**	**1.300**	**2.000**	**4.63**	**7.10**
Biodiesel – Targets 2010: 0.48 **2020: 0.**90 (million cubic meters)					
Oil palm	1.790	0.261	0.488	1.22	2.29
Cottonseed	0.053	0.008	0.015	0.03	0.07
Groundnut	1.354	0.197	0.369	0.47	0.88
Soybeans	0.099	0.014	0.027	0.08	0.14
Coconut	0.003	0.001	0.001	0.03	0.06
Total	**3.303**	**0.480**	**0.900**	**1.83**	**3.44**

6. Land and water footprints of potential crops for the Nigerian biofuels targets

Nigeria may be considered a land and water rich nation in view of the arable and fresh water resources of the country. The availability of these resources accounts for the inclusion of Nigeria in the global assessment of the countries with potential to become a biofuels producing country [1]. Though the summation of the country's water and land resources indicates abundance, the availability of these varies across the country. Some agro-ecological zones have high proportion of the available arable land, while others receive more rainfall, and by implication are repositories of more freshwaters. The Nigerian arable land stands at 370,000 km^2, the year precipitation stands at about 1062 km^3, and internal renewable water resource stands at 221km^3 [22].

Table 3 presents the summary of the estimation of the aggregate water and land footprints required for producing biofuels from the crops profiled. These estimates are based on the average biofuel yield per ton of feedstock as reported by Mekonnen and Hoekstra [14]. For the volume of crops required for producing ethanol, sorghum has the largest water footprint, followed by cassava and maize. The total water footprint for the crops required for producing ethanol to meet the 2010 target is 4.45 km^3, while the total water footprint for producing the crops for meeting the 2020 target for ethanol is 6.85 km^3. Oil palm and ground nut led the biodiesel crop with the highest water footprint, 1.30 km^3, and 1.22 km^3 respectively. The total water footprint required for producing biodiesel for meeting the 2010 target is 2.89 km^3, while 2020 biodiesel target requires 5.41 km^3. The total water footprint for producing the ethanol required for 2010 target from this study is lower than the estimate (6.0 km^3) reported by Adeoti [9]. The two figures are both from theoretical estimates. While Adeoti [9] estimate is focused on water footprint for meeting E5 blend from only cassava, this paper estimated water footprint for meeting E10 from 6 major crops. The estimated water footprint for meeting phases 1 and 2 biofuels targets can be considered minute vis-à-vis 1062 km^3 annual precipitation as well as other sources of fresh water, including surface and ground water in Nigeria. By implication, the blue and green water requirements for producing biofuels ought not to have negative impact or result to shortages of water supply for Nigeria. More so, the projection of feedstock only constitutes a small proportion of the current production of the crops of interest. If the current production level has been so well sustained by the available water resources, stretching the production beyond the current level in the pursuits of higher output and meeting other needs should be done to ensure there is no adverse effect on water resources, particularly availability for other purposes.

For the 2010 biofuels targets, the land needed for producing the required volume of feedstock, based on the current production capacity are 7.4 percent for ethanol crops and 14.5 percent for biodiesel crops. For the 2020 scenario, the crops profiled for ethanol will each require 11.5 percent of the current arable lands devoted to their production, while for biodiesel crops, the land requirement will be 27.2 percent of the current land use. With an improvement in productivity in terms of tonnage and yield per resources devoted to the production of these crops, the proportion of the crops and land required for meeting the biofuels quota might be lower. It is also worth noting that were Nigeria to focus on a few crops for producing the biofuels target, cassava alone will adequately supply the ethanol requirement of the country. In the same vein, crops such groundnut and palm oil will sufficiently meet the feedstock requirement for biodiesel.

Sorghum has the highest land requirement for its contribution towards the 2010 and 2020 ethanol targets for Nigeria. Oil palm has the highest land requirement (5, 312 km^2) for producing 55 percent of the biodiesel required for the 2010 target for Nigeria. There are corresponding increases in the land and water requirements from the 2010 to 2020 biofuels targets. Since the productions of the crops are still mainly rain-fed, the estimated water footprint should not adversely affect water resource availability considering the huge annual precipitation recorded for the country.

Table 3: Estimates of total land and water footprints for biofuels required for the phase 1 & 2 Targets

Feedstock	Total Water footprint of biofuels 2010 (km^3)	Total Land footprint of biofuels 2010 (km^2)	Total Water footprint of biofuels 2020 (km^3)	Total Land footprint of biofuels 2020 (km^2)
Bio-ethanol				
Cassava	1.70	3, 400	2.62	5,231
Maize	0.52	3, 679	0.79	5,661
Sugarcane	0.02	53	0.03	83
Sorghum	1.79	6,169	2.76	9,491
Potatoes	0.01	238	0.02	367
Rice	0.41	2,229	0.63	3,430
Total	**4.45**	**15,771**	**6.85**	**24,264**
Biodiesel				
Oil palm	1.30	5,312	2.43	9,961
Cotton seed	0.13	838	0.23	1,571
Groundnut	1.22	3,745	2.30	7, 023
Soybeans	0.16	880	0.30	1,650
Coconut	0.08	64	0.15	121
Total	**2.89**	**10,842**	**5.41**	**20,329**

7. Spatial distribution of the production capacity of the key biofuels crops across Nigeria

In meeting the volume of feedstock, land, water and other resources required for biofuels production, Nigeria may have to take advantage of the spatial distribution and variability of crop production capacities. Various agro-ecological zones exist across Nigeria with a distinctive variation in terms of rainfall, availability of land for arable crop production as well as the basic hydrological and soil requirements for producing various biofuels crops. The variation in agro-ecological zones, rainfall distribution, soil types among other factors impose a differentiation in the production capacity for the biofuels crops in Nigeria. This variability in the production capacity across the country shows some states are better suited for producing some of the crops. This diversity in production capacity gives a state, region or agro-ecological zone relative advantage over the others in the production of a particular crop. Figure 3 shows the spatial distribution of four of the key biofuels crops across Nigeria. As it can be seen in the figure, there is a clear variation in the production capacity for cassava and millet. The figure shows, while the southern part of the country has production advantage for the production of cassava, and indeed other root and tuber crops, the northern region are better suited for the production of millet and other grains that require less rainfall. Harnessing the spatial variation in production capacity will be an option for managing the land and water footprints implications for their production. Groundnut and cotton seed which have 1.22 and 0.13 km^3 of water footprint for 2010 target are grown mainly in the northern region of the country.

Based on the spatial distributions and variations of the soil types, rainfall and other conditions required for producing the key crops, the design and implementation of the biofuels policy tailored towards improving the production and productivity of the feedstock must be premised on the varying production advantages and capacities. The current biofuel policy being implemented by the Federal Government through the Nigerian National Petroleum Corporation (NNPC) and other government agencies makes a blanket categorization of the feedstocks of importance. Subsequent review and expansion of the policy must take cognizance of the obvious variation in the spatial distribution of the production capacity. The need to differentiate and serialize the policy incentives for promoting biofuels crops production is crucial from the obvious variation in capacity and how this imposes a variation in the efficient use of water, land and other resources. There is need for a distributive design and implementation of the policies as well as incentives that are tailored towards improving the production and productivity of the various biofuels crops.

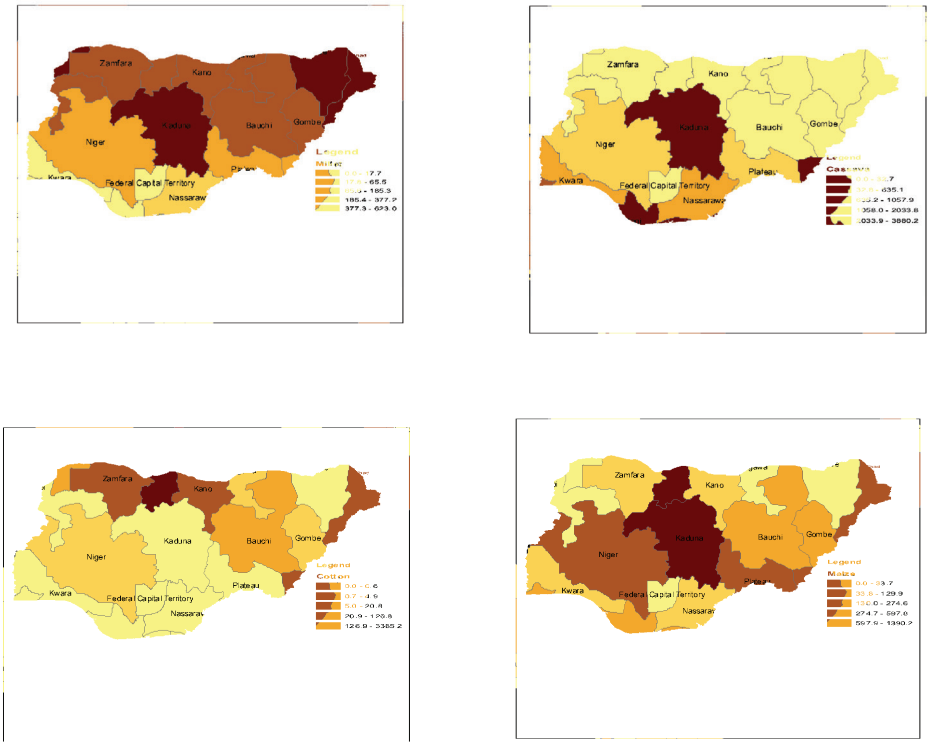

Figure 3: Spatial distribution of the production of major crops in Nigeria (Tonnes)

8. Conclusion

This paper has to assessed land and water footprints for meeting the set target for the biofuels policy being implemented in Nigeria. While only two crops are currently being promoted under the Nigerian biofuel policy and incentives for ethanol production, namely cassava and sugarcane, this paper includes other viable crops for both bio-ethanol and biodiesel. From the analysis, it can be concluded that going by the current production levels of the six crops profiled for ethanol and the five crops profiled for biodiesel, Nigeria can reasonably meet the target for the subsisting phase of the biofuels development, as well as the second phase meant to fully take off by 2020.

The estimation of land and water footprints is based on the global average values for biofuel yields per tonne of feedstock, and the blue/green water footprint per liter of biofuel. Therefore, it should be considered that the results of the analyses are conservative. It is recommended that future analysis of the water and land footprints be based on the empirical values of biofuel yield per tonne of feedstock and estimation of water requirements for the crops and biofuel processing conducted for Nigeria. The land and water footprint from this analysis does not also take into consideration the utilization of these resources beyond the core production and processing of biofuels. The result of this analysis does not foreclose the possibility of exploring alternative options, that is, more biofuels crops for meeting the biofuels needs of the country. In fact, there is need to explore other crops such as sweet potatoes, sesame, green maize, sweet sorghum which the country's soil and hydrological condition support their production. In line with the analyses by Iye and Bilsborrow [20, 21], Nigeria must explore the use of agricultural residue from the production of these crops in expanding the scope of the options for meeting the country's bioenergy needs.

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