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How much can the circular economy principle be adopted into Nigeria's biodiesel and to what extent does palm oil as a feedstock represent a strategic market opportunity.

(30 ECTS)

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Contents

Preface

This Master thesis depicts the completion of the degree of Master of Science in Engineering at the section of Sustainable Biotechnology at Aalborg University in Copenhagen. This dissertation presents the exploratory research work that has been performed during the last semester of the second year of this program from February 2020 and June 2020.

The original intent of this study was to conduct structured skype interviews with major industry players in both the palm oil industry and Nigerian National petroleum industry (NNPC) who are major players in the transition and adoption of biofuels in Nigeria. This would have afforded me with first-hand information and viable statistics with the state of the art in Nigeria regarding palm oil production (feedstock) and the stage of biofuel adoption (biodiesel production) in Nigeria. Unfortunately, due to the Covid-19 pandemic leading to the global lockdown, these intended interviews could not be conducted.

The secondary data utilized here includes theoretical literature obtained from various data bases both from Nigeria (which were inadequate) and global industry players.

In the making of this paper, I have worked with the hermeneutic science theoretical approach. Through its principles of text interpretation, I drew the analysis from Nigerian databases and other relevant sources on the internet and made assumptions based on cases where I could infer similarities.

I therefore acknowledge that I am, excluded from examining the true value of the statements presented in the secondary data. With the hermeneutic approach, I also acknowledge that this paper is, based on my interpretation of the sources and theory used in order to understand, analyse, and discuss the problem statement of the paper (MUGANGA1, 2015).

Furthermore, having to perform this work from home as a mother of a seven years old during the lock down was a challenge as I was faced with caring for my daughter and focusing on my master thesis.

I am most grateful to my supervisors, Mette Lübeck and Kristjan Jespersen for their encouragement in guiding me through this project, their flexibility with time and meeting schedules, their patience in looking through the writing stages and their constructive input throughout the span of this work in spite of the global lockdown resulting from the Covid-19 pandemic. I would also like to thank the entire members of the Section of Sustainable Biotechnology that have contributed collectively to the completion of this study.

The inspiration for pursuing this research on biodiesel using palm oil as a feedstock came during my credit transfer semester at Copenhagen business school where I took a course in Consulting on sustainability with Professor Kristjan Jespersen as the teacher. I have him to thank for stimulating the interest in palm oil and circular economy. The skills and tools I picked up from the course were extremely useful during this Master thesis.

I would also like to acknowledge my Late Parents Mr and Mrs I. E. Thompson for instilling in me the love and value for education and my entire family and friends for all the support, encouragement and sacrifices they had to make throughout the duration of my studies. They are undoubtedly the bedrock of this accomplishment.

Worthy of mention are my hubby, Mr Russell Chijioke Duruibe for his love and personal sacrifices and my daughter, Diamante who is my inspiration, shining star and guardian angel.

Lastly and most importantly, God almighty for all the abilities and opportunities He has afforded me with.

Abstract

In view of anthropogenic climatic pressures, the metamorphosis to sustainable alternatives in the transport fuel sector require further development. Biodiesel produced from palm oil is an interesting alternative.

Nigeria has unified with others globally in supporting biofuels (biodiesel). This research is based on literature reviews of articles and relevant data bases of FAOSTAT, Nigerian Bureau of statistics and some international databases, which focus on the topic. However, biodiesel development in Nigeria is still at the early stages, this master thesis investigates the following issues among others: the readiness for producing palm oil to be utilized as feedstock for biodiesel, the different co-products that can be generated from the utilization of remnant streams to add value to the production process hence incorporating the circular economy principle and the driving forces such as requirements, concerns and challenges that exists in the nation that should be improved to foster biodiesel implementation and advancement. The procedure that can be adopted to secure a balance in both food and feedstock sustainably, the assessment of fossil diesel utilization as a bedrock for implementing biodiesel as a means of determining the market opportunity to meet the goals recommended under the Nigerian (biofuel) biodiesel program and stimulus.

Biofuels (biodiesel) implementation in Nigeria is in the second phase, whereby the infrastructure for promoting biofuels (biodiesel) production is set down. Nigeria's entrance into the biofuels (biodiesel) sphere globally, will afford it to handle two major energy batons, specifically as a crude oil rich country as well as a biofuels (biodiesel) producing nation. The objectives of unifying with other countries in the implementation of biofuels (biodiesel) production and development consists of the following advantages: environmental, economic, and social gains. The advancement of biofuels (palm biodiesel) in Nigeria must be predicated on the capability of blending petroleum diesel, the availability of the necessary feedstock (palm oil) and a suitable environment for the production nationally.

Palm oil is a product of oil palm and a vital domestic industrial product that is utilized for diverse purposes. Preceding the discovery of crude oil in Nigeria in 1957, the Nigerian economy in the 1950s till the middle of 1960s was the biggest producer of palm oil globally. With the discovery of crude oil came the shift of the economic attention from agriculture to the exploitation of crude oil. There is a growing need for the diversification of the economy with emphasis on the revitalization of the palm oil sector. In developing countries like Nigeria, Palm oil production delves into new economic opportunities for most people living in rural communities. The cultivation of oil palm and milling of palm oil contributes extensively to job creation and investment opportunities for people.

Oil palm biomass is a cheap source of feedstock for palm biodiesel in comparison to alternative feedstocks utilized to produce biodiesel. The production of biodiesel from palm oil and palm fatty acid distillate (PFAD) have been found to be economically feasible when compared to fossil diesel and biodiesel derived from alternative oils. Notwithstanding the advantages of palm biodiesel, they also bring about negative socio-economic impact to society.

The literature review and databases employed in this study therefore, explore to some extent, the Nigerian capacity to produce palm oil as a feedstock, the utilization of residues obtained from the production pipelines to valorise the process thereby incorporating the circular economy principle as well as the amount of petroleum diesel consumed by the populace which indicates a viable market for the implementation of biodiesel.

List of figures

List of Tables

Abbreviations and Acronyms

ACOP	Annual Communications of Progress
AD	Anaerobic digestion
ASTM	American Society for Testing and Materials
B05	Fuel blend containing 5% biodiesel and 95% fossil diesel
B10	Fuel blend containing 10% biodiesel and 90% fossil diesel
B100	Pure biodiesel
BPD	Barrels per day
CBN	Central Bank of Nigeria
CFPP	Cold-filter plugging point
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
CPKO	Crude Palm Kernel Oil
CPO	Crude palm oil
CSPO	Certified Sustainable Palm Oil
ECOWAS	Economic Community Of West African States
EFB	Empty Fruit Bunches
EU	European Union
FAME	Fatty acid methyl esters
FAO	Food and Agricultural Organization
FCM	Fruit catching mechanism
FFA	Free fatty acid
FFB	Fresh Fruit Bunches
FGN	Federal government of Nigeria
GDP	Gross domestic Product
GHG	Green House Gases
HPL	Hydratable phospholipids
HPL	Hydratable phospholipids
IBC	Intermediate Bioenergy Carriers
ISCC	International Standard for Carbon Certification
ISPO	Indonesian Sustainable Palm Oil
MF	Mesocarp Fibre
MPOCC	Malaysian Palm Oil Certification Council
MPOB	Malaysian Palm Oil Board
ML	Million Litres
NERC	Nigerian Electricity Regulatory Commission
NGN	Nigerian Naira
NGO	Non-governmental organization
NHPL	Non-hydratable phospholipids
NIFOR	Nigerian Institute for Oil Palm Research
NNPC	Nigerian National Petroleum Corporation
NREEEP	National Renewable Energy and Energy Efficiency Policy
PFAD	Palm oil and palm fatty acid distillate
PJ	Petajoule
PKC	Palm Kernel Cake
PKO	Palm Kernel Oil
PKP	Palm Kernel Protein
PKS	Palm kernel Shell
PL	Phospholipids
POME	Palm Oil Mill Effluent
POS	Palm Oil Sludge

PPM	Parts Per Million
R&D	Research and Development
R/P	Reserves production
RBD	Refined Bleached Deodorised
RPO	Refined palm oil
RSPO	Roundtable on Sustainable Palm Oil
TAG	Triacylglycerides
TRL	Technological readiness level
UNFCCC	United Nations Framework Convention on Climate Change
UPO	Unrefined palm oil
USA	United States of America
USD	United States Dollar
USDA	United State Department of Agriculture

Chapter 1

Introduction

1.1 A new demand for green transition

Contemporary economic schemes have depended on definite production-consumption order to advance development since the industrial revolution. These advancements although positive for mankind, has exceptional burden on the environment. The United Kingdom Parliament became the first government in May 2019 to respond to protests globally regarding anthropogenic threats to the environment by declaring a climate emergency (BBC News, 2019). This can be weighed as a remarkable emphasis in constitutional support for green transition if other nations join with the United Kingdom in realizing the climate situation and establish earnest climate objectives.

The intensification of concern in biofuels in both the producing and consuming economies (either in developed or developing world) is further associated with the rising cost of fossil fuels and the concern to save the environment by reducing the carbon emission linked with fossil fuel usage. With growing interest in biofuels as green substitutes, as well as the demand to resolve issues related to petroleum products, energy concerns around the world's development programs are in focus. This trend climaxed in the emanation of bioenergy schemes both sectionally and globally, together with support in the form of aid, directives, and assets (Keam and McCormick 2008).

Biofuels are progressively advancing into the energy sector as well as a rising need for them as substitutes to fossil fuels. Globally, several nations and zones have strategized to advance the ratification and usage of biofuels (2020a; DeLucia, 2020; Hill, Tajibaeva & Polasky, 2016).The intensity in the advocacy, adoption, enactment, advancement and use of biofuels in Nigeria has been attributed to worries over the dwindling reserves, energy security and bad health effects arising from fossil fuel utilization, among others (Abila, 2012). The nation deals with several challenges: fluctuating supply and prices of petroleum products with severe scarcity; air contamination, biodiversity loss due to the exploitation and use of oil, degradation of land and environmental pollution; successive community clashes and union feuds, loss of sustenance and elevated poverty in the oil rich Niger Delta region; lack of primary infrastructure, food uncertainty and crises; and the breakdown of the existing sector (Abila 2012).

However, Nigeria is a big exporter of crude oil in the world, accruing vast earnings arising from sales of oil and exploration licences and royalties. The crude oil reserve is estimated at 37.2 billion barrels, with daily production capacity approximated at 2.2million barrels per day(bpd) and 47 years R/P (reserves/production) ratio as at 2008 (WEC, 2010). Notwithstanding its large scope of fossil fuel production, Nigeria has unified with other countries in the search for utilizing biofuels production possibility by advancing and enforcing the program for expansion and adoption of biofuels. The aim for the ratification of biofuels in Nigeria consists of the desire to curtail the nations reliance on imported refined petroleum products and control the environmental contamination which has been a primary critique laid up against oil exploration and production. The Federal government of Nigeria (FGN) seeks to diversify the nation's economy as well as generate workable additional profit-making areas which is a different reason for the emphasis for the support and utilization of biofuels program (Abila, 2020).

This increasing agitation for change will possibly transform the political and economic outlook of Nigeria and the world to favour green technologies that is beneficial to sustainability. While there is a change in the market, there must be a corresponding change in the way goods are produced and the quality of services. Having said this, a transition to green alternatives in the short lapse of time illustrated by scientists, agitators and governments necessitates high-technological readiness level (TRL) structures to sustain increasing investments.

The technology readiness levels of various biomass conversion processes are at different stages: some are at research and development, others are at demonstration stage, and yet a few are available commercially. Conventional biofuels, i.e. biofuel derived from sugar and starchy crops or by transesterification of vegetable oil, are relatively developed. But their feedstocks are first generation biomass, and so deals with the issue of sustainability. Sustainability of biotechnology can be enhanced to increase economic benefits, increase land-use efficiency and the environmental performance of regular biofuels. Additionally, cost improvements can be accomplished by co-processing of biofuel and petroleum, that is, by integrating bio-refining with the downstream petroleum processes. Producing conventional and/or advanced biofuels in biorefineries would boost a greater efficiency of biomass utilization and deliver related cost and environmental benefits (Biofuels and the sustainability challenge: a global assessment of sustainability issues, trends and policies for biofuels and related feedstocks (eBook, 2013) [WorldCat.org], 2020). One of the most promising plant species for the production of oil globally is the African oil palm (Elaeis guineensis). High-yielding oil palm varieties developed by cultivation schemes can produce over 20 tonnes of fresh fruit bunches/ha/yr. under optimal management, which is equivalent to 5 tonnes oil/ha/year (excluding the palm kernel oil) (THE STATE OF FOOD AND AGRICULTURE 2002, 2020).

1.2 Research Objectives and hypothesis

There are three essential questions that establish this hypothesis. The production of biodiesel from crude palm oil and the market strategies that can foster a circular economy in Nigeria can only be achieved via policies that answers the following questions:

1) To what extent does Nigeria have the capacity to produce palm oil as a feedstock for biodiesel production and the utilization of the generated residues to produce valuable co-products thereby adopting the circular economy principle?

This question is fundamental, as the entire biofuels policy targets cannot be developed if Nigeria cannot produce the feedstock for producing biodiesel. As stated by von Braun (2007), the availability of food security, arable land, and water are key to determine the capacity for feedstock production for biofuels.

(2) What are the driving forces such as requirements, concerns and challenges that exists in the nation that can foster biodiesel implementation and advancement? Why are specific incentives necessary?

Nigeria's adoption and acceptance of biodiesel can be developed if there are driving forces to create and stimulate the market for biodiesel.

(3) What is the past and current consumption of fossil fuels in the country and how does this form a framework for the implementation and advancement of biodiesel?

Blending of biodiesel with petroleum diesel for the transport sector is one of the basis for the formulation of the Nigerian biodiesel policy. It is necessary to investigate the historical trend and present day situation of petroleum diesel utilization. It is based on this, that an estimation into the future can be made as an argument for biodiesel investment.

1.3 Research Approach

This thesis delves into the capacity of Nigeria to produce palm oil feedstock for biodiesel production, the steps that can be applied to valorise the remnant streams from each stage of the process hence adopting the circular economy principle and the market strategy to drive the adoption of biodiesel in Nigeria. Altogether, this study attempts to produce a conceptual framework for an insight into palm oil as a potential feedstock for biodiesel production in Nigeria. It creates an understanding into the various processes along the production pipeline that are fundamental and important to incorporate the circular economy principle thus closing the loop as biodiesel evolution in Nigeria progresses.

The idea of this thesis falls under the category of a novel and yet to be fully explored area, especially in Nigeria. The country's inroad into the implementation and advancement of biofuels is still at the inception. This initiated the ratification of an exploratory research approach at the inception of this work. According to Shields and Rangarjan (2013), exploratory research is used for a scientific inquiry when the consequences of the problem at hand is not completely established. Exploratory research aids to form the framework for comprehending the problem adequately, forming a concept, in a few circumstances, establishes a blend that is beneficial to understand the network between different sections of a problem and how they are linked. Although there are few articles that delve into Nigeria's adoption of biodiesel, they are merely superficial. Part of the field explored includes the assessment of the potentials for biofuels development, assessment of the roles of government agencies, and assessment of the enabling biofuels policy.
To give answers to the research questions stated above, specific methodologies were utilized. To grasp the issues of sustainability of biofuels chains in Nigeria which includes the production of feedstock, production of biodiesel, processing and distribution, a qualitative and quantitative analysis are necessary. The approaches utilized for this study are mostly foundational; that is, they present a base for further research of the biodiesel sector, investment, policy, and sustainability in Nigeria. Various authors have initiated the assessment of different aspects of biofuels development in Nigeria (Abila 2012; Adeoti 2010; Ishola et al. 2013; Ohimain 2013 etc.).

To determine the data in this study, FAO statistics database was the major leadoff (FAO Statistical Yearbook 2012, 2020). This includes figures for production, acreage, yield, consumption, and import. Figures on crude palm oil are mostly utilized and other vegetable oils are employed for comparison. Given that FAOSTAT data constitutes the exclusive source to demonstrate the trends in palm oil production they are employed as the main source in this report, but other data sources have been applied as frames of reference such as published literature principally, which includes reports from government agencies like the National Bureau of Statistics Annual reports, national gazette, Central Bank of Nigeria reports and other relevant national and international databases like the Information Energy Agency and the United States Energy Information Administration.

1.4 Structure of thesis

Below is a brief synopsis of the thesis: The thesis is divided into five chapters.

Chapter 1 comprises of an introduction to the topic, general aspects like the need for transition to green energies, a structure of literature review elucidating the background into biofuel (biodiesel) adoption in Nigeria. The research questions and objectives are also included here.

Chapter 2 explores the concept of biorefinery, the production processes, the oil biorefinery incorporating the circular economy principle in which this thesis represents a minor contribution, palm oil as the feedstock, the properties of biodiesel and the advantages and disadvantages of its use. The final section of this chapter looks at the global biodiesel production.

Chapter 3 delves into the present palm oil (feedstock) production and the current situation of biodiesel implementation in Nigeria. The Research findings are also discussed here based on the investigation of the data retrieved.

Chapter 4 presents the discussion whereby the assessment of factors affecting commercial viability of palm oil (feedstock) and the organization of the market structure are looked into. The ethics of biodiesel in terms of the economic, social, and environmental issues are also discussed here. The Certification of palm oil (RSPO), limitations and future perspectives of palm oil and biodiesel implementation in Nigeria are highlighted here.

Chapter 5 is the conclusion of the research work that has been carried out.

1.5 Energy and a renewable Nigeria

Nigeria is a developing country situated in the western part of Africa with a population of 182 million persons, it is the most populated nation and the largest economy in the African continent, the 26th largest economy globally with half a trillion dollars in GDP. It is very rich in natural resources (2020b). Nevertheless, around 60% of Nigerians still live beneath the poverty line. This can likewise be connected to the energy access rate in the country. Presently, about 40% of Nigerians do not have access to electricity, and those who have may see the supply to be erratic.

Nigeria’s thriving population is presently underserviced and is regularly longing for socio-economic development. To enhance the welfare of Nigerians and boost the per capita income, the energy requirement will certainly surge in the future. Furthermore, Nigeria is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and has also committed itself to the Paris Accord to curtail its national Green House Gas (GHG) inventory. The electricity system is still controlled by natural gas, accounting for around 85% of the supply scheme while the transport sector is totally run by gasoline and diesel. Therefore, fulfilling the present unrealised energy demand, guaranteeing rapid economic growth, without enlarging greenhouse gas emissions with the finite resources available generates a problem for Nigerian decision makers. To defeat this dilemma, the government has resolved to follow its development agenda with a sustainable approach and equally promote the fight against climate change globally without neglecting its advancing priorities. The Federal Government of Nigeria has developed the National Renewable Energy and Energy Efficiency Policy (NREEEP). The NREEEP sketches different procedures and agenda for the distribution of renewable energy technologies in the country (Nigeria’s Renewable Energy Policy: A Fantasy or Reality? - Renewable Energy World, 2020). Energy supply to the industrial and transportation sectors, which uses large energy storage density fuels, can only be substituted by bioenergy carriers (Cornelissen et al., 2012). For the NREEEP scenario to be realised, major advancement in all renewable energy sectors must take place including, particularly for this project, a decarbonisation of the transport sector which can be attained through a development in the production of intermediate bioenergy carriers.

1.6 Intermediate bioenergy carriers

Intermediate bioenergy carriers (IBCs) are produced when biomass is refined to energy-dense, storable, and transportable intermediary products homologous to oil and other fossil fuels (KG, 2020). The role they play in a successful energy transmission as already stated above is in the substitution of fuel to the industrial and transportation sector. IBCs may be directly utilized for power generation, for heat or can be purified to bio-based products or final bioenergy. IBC’s consist of advanced biofuels originating from agricultural and forestry residues and waste feedstock (2020a). The ability of IBC'S to combine with current internal combustion engines with little or no modification in blends, makes them valuable permitting for a progressive and broad unhampered market uptake for transportation when considering renewable transition (Knothe et al., 2015).

Chapter 2

Biorefinery concept, general processing of oil palm to palm oil feedstock and biodiesel production

2.1 Biorefinery concept

Biorefining is the sustainable conversion of biomass into a wide range of profit-making biobased products /biofuels. It is an innovative and systematic approach to utilize available biomass for the synergistic co-generation of heat, power and biofuels with food and feed components pharmaceuticals etc. Biorefining is one of the essential blueprints of the circular economy, closing loops of raw biomass materials (re-utilization of forestry agro, process and post-consumer remnants, minerals, water, and carbon).

Consequently, biorefining is the optimum approach for sustainable utilization of biomass extensively in the Bioeconomy (2020c). However, biomass is mainly used for production of biofuels with the purpose of partially or completely substituting highly polluting fossil fuels. In the last ten years, the fundamental use of biomass for the production of a wide range of upgraded products in addition to biofuels like fine chemicals, biomaterials, biopolymers etc. has given recent opportunities to improve both the environmental conditions of the biofuel industry and the profit making aspects of the production of biofuels (Cherubini & Ulgiati, 2010). These advancements have substantially shown an indication that the existing fossil-based economy will progressively be replaced by a biomass-based economy.

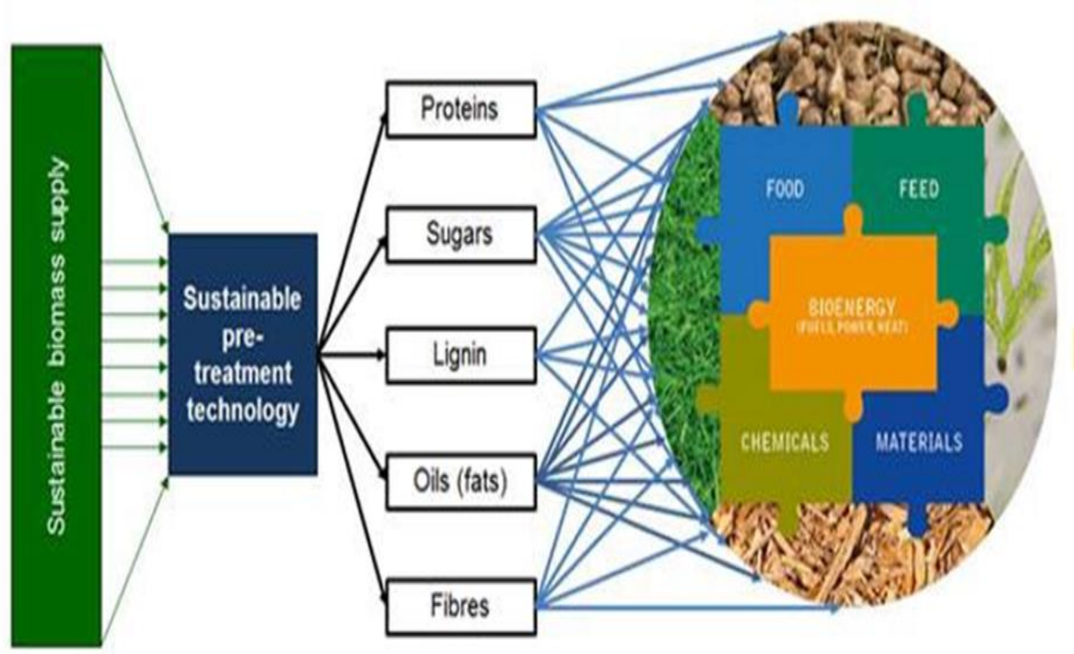


Figure 1. Bioenergy and biorefining being the lubricating oil of the Bio(based)economy as part of the overall Circular Economy (2020c).

Various kinds of biorefineries are presently developing. The primary challenge regardless of the kind of biorefinery, is the effective conversion of biomass and residues via a cost-efficient process that can contend with the petroleum-based industry eventually. Thus, the thorough conversion of biomass should be maximized, and the use of costly and unsustainable products necessary for the processing of biomass must be reduced. A synergistic combination of biological, technological, and chemical techniques is required to achieve this (Kamm, Gruber et al. 2007). Biorefineries can be erected in different areas. They can stimulate the rural area and create employment in the extremely depopulated areas, generating a balanced distribution of the population. In the long run, awareness can be created in the people of the available resources in their environment and how to improve on the forest and agricultural management (Demirbas, 2009). Additionally, several bio-industries can integrate their material flows aimed at the complete usage and transformation of the biomass considering that the waste and leftovers of one bioindustry could be an input for another industry.

2.1.1 The Oil biorefinery

Presently, the decline in petroleum-based energy reserves and its negative environmental impact have heightened the concern for other renewable energy sources. There is the immediate challenge of a twin crises of fossil fuel reduction and degradation to the environment globally (Lin et al. 2011). The random extraction and excessive utilization of fossil fuels have brought about the decline in carbon resources underneath the ground. The quest for substitute fuels that guarantees a friendly interaction with sustainability, environmental preservation efficiency and conservation of energy has become extremely evident today (Demirbas, 2007). With extensive efforts to cut down on petroleum fuel dependency and attain climate goals, recent targets for recommending biodiesel (renewable fuel) blends have been fixed globally for the transport sector in a lot of countries.

Vegetable oil and animal fats are utilized as substitutes in diesel engines. Their high viscosity and low volatility cause various problems in diesel engines. These problems can be removed using dilution, pyrolysis, and transesterification processes.

Oil and Fat feedstock

The figure 2 below presents the oil and fat feedstock in a biorefinery concept .

Source: Varrone, 2018, slide 6.

2.1.2 Previous and current research

Technologies and processes in late stages of development are vital to obtain investment from private and governmental initiatives and sequentially promote the movement to a renewable economy. As opposed to regular biofuels which are commercialized, advanced biofuels are still developing the research and development pipeline (Stafford et al., 2017). In the present paper, the focus is mostly to determine the capacity of Nigeria to produce palm oil as a feedstock for biodiesel production and the utilization of the remnant streams from the process for valuable co-products thus adopting the circular economy principle and how this can represent a strategic market opportunity in Nigeria.

Oil palm (Elaeis guineensis) has arisen as an important economic crop presently feeding the globe. Palm oil is one of the biggest universally consumed edible oil and a predominant feedstock to produce biodiesel. The structure for palm oil production comprises of oil palm cultivation, palm oil milling, and refining. It also includes various residues (i.e., kernel oil and cake), wastewater (effluents) etc. which are very important biomass/ bio-resources for industrial application (viz. cosmetics and chemicals) and energy production (i.e. bioelectricity and biogas). The use of palm oil for food is anticipated to rise next to population and economic growth.

In the palm oil milling sector, the volarisation of by-products, biogas (productivity, trapping and usage as a form of energy) and wastewater management, viz. palm oil mill effluent for final discharge compliance establishes that the industry meets its sustainable targets. It is obvious that synergising standard and innovative technologies at each stage of the palm oil supply chain is advantageous and necessary to thrust the industry forward.

2.2 Biodiesel

Biodiesel is a renewable fuel practically homologous to fossil diesel which is produced from vegetable/ algal oils or animal fats through chemical reaction and it is attaining a rise in world-wide recognition. The substrates utilized for biodiesel production are rich in triacylglycerides consisting of various forms of fatty acid giving the feedstock a distinct fatty acid profile. Triacylglycerides in the presence of a catalyst alongside an alcohol react yielding equivalent fatty acid methyl esters and glycerol in the process known as transesterification to give biodiesel. Crop feedstock such as soybean and rapeseed oil are utilized in Europe while Asian countries are analysing non-edible seed oils like jatropha that are less appealing biodiesel feedstock (Gui, Lee and Bhatia, 2008).

2.2.1 Biodiesel from Palm oil

Both palm oil and palm olein are both derived from a plant species called oil palm tree, which has been evident for over 5000 years in South-Eastern Asia, Africa, and Latin America (2020b). One hectare of oil palm plantation can produce ten times the amount of oil that can be derived from other primary oilseed crops (Ofori-Boateng and Lee, 2013). The average palm oil production is about 3.62 tons /ha/year, in comparison to soybean oil 0.4, sunflower oil 0.46 and rapeseed oil 0.68 ("Biofuels: Alternative Feedstocks and Conversion Processes for the Production of Liquid and Gaseous Biofuels | ScienceDirect", 2020). The growing palm oil biodiesel economy in nations such as Indonesia and Malaysia presents an assumption that oil palm biomass can be an additional approach to Nigerian Biodiesel industry due to the fact that the above mentioned countries and Nigeria are amongst the biggest producers of palm oil (2020d).

Palm oil is extracted straight from the ripened mesocarp and can be processed into refined palm oil which is commonly named "red oil" that can be consumed directly and also utilized in household cooking. There are disapprovals about the production of biofuels from crops like palm oil which can hinder the supply and demand of these crops bringing about a constant shortage of palm oil which is mainly used as cooking oil in Nigeria. However, in the palm oil industry, a substantial amount of different forms of by-products are produced in solid, liquid, and gaseous form. It has been proven that edible oil obtained from the total biomass recovered from palm plantation is only 10% plus either by-products or wastes making up of the remaining

90% . A typical evaluation of a palm oil refining process could generate a yield of 73% olein, 21% stearin, 5% palm fatty acid distillate (PFAD) and 0.5%gas effluent (2020d).

2.2.1.1 Palm oil as oil feedstocks

Biodiesel can be produced from any raw material that contains fatty acids, either bonded to other molecules or present as free molecules. Hence, a variety of vegetable fats and oils, animal fats, waste greases, and edible oil processing wastes can be utilized as feedstocks for biodiesel production. The choice of feedstock is dependent on such variables as local availability, cost, government support, and performance as a fuel. Various countries are finding separate types of fats and oils as feedstocks for biodiesel (Ghadge and Raheman, 2005; Meher et al., 2006; and Sarin et al., 2007). Palm oil yields high productivity which produce about 6000 litres/ha compared to alternative feedstock.

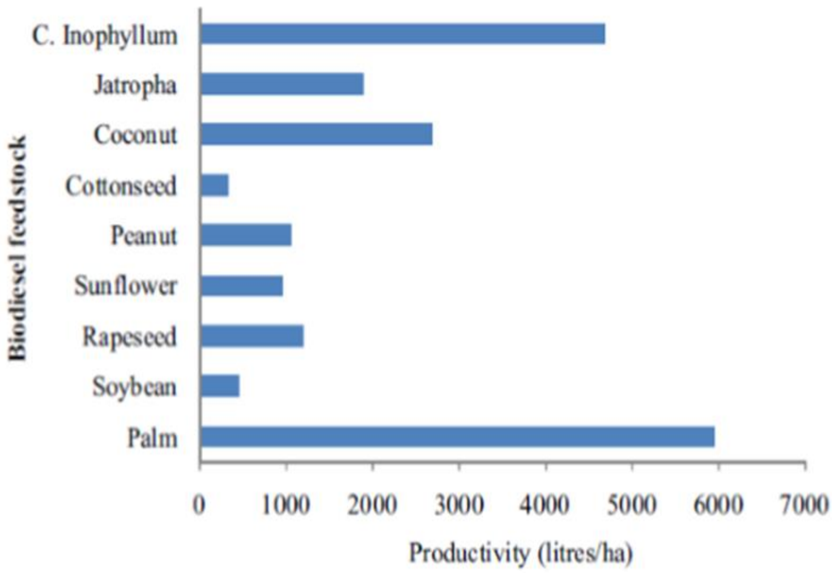


Figure 3. Production Oil Yield for Various Source of Biodiesel Feedstock (Source: Karmakar et al., 2010).

Fats and oils are generally insoluble in water. The main component of oils and fats is triglycerides, which constitutes around 90% - 98% of total mass (Srivastava and Prasad, 2000). Palm oil is the most promising feedstock for biodiesel production compared to other oilseeds. It has a higher production yield, less water and pesticide required for the plantation and low fertilizer usage. Compared to other vegetable oils in the market globally, CPO and refined palm oil top the list. The global production of palm oil is 45 million tones and highest production is in South East Asia with a total 89% of total oil production (40% in Malaysia, 46% in Indonesia, 3% in Thailand).

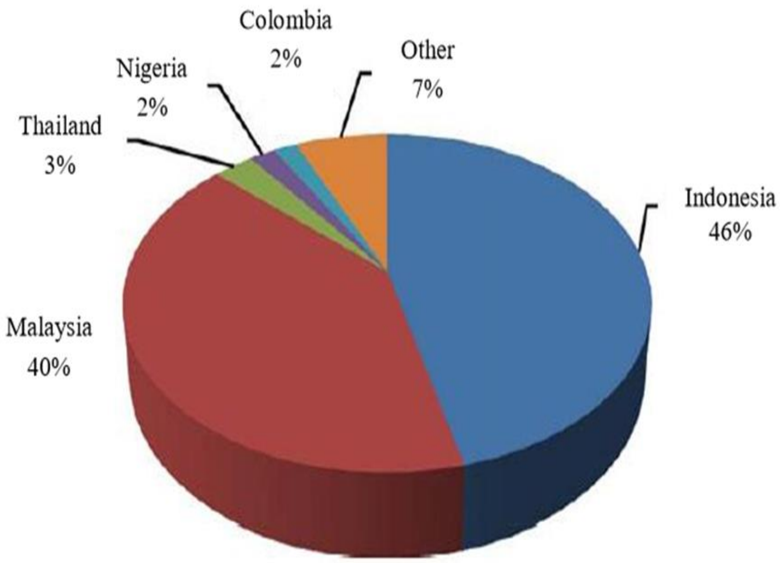


Figure 4. World Palm Oil Production 2009 (Source: USDA, 2010).

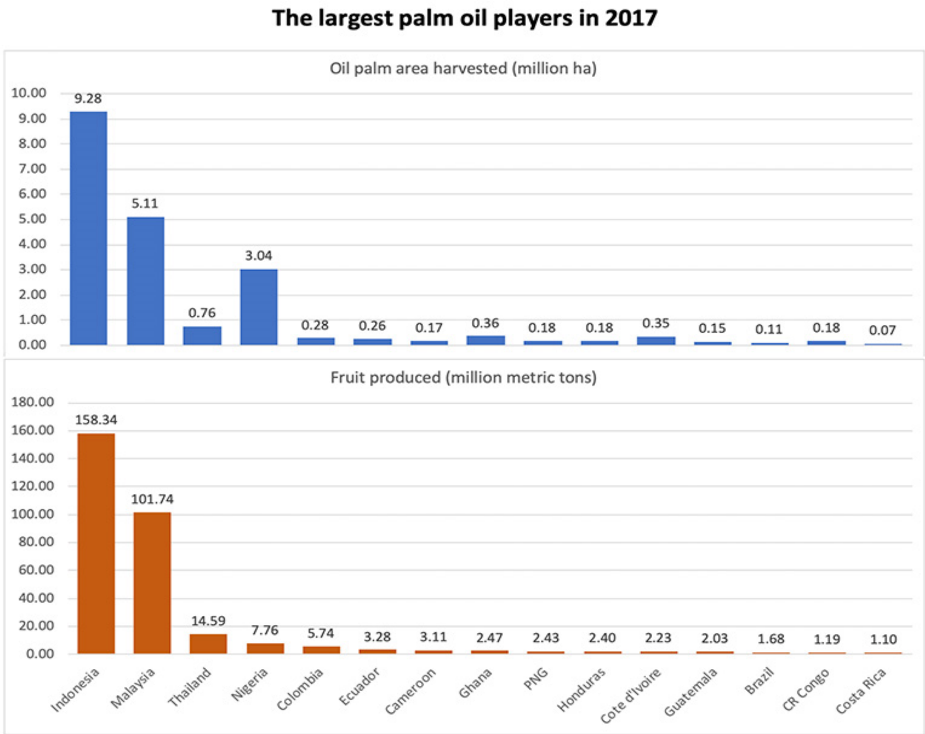


Figure 5. Source: (Small-Scale Palm Oil Processing Business in Nigeria; A Feasibility Study, 2020).

Palm-diesel has also become additionally attractive because, based on the present practices in the Malaysian palm oil industry, palm-diesel usage can generally contribute to GHG emissions preserving 50-70% in comparison to petroleum diesel (Hassan, Jaramillo, and Griffin, 2011). A lot of researchers have postulated the reduction of CO2 emission although some investigations recorded that South East Asia emit enormous emissions from palm oil biodiesel (Kalam and Masjuki, 2004).

2.2.1.2 Palm Oil and the Circular Economy

The circular economy (CE) as against a linear one illustrates a developmental system in which resource utilization and waste production, emissions and energy waste are reduced by curbing lowering and closing the energy and material cycles**.** Realistically, recycling i.e. bringing waste products back into the cycle as secondary raw materials plays the key role in the CE. This is of distinct significance to the palm oil industry (Palm Oil and the Circular Economy | Global Oil & Fats Business Online – gofbonline.com, 2020). CPO, palm kernel oil (PKO) from several biomass from the oil palm industry can be valorised to valuable co-products to close the loop in the system (Liew, Hassim and Ng, 2020).

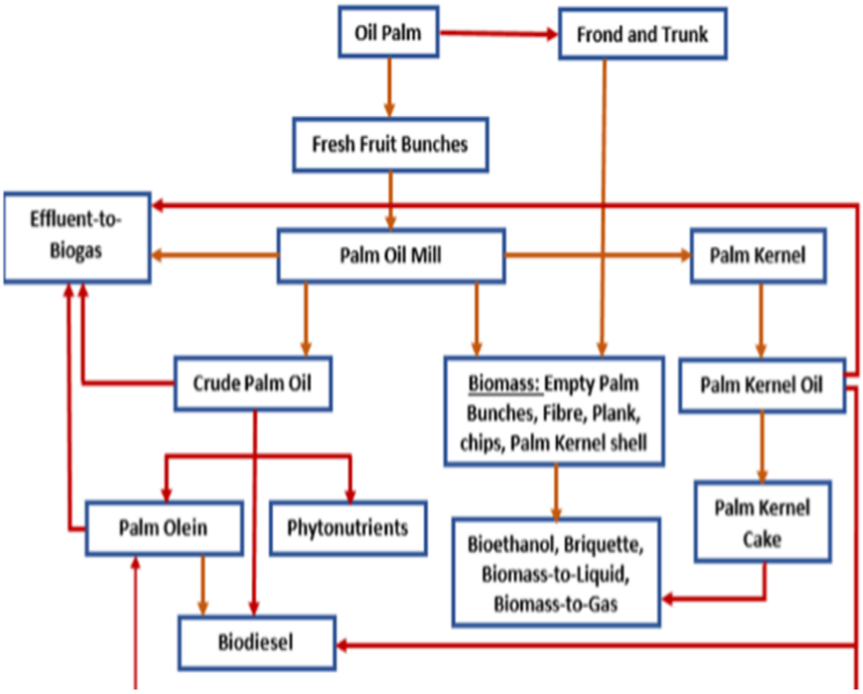


Figure 6. An analytical Renewable Energy Potential Analysis Model for Oil palm (2020d)

The linear economy, also known as the 'throwaway economy', is the predominant principle of industrial production presently**.** A huge part of the raw materials utilized is stashed or burned according to the life cycle of the products. Only a tiny fraction is reutilized. Expressed as a simple formula, the antagonism between the two concepts is expressed as take-make-dispose (linear model) vs reduce-reuse-recycle (circular model).

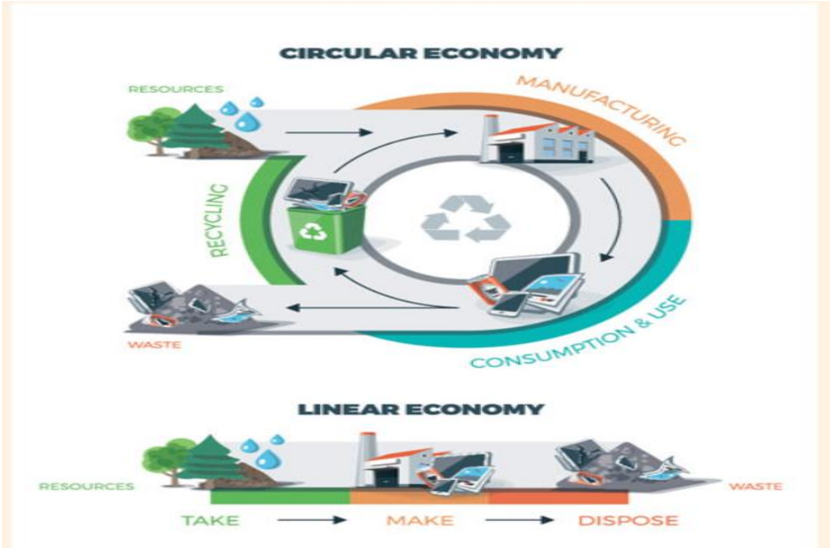


Figure 7. Comparison of concepts.

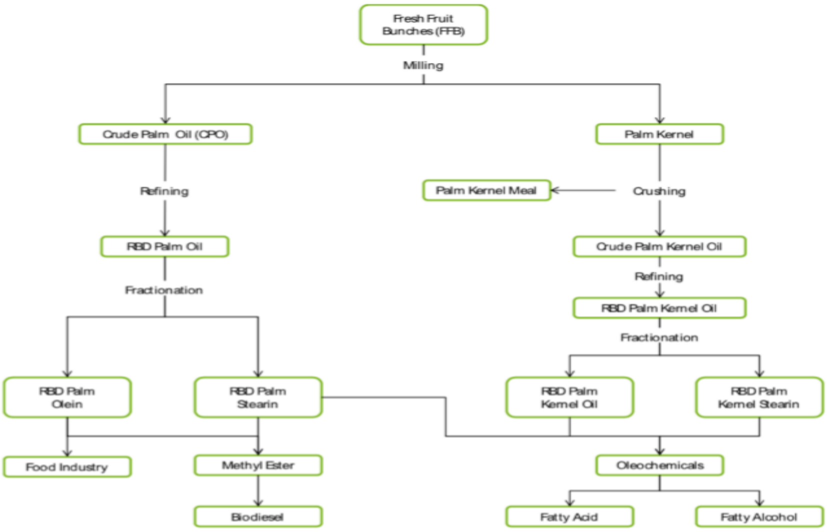
Source: © petovarga/fotolia.com (Palm Oil and the Circular Economy | Global Oil & Fats Business Online – gofbonline.com, 2020)

The production of palm oil produces vast number of secondary products – palm oil mill effluent (POME), empty fruit bunches (EFB), palm oil mill sludge, oil palm fronds, oil palm trunks, decanter cake, seed shells and palm pressed fibres. The biomass has massive economic potential:

Biomass energy can provide an important fraction of on-site energy requirement, increasing energy independence for mill operators and private housing. Motor engines could run on biodiesel, hence reducing pollution. Rural economies can be stimulated since smallholders gain additional income. Nevertheless, to make a financially feasible transformation to the CE is complex.

The crude palm oil has been selected for biodiesel production in this study. The entire process is split into distinct functions along the production channel. The alternative methods and justification of selected processes will be covered in this section.

There are two distinct pathways in the milling of fresh fruit bunches to win oil as shown in Figure 8 below. The PKO and the CPO. The CPO is the focus of this thesis.



Source: (Global Agribusiness Market Intelligence & Consulting | LMC, 2020)

The PKO and the CPO. The CPO is the focus of this thesis.

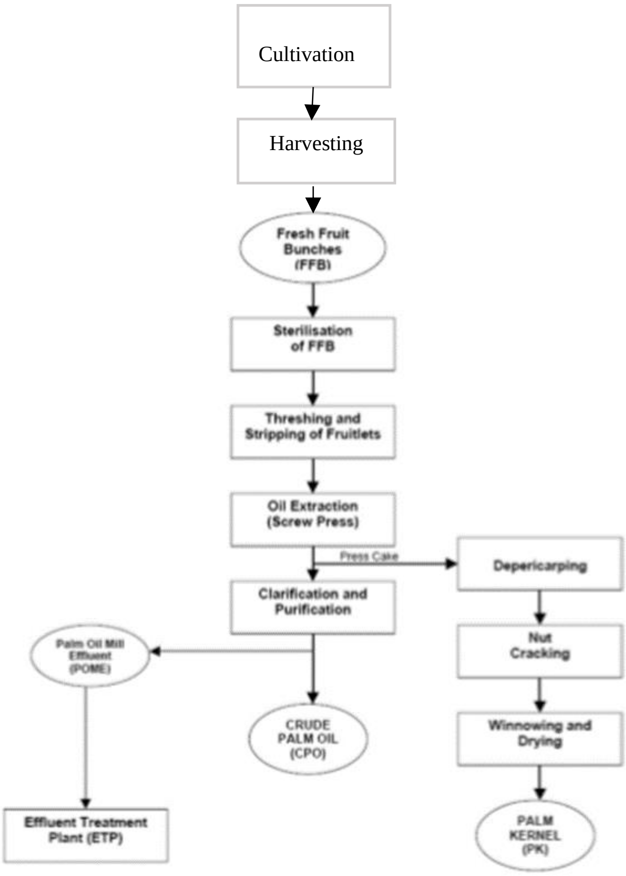


Figure 9. The process diagram for transforming oil palm into crude palm oil:

Source: (What is palm oil, 2020).

2.3 Cultivation

The major economic limitation for the production of biodiesel commercially is stated to be the cost of feedstock (Gebremariam & Marchetti, 2018). These feedstocks consists mainly of vegetable oil and waste cooking oil that comprises 77% of the running costs for a small-scale biodiesel plant (Sakai et al., 2009). Cultivating the oil feedstock within the production area can eliminate the cost of transportation, expand the control of operations to benefit a particular product and create a more stable, homogeneous feedstock stream hence an approach that can introduce savings to the process. The main aim of this work is to assess the capacity of Nigeria to produce palm oil (feedstock) for producing biodiesel, a pipeline for the utilization of remnant streams to generate valuable co-products thus incorporating the circular economy principle to close the loop.

2.3.1 Cultivation site

In Nigeria, oil palm cultivation covers twenty-four states in the South East Zone and the Niger Delta areas. The 9 states of the Niger Delta account for about 57% of the total palm oil production in Nigeria. Several millions of dispersed smallholders which account for 80% of this production spread across an estimated area ranging from 1.65million hectares to 2.4million ha and a maximum of 3 million ha. The estimate for oil palm plantations ranges between 169,000 ha (72,000 ha of estate plantations and 97,000 ha of smallholder plantations) to 360,000ha of plantations (2020d). The Oil palm is a conventional crop of the rainy tropical lowlands. During the entire year, the tree requires a deep soil, a comparatively stable high temperature and constant moisture. The fertility of the soil is lesser than the physical soil properties. The plants are nurtured in nurseries where adequate care is given to the seedlings. The seedlings spend 12months in the nursery before they are transplanted to the field (Agric, 2020). Oil palm is cultivated in the palm plantation in a triangular arrangement at a spacing of 9 meters accommodating 140 palms per ha. A mature palm is single stemmed and grows to 20m tall. The outset of the rainfall during May-June is preferred for planting. After 3.5-4 years of planting, the initial harvest can be taken.

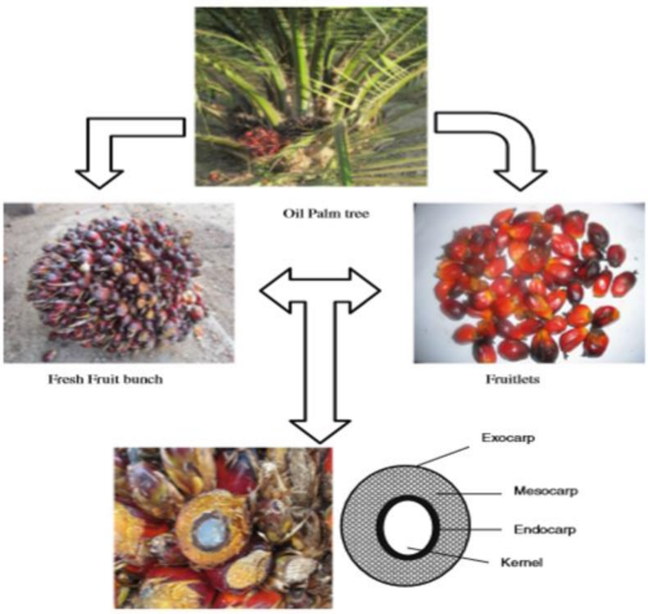


Figure 10. Oil palm plantation   Figure 11. Parts of the oil palm fruitlet

(Sustainability of Biofuel Production from Oil Palm Biomass: (Ofori-Boateng and Lee, 2013).

Due to the economic significance as a high-yielding source of edible and technical oils, the oil palm is now grown as a plantation crop in most countries with huge rainfall (minimum 1 600 mm/yr.) in tropical climates within 10° of the equator. The palm bears its fruit in bunches (Figure. 11) varying in weight from 10kg to 40 kg. A single fruit ranges from 6 to 20 gm consists of an outer skin (the exocarp), a pulp (mesocarp) containing the palm oil in a fibrous matrix; a central nut consisting of a shell (endocarp); and the kernel, which in itself contains an oil, quite distinct to palm oil, looking like coconut oil. (Small-Scale Palm Oil Processing in Africa, 2020).

Bunch weight	23-27 kg
Fruit/bunch	60-65 %
Oil/bunch	21-23 %
Kernel/bunch	5-7 %
Mesocarp/bunch	44-46 %
Mesocarp/fruit	71-76 %
Kernel/fruit	21-22 %
Shell/fruit	10-11 %

Table 1: Ideal composition of palm fruit bunch

Source: (Small-Scale Palm Oil Processing in Africa, 2020)

Nigeria has three types of oil palm: namely Dura, Pisifera and Tenera. Oil palm farmers in Nigeria prefer the hybrid Tenera which is a crossbreed of the Dura (female) and the Pisifera (male). Tenera seedlings are produced by the Nigeria Institute for Oil Palm Research (NIFOR) and commonly referred to as the extension work seeds. In terms of comparison, the fruit of the Tenera variety contains 25% oil, by weight, and the Dura variety 18%, so the same amount of Tenera can yield 30% more oil than the equivalent fruit of the Dura (2020d). The Niger Delta region of Nigeria is the preferred focus as the location for this study and the Tenera seedling will be the recommended type of oil palm.

2.4 Harvesting

Harvesting needs a lot of time and great care since only those fruit clusters which are cut at the right time yield a lot of good-quality oil. A cluster is ripe for harvesting when the fruits start to turn red, and when 5 or 6 fruits fall to the ground. Depending on the age of the plant, tools like chisel, machete, and sickle are used for the harvest.

Harvesting implies the cutting of the bunch from the tree and allowing it to drop to the ground by gravity. Fruits may be flawed in the process of pruning palm fronds to reveal the bunch base to aid bunch cutting. As the bunch (weighing about 25 kg) drops down, the effect bruises the fruit. Amid loading and unloading of bunches inside and away of transport vessels there are additional opportunities for the fruit to be broken. Most bunches are transferred to the processing location in baskets borne on the head in Africa. Occasionally, trucks and push carts, inadequate to set bunches down gently, transport the load from the villages to the processing location (Small-Scale Palm Oil Processing in Africa, 2020).

According to Saibani, et al (2015) and Syuaib, et al (2015) the manual harvesting tasks consists of the following steps: search for FFB on trees, adjust the length of aluminium pole and sickle, position the pole's sickle for pruning, perform pruning, position the pole's sickle for harvesting of FFB, perform harvesting of FFB, collect FFB bunches, move harvesting tool to another tree, repeat.

Figure12. Manual harvesting task of FFB; Figure 13. The mechanical harvesting machine

Source: (Aldaz, 2020)

2.4.1 Mechanizing the process of oil Palm crop production

It is vital to boost the productivity of oil palm (Elaeis guineensis). Capacity and cost can be improved by utilizing mechanical means to eliminate drudgery from the whole production processes (Aldaz, 2020). Standard agricultural tractors can presently be utilized for harvesting processes, loading, unloading, spraying, or fertilizing the oil palm crop. Fruit catching mechanism (FCM) was constructed by Malaysian palm Oil board (MPOB) Japanese firm. FCM is a harvesting machine with the cutting tool attached to the boom. It can extend to 10 meters in height which is the upper limit that can be reached by hydraulic cylinders. When a bunch is spotted, the operator moves the vehicle close to the palm crown by sliding the corresponding joystick control. Once the cutter is at a suitable position, the operator cuts the front and bunches. The bunches drop and are placed into the receptacle (Biological Research Division - Biological Research Division, 2020). The prime mover is a tracked type vehicle with a 500 kg loading capacity and is powered by a 31.5 hp diesel engine. Regarding productivity, the machine is capable to harvest between 4 to 6 t FFB per day.

2.5 Fresh Fruit Bunches reception (FFB)

Fresh fruit reaches from the plantation as bunches or loose fruit. The fresh fruit is usually emptied into wooden boxes proper for weighing on a scale such that quantities of fruit landing at the processing section may be checked. For large establishments, weighbridges are used to weigh materials in trucks. The quality obtained is originally dependent on the condition of the fruit arriving at the mill. The mill can reduce or prevent further degradation but cannot better the quality. The plantation factors that affect the composition and quality of the end product are genetic: the agronomy, environment, age of the tree, harvesting-technique, handling, and transportation (3. Palm oil processing, 2020).

2.5.1 Sterilization of FFB

Steam or water is used to sterilize the fresh palm fruits in the disinfection process. Dry sterilizing involves roasting or smoking the fruits, while wet process involves boiling or steaming the fruits. If the dry process is utilized, the palm fruits are separated first before been sterilized. Whereas in the wet process, the fruits are sterilized before threshing. The sterilization or cooking process involves the use of high-temperature wet-heat treatment to detach fruits. Hot water is usually used for the cooking; sterilization is done using pressurized steam in a sterilizer. The cooking action has various functions (3. PALM OIL PROCESSING, 2020). Heat treatment destroys oil-splitting enzymes and slows down hydrolysis and autoxidation.

For large-scale production, where the entire bunches are cooked, the wet heat weakens the fruit stem and causes an easier removal of the fruit from bunches on shaking or tumbling in the threshing machine. Heat aids to solidify proteins in which the oil-bearing cells are microscopically split up. The protein solidification (coagulation) allows the oil-bearing cells to merge and flow more easily when pressure is applied (3. Palm oil processing, 2020).

Cooking the fruit weakens the pulp structure, softening it and making it easier to separate the fibrous material and its contents during the digestion process. The liquid introduced by the steam acts chemically to break down gums and resins. The rest can be made to dissolve in water, when broken down by wet steam (hydrolysis), so that they can be removed during oil clarification. The starches produced in the fruit are hydrolyzed and eliminated by this method (3. Palm oil processing, 2020).

During high-pressure sterilization, the heat causes the liquid in the nuts to expand. When the pressure is reduced, the contraction of the nut brings about the separation of the kernel from the shell wall, hence loosening the kernels within their shells. From the aforementioned, it is apparent that sterilization (cooking) is an essential process in oil processing, ensuring the success of different steps (3. Palm oil processing, 2020).

2.5.2.Threshing and Stripping of Fruitlets

The FFB consists of fruits ingrained in spikelets growing on a primary stem. Threshing can be done manually by cutting the fruit loaded spikelets from the bunch with a machete or an axe and then separating the fruit from the spikelets by hand. The elderly as well as kids make a livelihood as casual workers performing this action at the mill.

A rotating or fixed drum equipped with rotary beater bars called a thresher remove the fruit from the bunch in an industrialized system (3. Palm oil processing, 2020). High pressure sterilization systems are utilized to thresh bunches after heating to loosen the fruits. Most small-scale processors lack the capacity to produce steam for sterilization, as a result, the threshed fruits are cooked in water. The entire bunches which consists of spikelets absorb a large amount of water during the cooking process. Hence, the bulk of small-scale operators thresh bunches before cooking the fruits (3. Palm oil processing, 2020).

2.5.3 Digestion of the fruit

The rupture or breaking down of the oil-bearing cells to release the palm oil in the fruit is known as digestion. The digester is usually utilized for this; it is a steam-heated cylindrical vessel fitted with a central rotating shaft carrying a number of beater (stirring) arms. The fruit is crushed by the action of the rotating beater arms. Digesting or crushing the fruit at a high temperature, aids to reduce the viscosity of the oil, destroys the exocarp (outer covering of the fruit), and finalizes the disruption of the oil cells which started at the sterilization phase (3. Palm oil processing, 2020).

2.5.4 Pressing (Extracting the palm oil)

Two distinct procedures are used for extracting oil from the digested substance. A dry approach which involves the use of mechanical presses and a wet approach which involves the use of hot water to extract the oil. In the dry method, mechanical pressure is applied to the digested mash to squeeze the oil out of a mixture of oil, moisture, fibre, and nuts. There are different types of presses that can be used to press the fruit pulp: manual presses, hydraulic presses, and screw presses, but the operating principle is related to each. The presses may be performed for batch (small amounts of material operated upon for period of time) or continuous operations. The screw press is the generally used machine in palm oil making in both small and large scale palm oil manufacturing plant due to its high oil extraction rate. The motorised design is faster but more expensive. Spindle press screw threads are made from hard steel and held by softer steel nuts so that the nuts wear out faster than the screw. These are simple and cheaper to replace than the screw (BEST Palm Oil Processing Plant Design and Construction, 2020). Oil extraction of oilseeds also produces an oilcake (or meal) which is considered a valuable livestock feed product.

2.5.5 Clarification and Purification

In the palm oil manufacturing process, clarification is done to remove entrained impurities. The end product crude palm oil (CPO) is stored in bulk in a tank (Start a Small Scale Palm Oil Processing Business | Turnkey. Project, 2020). The dilution (addition of water) gives a boundary making the heavy solids to fall to the bottom of the container while the lighter oil droplets cascade through the watery mixture to the top when heat is applied to break the emulsion (oil suspended in water with the aid of gums and resins). Water is added in a ratio of 3:1. The diluted mixture is passed through a screen to discard coarse fibre. The screened mixture is boiled from one or two hours and then allowed to settle by gravity in the large tank so that the palm oil, being lighter than water, will separate and rise to the top. The clear oil is emptied into a reception tank. (3. Palm oil processing, 2020).

2.5.6 Kernel recovery

The leftover part from the press consists of a mix of fibre and palm nuts. The nuts are separated from the fibre by hand in the small-scale operations. The sorted fibre is closed and allowed to heat, utilizing its own internal exothermic reactions, for around two or three days. The fibre is then pressed in spindle presses to recover a second grade (technical) oil that is generally utilized in soap-making. The nuts are normally dried and sold to other operators who process them into PKO. The sorting action is mostly reserved for the youth and elders in the suburb which is done intentionally to help them earn some income.

The recovered fibre and nutshells are used to heat the steam boilers in large-scale mills. The super-heated steam is subsequently utilized to drive turbines to produce electricity for the mill. Hence, it is viable to recover the fibre and to shell the palm nuts. In a large-scale recovery process, the depericarper is used to separate the fibre from nuts enclosed in the press cake (3. Palm oil processing, 2020).

Figure 14. Representation of a complete commercial palm oil factory.

Source: (BEST Palm Oil Processing Plant Design and Construction, 2020).

2.6 Biodiesel production

After clarification and drying of oil, the crude palm oil enters the biodiesel production section where the aim is the production of biodiesel.

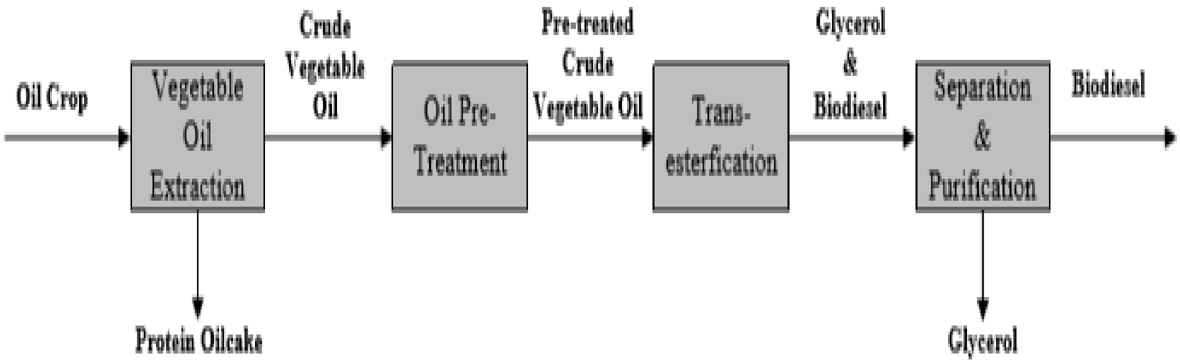


Figure 15. Schematic presentation of ‘crop to engine process’ (2020e).

To achieve this product, three processes are required: degumming, a two-step esterification and purification as presented in the figure16 below.

2.6.1 Degumming (Phospholipids) Gums

Degumming refers to the removal of gums, which are principally phospholipids (PL) and other impurities. PL are considered unwanted compounds that need to be extracted, as phosphorus can damage diesel engines and for this reason its content is controlled (Ministry Of Business, Innovation & Employment New Zealand Government, 2015; ACEA, 2009). PL are found in hydratable forms or nonhydratable (NHPL).).Gums are produced when the oil absorbs water, making some of the PL to become hydrated and hence not soluble in oil, making them easy to remove.

Degumming is not applied for fruit oils like olive oil and palm oil since these oils have previously been in contact with water during their production. Most crude vegetable oils can be fed directly for the process of transesterification without pre-treatment. Crude palm oil consists of polar lipids such as phospholipids and glycolipids. Polar lipids get an important attention due to the suspected harmful effect of phosphorus on oil quality. Inorganic phosphorus and phospholipids are two forms of phosphorus compounds in CPO, (1. Composition of Palm Oil, 2020). Deacidification is employed for oils with a high free fatty acid (FFA) content, >5%, (Mittelbach and Remschmidt, 2005). This involves the elimination of excessive free fatty acids in the oil to less than 1mg KOH/g equivalent. Glycerol and biodiesel separation process can be hindered by the presence of this FFA by reducing the catalyst especially alkaline activity.

Research reveals that to get good quality and stable oil after refining, the phosphorous content of the crude oil should not exceed 20 ppm, and the phosphorous content of the pre-treated oil immediately prior to physical refining should not go beyond 5 ppm (Physical Refining – Degumming, 2020).

2.6.2 Transesterification

Transesterification is the reaction required to produce biodiesel from extracted crude palm oil. The process involves the reaction of an alcohol and a catalyst with TAG to produce FAME and glycerol as a by-product. FAME is converted to biodiesel after purification (Meher et al., 2006). Transesterification can be catalysed using an acid, enzymatic or alkali catalyst.

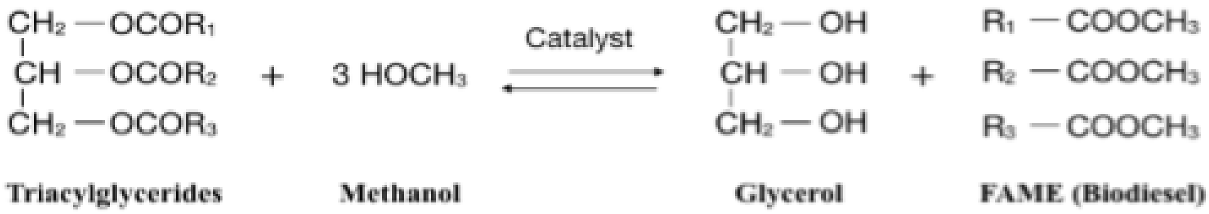


Figure 16. Transesterification reaction. TAG react with methanol on a 3:1 ratio to produce biodiesel and glycerol. (Adapted from Chisti, 2007).

For transesterification to take place, an alcohol is needed. Methanol is the alcohol that is generally preferred due to its low cost. Ethanol is utilized in countries where its cost of production is lower than that of methanol like in Brazil (Faiz, Gautam and Burki, 1995). The stoichiometry of methanol to TAG on a molar ratio is 3:1, but transesterification is a reversible reaction, so methanol is used in excess, thus 6:1 is used in industrial processes to establish that the reaction is directed towards the production of FAME (Trejo-Zárraga et al, 2018). If the amount of methanol is inadequate, soaps can be formed and if there is an excess amount, glycerol solubility is increased which may inhibit the separation of biodiesel and other by-products (Rahman et al., 2017). Transesterification reactions can be catalysed with both homogenous and heterogenous reagents. Homogenous reagents were chosen in this study since they have a faster reaction rate and give higher biodiesel yields for feedstock with high acid value and faster reaction rates(Singh et al., 2014). However, homogenous catalysts are corrosive and have waste toxicity which is disadvantageous (Sirsam et al., 2016). For homogenous catalysts, an alkaline catalyst is considered over an acid catalyst for the transesterification reaction because the prior is cheaper, faster and do not require intense conditions to work (Vicente et al., 2004; Leung et al., 2010). Although the use of enzymes are promising, they are still expensive when compared to the others (Bux & Chisti, 2016).

2.6.2.1 Two-step esterification process

FFA content is very critical in the yield obtained from transesterification reaction. Some side reactions like saponification or hydrolyzation may occur if the FFA content is higher than 2-3% of TAG and a formation of more FFA (Vyas et al., 2010; Raheman et al., 2013; Leung et al., 2010). Soap formation is undesirable when producing biodiesel since it uses up the catalyst partially and reduces the biodiesel yield.

In order to reduce the anticipated saponification resulting from a high FFA content, an acid esterification preceding the alkali-transesterification is crucial. The first step acts as a pre-treatment to decrease the FFA content in the oil, as proposed by numerous authors while the second step converts TAG into FAME in an alkali-catalysed transesterification reaction (Chen et al., 2012; Singh et al., 2014; Bux & Chisti, 2016).

First step: acid esterification

In acid esterification reactions sulphuric acid is commonly used as a catalyst (Singh et al., 2014).

Second step: alkali transesterification

Saponification side-reactions occurs when the alkali catalyst is potassium or sodium hydroxide, because they consist of the basic hydroxide group for the reaction. Thus, if catalysts like basic methoxides (potassium methoxide/sodium methoxide) are employed, which consists of hydroxide ion only as an impurity; a lower saponification will be anticipated (Fröhlich & Rice, 1995).

Vicente et al. (2004) achieved higher biodiesel yields when sodium or potassium methoxide was used (99.33 and 98.46 wt.%, respectively) transesterification in comparison to sodium or potassium hydroxides. Sodium methoxide (CH3NaO) was preferred, because it has a lower TAG saponification percentage and residual methyl ester measure in glycerol and thus is the most economical in comparison with other alkali catalysts. Although alkaline catalysts are more costly, the advantage obtained from a decrease in saponification will surpass the increased economic costs of the catalyst.

2.6.2.2 Separation and Purification of biodiesel

According to Leung et al. (2010), purification of biodiesel is required to eliminate impurities and residual catalyst present in FAME. Phosphoric acid can be added as a first step to disintegrate soaps into FFA which are insoluble in glycerol forming separate phase which is separated further (Mittelbach and Remschmidt, 2005). If KOH is utilized as a catalyst during transesterification, potassium dihydrogen phosphate is formed. This can be utilized as fertilizer (Mittelbach and Remschmidt, 2005). Alternatively, the derived separated solids have to be treated as waste products.

The derived FFA can be esterified with sulphuric acid and ethanol or interact with FAME and alkaline glycerol for two hours at 200°C to produce triglycerides. The two products can be recycled back into the feed of the transesterification reactor.

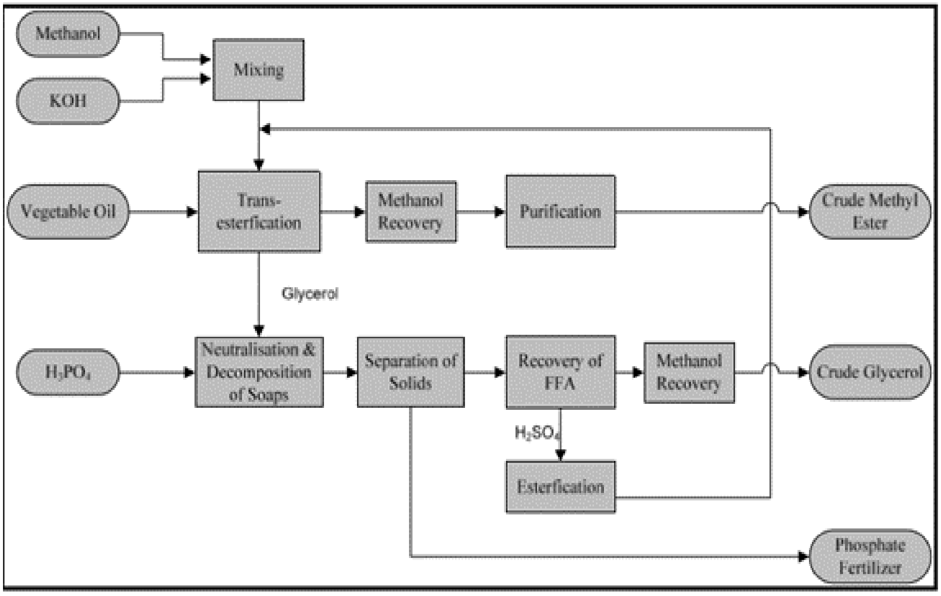


Figure 17. Typical biodiesel production process according to Mittelbach (2005).

Purified biodiesel can be sold for 0.693 $/kg biodiesel (Biodiesel prices (SME & FAME), 2020).

According to Mittelbach and Remschmidt(2005), methanol is commonly used in the transesterification process because of its low price and high reactivity in comparison to longer chain alcohols. Alcohol catalysed methanolysis can be run at moderate conditions to achieve a high yield.

However, to shift the equilibrium of the reaction to the right hand side, the alcohol utilized is in excess amount. Generally, the recommended molar ratio of 6:1 methanol to vegetable oil in alkali catalysis is not surpassed (Mittelbach and Remschmidt, 2005). A molar ratio of methanol to vegetable oil of up to 30:1 is necessary for acid catalysis.

But, ethanolysis is regarded as more environmentally favourable because ethanol can be produced via fermentation and gives a higher cetane number to the biodiesel. It generates difficulty for the product separation phase and consumes more energy.

The separate catalyst alternatives and their advantages and disadvantages have been discussed above. Mittelbach and Remschmidt, (2005) states that alkali catalyst has an optimum concentration of around 0.5-1.0% by weight of oil.

2.6.2.3 Supercritical transesterification process

In the transesterification reaction, the use of supercritical methanol makes the entire process straightforward and enhances the yield generally. But the high pressure and high temperature conditions needed for supercritical methanol transesterification require sophisticated reactor design and high energy input (Kurnia et al., 2016). The use of a catalyst can be circumvented completely, transesterification under supercritical conditions has been studied and found to decrease reaction times to (2-4 minutes) compared to conventional catalytic transesterification and a high conversion rate is expected. The conditions of this process are between 300-400 °C and about 80 atm (Helwani et al., 2009; Thanh et al., 2012). Under supercritical conditions all reactants are in a single homogenous phase, accelerating reaction times and no mass transfer nor catalyst is necessary, in such conditions the alcohol acts as an acid catalyst (Vyas et al., 2010).

2.6.2.4 Ultrasonic irradiation

For immiscible phases, i.e., oil and alcohol are involved in the transesterification reaction; ultrasound irradiations had been shown as a useful tool to accelerate mass transfer and consequently the efficiency of the reaction. Ultrasonic irradiations induce cavitation of bubbles near the phase boundary between immiscible liquid phases altogether. The irregular breakdown of the cavitation bubbles obstructs the phase boundary and initiates emulsification immediately. Hence, the alcohol and oil bubbles are adequately close for the transesterification reaction to occur quickly. So, lower amounts of catalyst and methanol would be necessary in comparison to regular methods (Sarkar and Bhattacharyya, 2011; Thanh et al., 2012).

2.7 Description of application of palm mill by-products

During oil palm processing three major wastes streams are produced in various sections of processing in very large amount. For example, empty fruit bunch (EFB) is generated during threshing, palm press fibre (PPF) is generated during fibre separation after palm oil extraction. Palm kernel shell (PKS) is generated during kernel recovery from the nut and chaff, it is recovered when carrying out the act of sieving (Ohimain and Izah, 2014). Additional wastes streams produced are in liquid form either as palm oil mill effluents (POME) or as gaseous emissions (Izah and Ohimain, 2013). Nigeria being one of the largest producers of palm oil accounts for nearly 1.5% (930,000 metric tonnes) of the production globally, producing millions of tonnes of palm oil processing solid and liquid wastes (Izah and Ohimain, 2013).

The solid waste is utilized as boilers fuel in palm oil mills (Ubabuike, 2013). The degree of incorporation/utilization in Nigeria rest on the scale of palm oil processing either smallholder, semi-mechanized or mechanized mills.
Various technologies exist that can allow mills to produce energy for its consumption and export excess for usage as electricity and biofuel. In bigger oil palm producing countries such as Indonesia, Malaysia, Thailand, the industry is attentive of the pollution that follows palm oil processing and are driven towards quality and environmental preservation (Yusoff, 2006) via energy production and bio-valued products. Owing to inadequate data on thermal energy evaluation of oil palm solid wastes processing in Nigeria, it is necessary to integrate the surplus biomass into valuable co-products as a technique of upgrading the system and creating a loop for a circular economy. Supplementary uses for oil palm by-products consists of the preparation of poultry feeds, very much like groundnut cake (Onwudike, 1986; Nwokolo, Bragg and Saben, 1977) explain that palm kernel cake (PKC) may be used in poultry feeds up to 30 percent without any negative effects. The mixture is strained to extract fibre and then utilized as fuel, leaving an aqueous mixture called palm oil sludge (POS) (THOMSON, 2007).

2.7.1 Anaerobic digestion of palm oil mill effluent (POME)

The residual biomass coming from the POME can be converted to biogas. This procedure can be employed to valorise waste streams from the biodiesel production process. The utilization of residues can reduce the environmental footprint of the system through recirculation of key components and better realise the full economic potential of the palm oil feedstock. Anaerobic digestion (AD) also contributes to nutrient recycling through the selling of digestate as fertiliser (Ward et al., 2008).

AD is an applicable choice for upgrading feedstock with high water content since it is a typically aqueous procedure. AD can be chosen as the approach to process waste streams in the system for three main reasons: (1) products of AD are either vital to the production process or can be sold; (2) an AD consortia is robust and can cope with changes in feedstock that occur due to seasonal variation/contamination and; (3) AD consortia can use complex and non-sterile substrates (Schnurer & Jarvis, 2010).

AD is an organic technique whereby organic carbon is converted through successive bio-chemical reactions in the absence of oxygen to biogas, consisting of mainly methane (CH4), carbon dioxide (CO2) and nutrient rich digestate that can be employed as compost (Alves et al., 2009). CH4 can be upgraded to energy via combustion and utilized within this system or sold to end users. The digestate can be sold as compost for agricultural use at 5.16 $/t (Wrap.org.uk, 2020).

Pome has generally been the core of bioenergy profiteering and environmental interest. Due to its high organic content, it can cause damage to the environment if released to the environment untreated. (Welcome to MPOB's Journal of Oil Palm Research Website, 2020).

The methane produced would be a source of energy to power the mill's operations. Biogas energy will be adequate to cater for the total electrical energy required for both mill demand and other new biomass business, since electricity could be produced from the biogas developed by anaerobic digestion of POME supplemented with EFB (Change, 2020; Ali, Othman, Shirai and Hassan, 2020). With suitable additional treatment like the use of biochar or activated carbon, the refined POME final discharge with river water quality could be recycled to the mill to be reused as boiler feed water (Othman et al., 2014). Excess biomass, steam, heat and energy are now usable for conversion into a spectrum of desired bioproducts such as bioethanol, biobutanol, biohydrogen, bioplastics, biodiesel, biovanillin, biocomposite, bioadsorbent, biocompost and biochar (Coats et al., 2008; Sanchez and Cardona, 2008; Kaparaju et al., 2009; de Souza et al., 2010; Ismail et al., 2010; Rebitanim et al., 2013).

According to Malaysia palm oil board (MPOB), estimate of about 0.65m^3 POME is generated from every processed ton of fresh fruit bunch (NIGERIA, 2020).
Glycerol is known to be an efficient co-substrate in AD. As glycerol is formed in the transesterification reaction for biodiesel production, its co-digestion can be thought-out an efficient application of all waste segments in the system. Glycerol feeding to an AD process can boost CH4 production (Santibáñez et al. 2011). An increase in yield can additionally enhance the value of the waste streams and successively increase the economic output of the system. In the palm oil biorefinery proposed, a total solution whereby production of biodiesel from CPO is maintained alongside a simultaneous utilization of the by-products generated and upgraded into value-added bio-materials i.e. geared towards a circular economy. Figure 18 below presents a typology of an ongoing biomass and energy usage at a conventional palm oil mill processing 300,000 tonnes (300,000,000 kg) of FFB yearly. Within the present system, for each tonne (1000 kg) of FFB processed, 200kg of CPO and 50kg of PK are produced (Lam and Lee, 2011).

Notwithstanding, to process one tonne of FFB, a tonne of fresh river water is pumped up from the river or holding pond (Othman et al., 2014). High-pressure steam is created by burning all of the Mesocarp Fibre (MF) and part of the Palm kernel Shell (PKS) in the regular low-efficiency boilers. The steam passes through the turbines first, producing electricity to power the mill's operations. The low-pressure steam is utilized to cook the FFB in the sterilizers later. Around 230 kg of EFB is produced after the sterilisation of FFB, which is used for mulching partially on the plantations (Azhari et al., 2011; Lam and Lee, 2011). Nearly 700 kg of POME is produced (Change, 2020) in the mill which is pumped into large lagoons or tanks for treatment in order to satisfy the discharge standards before being discharged to a nearby river or waterway. AD treatment produces biogas containing methane, a GHG, which is released unnecessarily into the atmosphere (Yacob et al., 2005). The present shortfall in terms of sustainability would be the untapped potential of generating a new green industry and financial revenue streams from the excess biomass and energy(profit), unused potential of creating new job employments for the local community and human capacity building (people), as well as the present release of approximately 37,251 tonnes of CO2e (carbon dioxide equivalent) yearly (Yoshizakietal., 2012) into the atmosphere as a result of the anaerobic treatment of POME (earth).

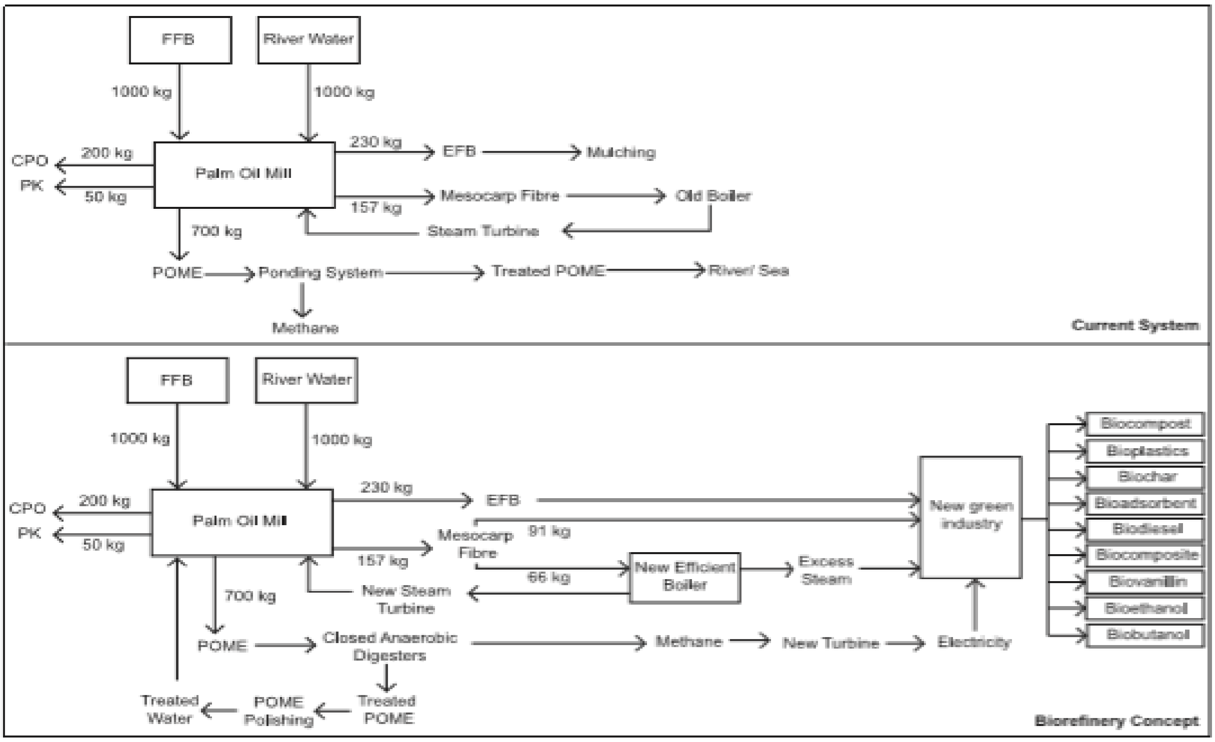


Figure 18. Proposed sustainable and integrated biorefinery concept with zero emission system (Mohd Yusof et al., 2020)

2.8 Biodiesel properties and Quality standards

Along with MPOB, Mercedes-Benz, and Cycle & Carriage in June 1990 until July 1995, Choo et al (2005), reported an extensive field analysis using palm-biodiesel as a diesel fuel on 30 Mercedes-Benz buses with OF 1313 chassis and OM 352 engines. All the buses managed to cover ranges of up to 300,000 to 351,000 km. Their investigation found that the OF 1313 with OM 352 engines could be driven well with neat or blended palm-biodiesel despite the fact that the engines are invented for petro-diesel (no alteration necessary). This applies to the long-term engine operation and engine performance, which can be adapted to other direct-injection engine modules. Additionally, they discovered that the engines investigated were noticed to have smooth and no knocking sound when starting. Furthermore, much cleaner exhaust emissions were reported with usual carbon build-up in the engine nozzles and commensurate fuel consumption over petro-diesel.

2.8.1 Fuel properties

There is a huge difference in the chemical composition of petroleum diesel and biodiesel. As a consequence, biodiesel differs in both its physical and chemical properties. The feedstock used in the production process of biodiesel plays a role in its composition and properties.

The **cetane number** indicates the readiness of the fuel to auto ignite after being injected into the diesel engine. A cetane number higher than 40 is appropriate for diesel fuels even though most refineries produce diesel with cetane numbers between 40-45. Depending on the feedstock utilized, biodiesel has a cetane number between 46-60 which minimizes the ignition delay in the engine thus improving the combustion characteristics (Biodiesel Magazine - The Latest News and Data About Biodiesel Production, 2020).

The **flashpoint** of fuel refers to the temperature at which the vapour above the fuel turns into flame. The flash point for petroleum based diesels is between 50°C to 80°C thereby basically safe. On the other hand, biodiesel has a flashpoint of above 160°C which implies that the fire hazard related to transportation, storage and usage of biodiesel is lesser in comparison to other regularly utilized fossil diesel (Biodiesel Magazine - The Latest News and Data About Biodiesel Production, 2020).

Lubricity can be described as**: "**The property of a lubricant that creates a change in friction below conditions of outer limit lubrication when all the known factors other than the lubricant itself are the same. Reduced friction means higher lubricity" (Friedrich, 2003). The removal of sulphur from petroleum diesel, is necessary by current global regulations, which decreases the fuel lubricity . Pure biodiesel and high level mix possess outstanding lubricity even though small quantities of biodiesel to fossil diesel affects the lubricity of the fuel (Biodiesel Magazine - The Latest News and Data About Biodiesel Production, 2020).

The **sulphur content** of fossil diesel should be under 50 ppm since the onset of 2005 because high sulphur contents in fuels is said to bring about negative health effects and raises regularity in service of vehicles. Biodiesel is basically regarded as sulphur free when produced from fresh vegetable oil. Biodiesel produced from waste vegetable oil (WVO) might have traces of sulphur and should be tested to fall into regulatory limits (Mittelbach and Remschmidt, 2005).

Cold temperature features are part of the behaviour of the fuel below ambient temperatures. These are particularly crucial in countries where the temperature is known to drop under 5°C. The cloud point means the temperature at which the first visible crystals are created. The pour point is the lowest temperature to which the sample may be cooled while still maintaining its fluidity. The cold-filter plugging point (CFPP) is considered an advantageous signal of trip limits of the fuel (Mittelbach and Remschmidt, 2005).

The **heating value**, also known as the heat of combustion, of biodiesel is dependent on the feedstock. In relation to mass, fossil diesel has a greater heating rate**;** around 13% higher than that of biodiesel. However, because of the higher density of biodiesel, the disadvantage of biodiesel is that it is around 8% lower on a volumetric basis. This indicates slightly lower power and torque for the same injection volumes in biodiesel ignited engines. The same power and torque can be obtained if injection volumes are altered for biodiesel**.** When utilizing biodiesel an increase of the injection volumes shows a slightly higher specific fuel consumption. It is significant to consider that the above properties are those of pure biodiesel. If biodiesel is blended into fossil diesel at 5% or 10%, the features of the fossil diesel will not be altered remarkably. It is only the 'lubricity' property of the biodiesel that has an outcome even when utilized in very low blends; this characteristic makes biodiesel an excellent additive for fossil diesel.

Property	Diesel (Singh and Singh, 2010)	Biodiesel (Machacon et al., 2001)	Palm oil (Singh and Singh, 2010)
Flash point ºC	76	-	267
Kinematic viscosity at 38ºC	3.06	4.3 – 4.5	39.6
Density kg/l	0.8550	0.872 – 0.877	0.9180
Cetane number ºC	50	64.3 – 70	42.0
Lower calorific/heating value (MJ/kg)	43.8	32.4	-
Carbon residue wt.%	-	-	0.23

Table 2: Some fuel Properties of diesel, biodiesel, and palm oil. Source: (2020f).

2.8.2 Quality Standards

According to Prankl (2002), quality standards are requisite for the commercial utilization of any fuel product. They represent guidelines for the production process, providing the authorities with endorsed tools for the evaluation of safety risks and environmental pollution as well as guaranteeing customers that they are purchasing high-quality fuel.

The specifications for biodiesel need specific and close attention because of the large diversity of vegetable oils that can be utilized for the production of biodiesel, and the irregularity in the fuel characteristics that can take place with fuel produced from these feedstock. There are various biodiesel standards presently obtainable in some countries such as the EN 14214 in the EU and the ASTM 6751 in the USA (Mittelbach and Remschmidt, 2005). Nigeria presently uses the NIS: 949: 2017 – Standard for Diesel Fuel (AGO) – Sulphur content – 50ppm (max) (SON releases new standards for imported petroleum products, 2020). This signifies a switch to low-sulphur diesel plus the use of cleaner vehicles from the norm and has resulted in annual savings in health costs of about $6 billion in Sub-Saharan Africa. National president of Jatropha Growers, Processors and Exporters Association of Nigerian (JAGPEAN), disclosed that about 12 million litres of diesel were consumed daily in the country. He stated that with a blend with 20 percent biodiesel, the country needs 2.4 million litres of biodiesel daily while for 365 days 876 million would be required (2020g). With national guidelines being active documents that are frequently amended, this standard will most probably be altered in the near future.

2.9 Biodiesel use

Biodiesel can be utilized in its pure form or as a blend with existing conventional diesel which is achievable since biodiesel and fossil diesel are miscible hence can be utilized in internal combustion engines without modification. It can be used as an additive (1%-2%) and is known as B01 or B02. Lubricity tests have demonstrated effective lubricity improvement. Biodiesel blends presently used globally include B5 (5 % biodiesel, 95 % PD), B10 (10 % biodiesel, 90 % PD) (Friedrich, 2003). B20 (20 % biodiesel, 80 % PD), B80 (80 % biodiesel, 20 % PD). Other high-diesel blends (from B25 to B95) and B100 are not used generally in comparison to B5 and B20 since they are expensive, frequently require special engine modification and are not usually subsidized by alternative strategic governing stimulus. (Biodiesel Magazine - The Latest News and Data About Biodiesel Production, 2020).

2.9.1 Advantages of biodiesel use

The utilization of biodiesel has the following advantages for consumers (Biodiesel: Journey to Forever, 2020):

- No engine modification is required. Most diesel engines assembled after 1995 can run on either a blend or on pure biodiesel.

- Biodiesel is more environmentally friendly. It burns up to 75% cleaner than typical fossil diesel as it decreases unburned hydrocarbons considerably, carbon monoxide and particulate matter and removes sulphur dioxide emissions in exhaust fumes. And its ozone-forming potential is nearly 50% less than fossil diesel fuel.
- Biodiesel is a renewable energy source as it is plant-based
- Biodiesel is thought-out to be non-toxic and biodegradable.
- Biodiesel has a high cetane rating which enhances engine performance and is a much better lubricant than fossil diesel and can prolong engine life.

2.9.2 Disadvantages of biodiesel use

Even though the advantages make biodiesel seem very attractive, there are also valued disadvantages to deal with when using biodiesel (2020f). As a result of the high oxygen content, it generates relatively high NOx levels during combustion. However, these can be decreased to lower fossil diesel fuel levels by adjusting engine timing and using a catalytic converter.

- Storage conditions of biodiesel should be strictly supervised as biodiesel has a lower oxidation stability. Oxidation products that may be bad for vehicle components could be produced. Contact with humidity must be avoided due to its hygroscopic nature.
- The lower volumetric energy density of biodiesel implies that more fuel is required for the same distance travelled.
- Biodiesel has a higher cold-filter plugging point temperature than fossil diesel which means it will crystallize into a gel at low temperatures when utilized in its pure form.
- It can cause dilution of engine lubricant oil, needing more frequent oil change than in standard diesel-fuelled engines.
- Biodiesel is a strong solvent and washes out all the tars, varnishes, and gums left by fossil diesel in the fuel system which suggests that the fuel filter will have to be replaced a few times during the initial stages of biodiesel use.
- A modified refuelling framework is required to handle biodiesel, which shoots up their total cost.

2.9.3 World Biodiesel Production

In view of the fact that biofuel, ethanol and biodiesel, production has more than doubled in the last 5 years while world oil production increased by only 7%, it can be assumed overall that biofuels have the potential to substitute petroleum fuels and increase energy security for many nations like Nigeria.

In 2018, global biofuel production levels reached 95.4 million metric tons of oil equivalent, in absolute comparison to the 9.2 million metric tons of oil equivalent that was produced in 2000 (Global biofuel production 2018 | Statista, 2020). Global biofuels and biodiesel market is likely to grow with approx. 5.48% CAGR during the years 2018-2026. The base year considered for the study was 2017 and the forecast period is between 2018 and 2026 (Biofuels Market - Global Industry Trends, Share, Forecast & Analysis 2026, 2020). The rising need for biofuels is principally driven by the following factors:

- Varying petroleum prices
- Increased interest in clean and alternative fuel
- Rising availability of feedstocks
- Government regulations promoting the adoption of bio-based fuel alternatives
- Increased applications of biofuels
- Sustainability questions raised by U.N and others

Countries	Production in thousand metric tons
United States	38,088
Brazil	21,375
Indonesia	4,849
Germany	3,445
China	3,099

Table 3: Top five biodiesel producers in 2018 (Biofuel production in leading countries 2018 | Statista, 2020).

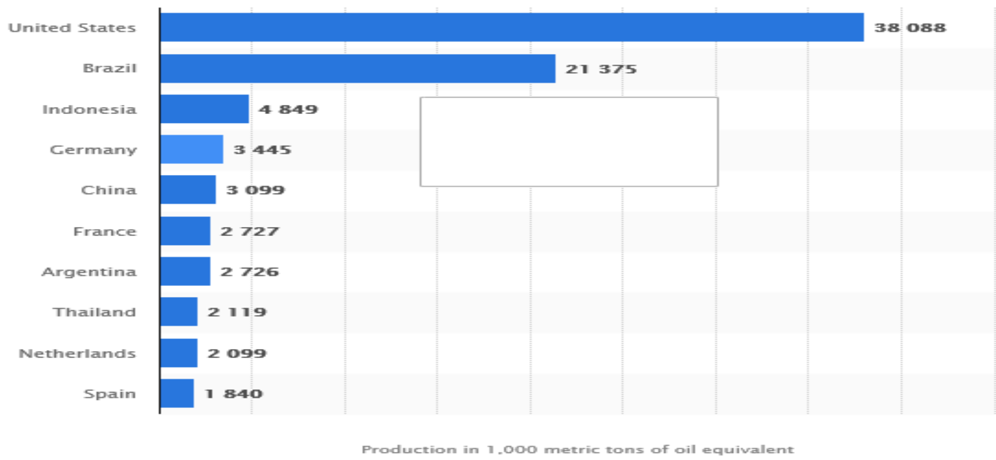


Figure19. Leading countries based on biofuel production in 2018 (in thousand metric tons of oil equivalent) (Biofuel production in leading countries 2018 | Statista, 2020).

Chapter 3

Biodiesel situation in Nigeria

3.1 The current and future avenues for Nigerian energy production.

Nigeria's main energy consumption was around 108 Mton in 2011 (Energy in Nigeria, 2020). Most of the energy comes from regular biomass and waste, which account for 83% of total basic production. The remaining is from fossil fuels (16%) and hydropower (1%) (2020h). Energy is one of the fundamental social amenity that plays a critical role in the socio-economic development of a country, and its demand has a direct link with the improving standard and living conditions of a populace (Yusuff et al, 2019).

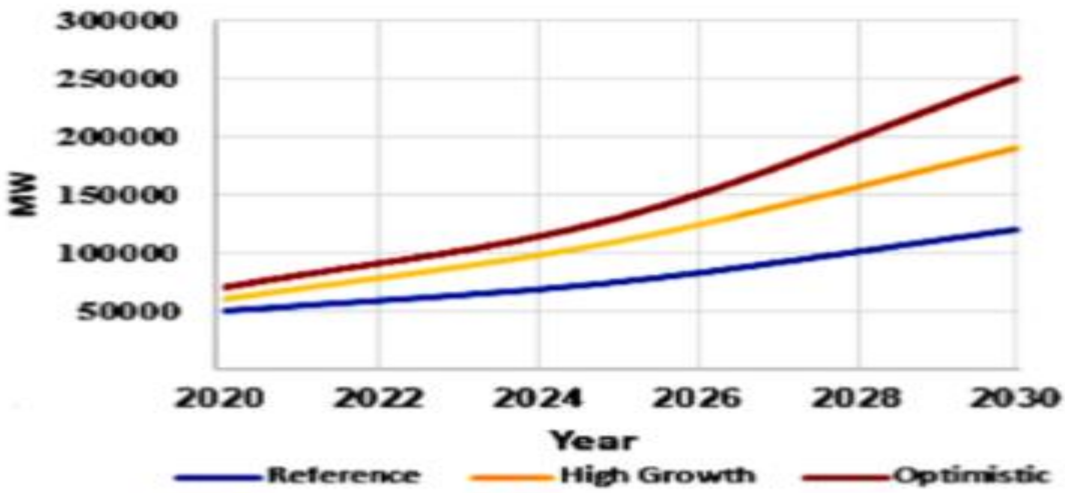


Figure 20. Representation of the total energy demand projections for Nigeria using reference, high-growth, and optimistic economic growth scenarios (Sambo, 2008 in World Future Council Workshop on Renewable Energy Policies).

The graph above illustrates that the amount of Nigerian energy demand has been estimated to be on a geometrical increase over the years. The Nigerian energy demand forecast is identical to the model globally which shows that the road transport sector is to increase by 50% by 2030 and 80% by 2050. Currently, fossil fuels record for around 94% of total energy demand in the transport sector and nearly three quarters are in road transport (Dias, Antunes and Tchepel, 2019). The accelerated decline rate of the fossil energy reserves globally has remained unparalleled by analysis. The above reckons that alternative fuels such as biodiesel in the transportation sector may go a long way to aid the reduction of dependence on diesel and consequently contribute to a vital decrease in the greenhouse gas emissions in Nigeria (Ben-Iwo et al, 2016). The growing Nigerian population has also presented a fundamental increase in energy demand in all other sectors besides transportation (Ishola et al., 2020).

The country has four oil refineries (Port Harcourt I and II, Warri, and Kaduna) with a combined crude oil distillation capacity of 445,000 b/d. The refineries chronically operate below full capacity due to operational failures, fires, and sabotage, mostly on the crude oil pipelines feeding the refineries. The combined refinery utilization rate dropped to 14.4% in 2014 from 22% in 2013 (Charge et al., 2020) therefore, the country imports petroleum products, even though its refinery badge capacity surpasses domestic demand. Nigeria imported 156,000 b/d of petroleum products in 2014 (2020i). Due to the coronavirus pandemic coupled with the volatile crude oil price and the fluctuating Naira/Dollar exchange rates, the diesel pump price is selling at $0.35/litre (Why Buhari reduced petrol price to N125, 2020) . This dwindling prices necessitates the urgent need for a diversification of the nation's economy from the dependence on fossil fuels exportation.

3.2 Driving Forces of Biodiesel and Biofuels in Nigeria

Biofuels could become part of the answer to the above mentioned problems as it would:

1. Reduce Nigeria's dependence on fossil fuels and imported oil.

2. Advance renewable energy.

3. Decrease pollution.

4. Assist the FGN in achieving the objectives of NREEEP. The NREEEP sketches different procedures and agenda for the distribution of renewable energy technologies in the country.

5. Ratification of United Nations Framework Convention on Climate Change and also the Paris Accord to curtail its national Green House Gas (GHG) inventory.

Nigeria's Biofuels Demand Potential

Biofuels Type	Time frame		
	Short	Medium	Long (>15yrs)
Bioethanol (demand in billion litres/yr)	1.3 (at 10% blend)	3.4 (at 15% blend)	52.5 (at 50% blend)
Biodiesel (demand in billion litres/yr)	0.233 (at 10% blend)	1.951 (at 20% blend)	12.7 (at 50% blend)

Figure. 21. Nigeria's projected biofuels demand potential (Source: 2020j).

3.3 Nigeria's present capacity for palm oil (feedstock) production

The advancement of biofuels in Nigeria should be predicated on the favourability of the environment for local production, the availability of the required resources and the ability to consume the fuels locally (Abila, 2012).

3.3.1 Description of the value chain and processing

The palm oil value chain involves a vast number of actors belonging to distinct channels depending on the production process and kind of oil. Overall, palm oil is produced in South Nigeria and marketed all over the country. Production is carried out by three production schemes. Small scale farms and wild groves correspond to the largest avenue (1). Nevertheless, its size gravitates toward deterioration after being inactive for several years. Avenue (2) comprises of medium and large scale farmers, which have been growing rapidly since 2003 (inception of the privatization) and actors from avenue1 are moving to avenue 2 because they tend to improve their production processes, so as to achieve better extraction rate. Channel (3) comprises of small and medium scale estates growing steadily and channel (4) comprises of out growers and large scale estates which demands more investments to be well -developed but shows a strong potential (PIND, 2011).

1)Wild-groves

In this structure, farmers rent trees from the landowners. The yield for this kind of production are very low, which makes it the least productive channel.

2) Small / medium and large scale farms

They have acreages of between 1 and 25 hectares (PIND, 2011). The Tenera variety is mostly planted. Small scale farms are primarily unofficial and palm oil is processed at family or community level, so the utilization of manual processing is prevalent. Production is governed by traditional methods. The medium and large scale farms tend to use improved processing technologies and are using new techniques to improve marketing.

Production systems	Hectares	Yields
Wild grove	n.a	1.5FFB tonnes/ha/year
Small scale farm	1-10 ha	3 FFB tonnes/ha/year
Medium scale farm	10-25 ha	3 FFB tonnes/ha/year
Large scale farm	10-25 ha	n.a
Estate	+100 ha	5 FFB tonnes/ha/year

Table 4: Yields per production systems (Fresh Fruit Bunches / tonnes /hectares/ year.
Source: PIND, 2011.

Nigeria has been classified to be among countries that are promising for bioenergy development, with around 72 million hectares of arable land available. Around 60% of tillable land is still bare for out-growers to perform crop plantation efficiently to meet up with any practical feedstock demand for biodiesel production both for consumption locally and export purposes (Oyedepo et al., 2018). The focus on a viable feedstock like palm oil that is naturally prevalent on Nigerian soil may engender the production of biodiesel.

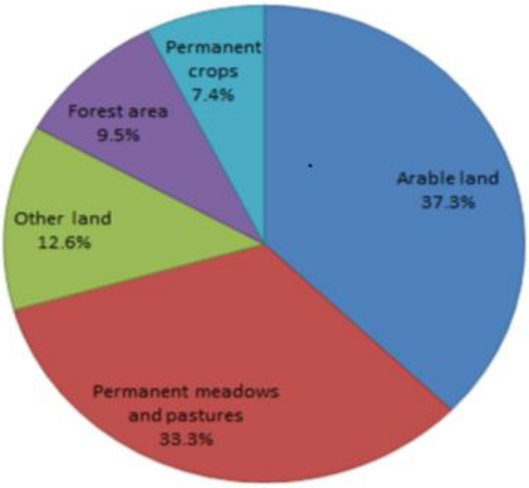


Figure 22. Nigeria land use in 2015: (FAOSTAT, 2020).

There is a warm tropical climate with relatively high temperatures through most of the year and two seasons (rainy & dry). Both rainy and dry seasons in Nigeria allows various kinds of food crops to thrive including oil palm. The climatic weather in Nigeria guarantees very high yield which correspondingly assures constant supply of feedstock for Biofuels production (Source: 2020j).

Nigeria is immensely enriched with bountiful renewable energy resources capable of meeting the country's needs including enormous supplies of water, solar, wind and various biomass as raw materials to produce green-energy. In 2005, the FGN directed the NNPC to inaugurate the development of Biofuels Industry and other Renewable Energy sources in Nigeria. The Renewable Energy Division of the NNPC was established in August 2005 accordingly with the aim of not only improving Nigeria's energy capacity, but also promoting her economic prospects for potential global investment (Source: 2020j). The idea of the biofuel initiative is to:

- Connect the Oil & Gas Industry with the Agric sector through the commercial production of biofuels from selected energy crops.
- Utilize the biofuels as blend-stock, or alternatives for gasoline and petro-diesel Fuels to promote tail-gas emissions in transportation sector and mitigate climate change.
- Create wealth and green jobs under a low-carbon business environment and diversify the Economy.
- Exploit other Renewable Energy Sources such as Solar, Wind, Geothermal and Waste-to-Energy, etc. (Source: 2020j).

The FGN, through the Federal Ministry of Environment, has also put in place a Renewable Energy Programme targeted at guaranteeing the development and growth of the sector**.** The biofuel project, as part of the alternative energy development approach is tailored towards using agricultural potential energy crops to produce alternative fuels that can serve as good as fossil diesel presently in use i.e. biodiesel (to be derived from palm oil) (Source: 2020j).

3.4 Research findings and implications for palm oil biodiesel

According to Weber's theory of industrial location, the implementation of biofuels (biodiesel) with the concomitant investment in plant feedstock and plantation should be predicated on the existence of adequate capacity (Weber 1909). A worldwide assessment carried out in the past on biofuels production potential counted Nigeria amidst the countries that fulfil the benchmark as an up-and-coming producer of biofuels (biodiesel). The table 5 below shows the nation's capacity and its ranking globally in the production of major feedstocks such as palm oil for biodiesel. However, the outcome is exploratory but to some degree may contribute to the infrastructure for a broader estimation of the country's capability to produce biodiesel.

Crop	2007 Average yield (MT)	Biofuel Fuel type Derivation	Derivable fuel (L/Ha)	Bio-yield	Nigeria's Production Ranking (globally)
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

Table 5: Nigeria's Biodiesel Crops Production. *Data from Leibig (2008); other fuel yield/ha from Mobius LLC (2007) : Adopted from Abila (2010).

However, these estimates did not contemplate the competition between food and fuel. Howbeit, it guarantees the opportunity of the potentiality for the production of biofuels (biodiesel) which the nation's renewable energy procedure should be geared towards utilizing. CPO and PKO have the highest biofuel (biodiesel) potential for Nigeria. In 2007, the country ranked third in these feedstocks production worldwide (Statistics, 2020).

Derivable feedstock	Cultivated area (ha) 2007	Derivable biofuel type	Estimated Biofuel production potential (million litres, 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

Table 6: Estimate of Biofuel potential production in Nigeria. Adopted from (Statistics, 2020).

Note: *ML= million litres

Due to the fact that the Nigerian biofuels (biodiesel) sector is at its inception, this research on palm oil as a potential feedstock for Nigeria's biodiesel production provides recommendations in relation to the current biofuels (biodiesel) scheme.

The findings from this study may be valuable in promoting strategies to be adopted regarding biofuels (biodiesel) implementation in Nigeria.

These are the key findings relevant to palm biodiesel development:

1) The current biodiesel policy lacks the description of techniques employed for palm oil (feedstock) availability and describes a few crops for biodiesel production in Nigeria. This should clearly be improved on. This will promote a better engagement in the rehabilitation of the palm oil industry as key actors can benefit from the various incentives, as illustrated by the Nigerian Biofuels Policy and Incentives (Abila, 2020). The lack of adequate data for the palm oil production stream coming from the small scale producers poses a challenge to evaluate the precise amount of palm oil produced in Nigeria.

2) Presently, the (biofuels) biodiesel implementation policy on utilizing palm oil as a raw material should be contemplated as palm oil feedstock for biodiesel competes with palm oil as a cooking oil (food) currently. This viewpoint should be integrated into successive strategies, to attain a balance between food versus fuel nexus.

3) The estimation and goals stipulated for blending of biodiesel with fossil diesel should be predicated on a clear-cut valuation of the present and prospective consumption of fossil diesel in Nigeria. The blending goals proposed by the country for biodiesel production tops the blending specifications based on the actual and general utilization.

4) The utilization of remnant streams generated from the palm oil winning and biodiesel production processes respectively have been stated to be economically viable. Nigeria needs a synergistic optimization of both its scientific know-how and machinery to employ this advancements that can foster a circular economy hence closing loops and making the process socially, environmentally, and economically sustainable.

Therefore, subsequent biofuels (biodiesel) policies should be predicated on the upgrade of the machineries utilized by small scale producers in Nigeria who play a key role in the in the oil palm industry. This consequently ensures the availability of feedstock which is the core of biofuels (biodiesel) production in the country.

Chapter 4

Discussion

4.1 Assessment of factors affecting commercial viability of palm oil (feedstock) and the organization of the market structure.

The market for palm products is branched into palm oil, palm kernel oil, and by-products. Palm oil with palm kernel oil simultaneously makes for 72 percent of vegetable oil production in Nigeria (Oyaide, 2004a).

Annual demand	1.6 million tonnes
Growth in demand (annually from 1996)	5%
Annual Domestic Production	1.3 million tonnes
Palm/Palm Kernel Oil	72%
Groundnut Oil	23%
Others	5%
Annual Production Deficit	0.3 million tonnes

Table 7: Demand of vegetable oils and fats in Nigeria 2001. Source: (Oyaide, 2004b).

According to FAOSTAT Nigeria's population of nearly 194m and per capita consumption of 12.5 Kg per person annually versus the global average of about 20 Kg per person per annum, estimates yearly consumption at 2.4 million tons. Nigeria has a shortfall of 0.9 million tons worth of nearly USD 800 million based on the demand as stated above (Fact File on Crude Palm Oil (CPO) in Nigeria, Cote d'Ivoire and Ecowas, 2020).

While Malaysia and Indonesia productions have increased highly over the years, it has hardly been the case for Nigeria, mostly due to its reliance on traditional production processes (FAOSTAT, 2012).

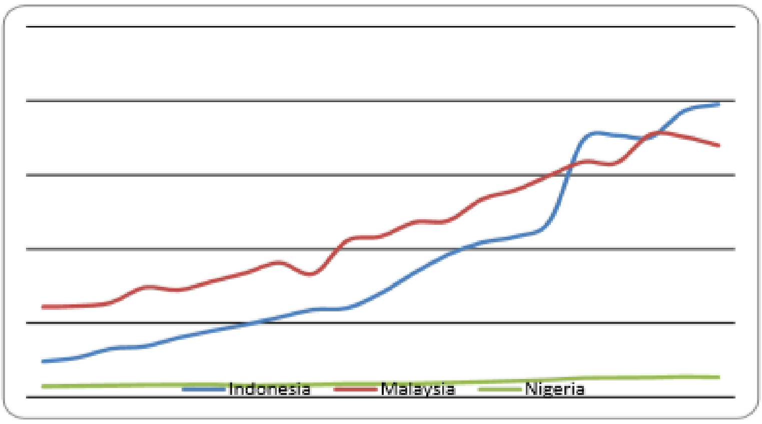


Figure 23. Indonesia, Malaysia, and Nigeria‘ palm oil production (‘000 tones), 1990-2010.

Source: (FAO Statistical Yearbook 2012, 2020).

Although palm oil production has been increasing since 1990, the output is inadequate to match the consumption locally. The national demand has increased rapidly than the domestic supply (PIND, 2011). Therefore, Nigeria imports palm oil to meet the local demand. However, Nigeria has a potential to increase its production through the utilization of improved processing procedure and better marketing. From the demand gaps necessary to meet the country's need for cooking oil presently, the restructuring of the oil palm industry seems to be the fundamental goal to be realized before the commencement of the biofuels era. A cooperation between the major players and the small scale producers regarding the upgrade in oil extraction machineries can boost the supply which may fill the local demand gap for cooking in the nation.

Import of refined palm oil / vegetable oil is restricted and there is a duty of 35% on the import of Crude Palm Oil / Crude Vegetable Oil. By maintaining this policy, the nation is able to create employment in manufacturing / refining industry and also uphold the oil palm plantation by preserving them with an extra limit of more than $300 per ton on and above sales price realized by Malaysia and Indonesia's palm oil plantation (Fact File on Crude Palm Oil (CPO) in Nigeria, Cote d'Ivoire and Ecowas, 2020).

Value in million USD	2012	2013	2014	2015	2016
Legal import	224.5	261.3	546.9	374.3	278.3
Unaccounted estimated import	575.5	538.7	253.1	425.7	521.7

Table 8: Fact File on Crude Palm Oil (CPO) in Nigeria, Cote d'Ivoire and Ecowas, 2020).

According to Market analysis and Research wing of International Trade centre (ITC), Geneva, Switzerland, who compiles data for trade statistics for international business development, the reported legal import ranges between 224 to 546 million USD as presented in the table below.

Value in million USD	2012	2013	2014	2015	2016	Total
Unaccounted estimated import	575.5	538.7	253.1	425.7	521.7	2,314.7
Revenue loss on account of duty	224.17	209.82	98.58	165.82	203.19	901.6

Table 9: Palm oil import into Nigeria (Fact File on Crude Palm Oil (CPO) in Nigeria, Cote d'Ivoire and Ecowas, 2020).

Most of the unaccounted import occurs through long porous borders and the estimated total revenue loss for the time between 2012-2016 was 901.6 million USD and 275 billion Naira converted at Central bank of Nigeria (CBN) official exchange rate of 306 Naira per USD.

The demand for palm oil is propelled essentially by the household consumption for food utilization. 90% of palm oil consumption in Nigeria is by the food industry while the non-food industry accounts for 10%. Products such as noodles, biscuits, margarines, shortenings, cereals, baked items, and cosmetics thrive on palm oil. This is enhanced by a rising demand for the special palm oil which is used to meet the needs of industrial processors. Consequently, the large and fast growing population continues to be a major driver of demand.

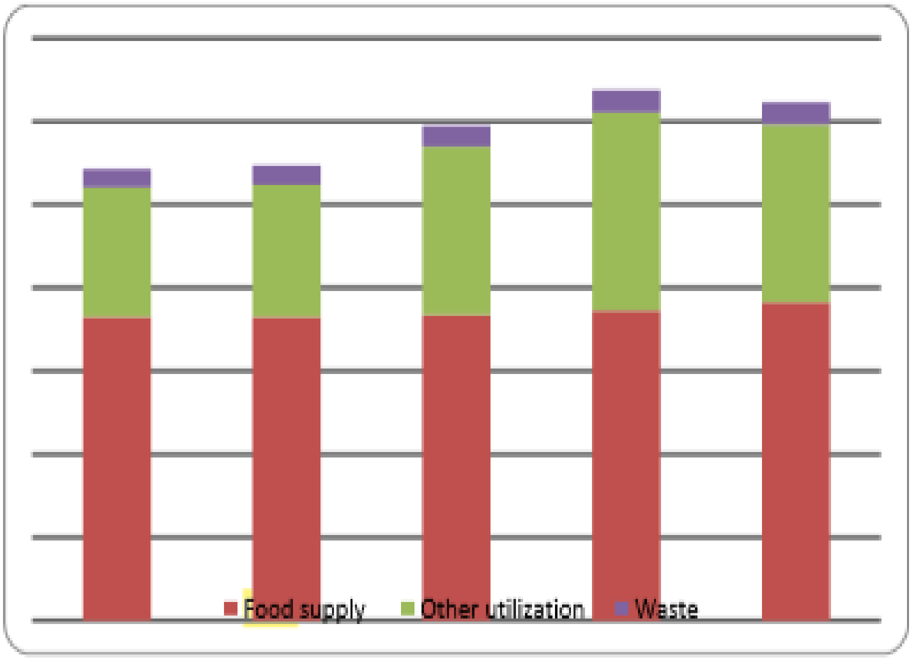


Figure. 24. Food and non-food supply (‘000t), 2005-2009.

Source: (FAO Statistical Yearbook 2012, 2020).

The demand in the regular market is three times higher than the industrial demand (food and non-food), due to the lack of development of the industry for primary or secondary transformation (PIND, 2011). This also means that the regular household market is a crucial influence of the supply deficit in Nigeria.

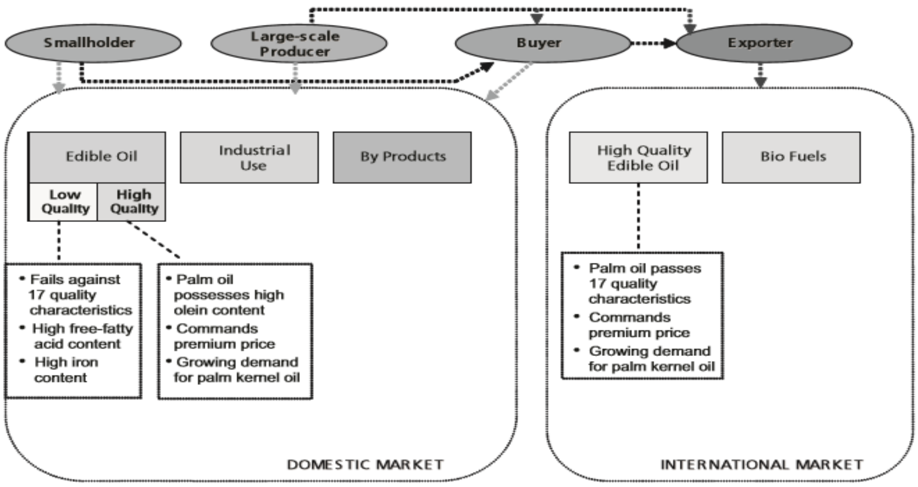


Figure 25. Visual demonstration of the market structure of the Nigerian oil palm industry (Small-Scale Palm Oil Processing Business in Nigeria; A Feasibility Study, 2020).

Oil Palm production in Nigeria hinges on three groups of oil plantation holding; small holding plantation, medium scale plantation and large scale plantation as already highlighted. From these groups, small holder oil plantation controls oil palm cultivation in Nigeria covering about 1-5 hectares of farm and are generally typified by mixed cropping evidently meant to maximize the use of the land (Ayodele and Ehalomi, 2010). A huge portion of oil palm exists in the wild or semi-wild state, when combined to those that are cultivated by smallholders, it demonstrates that the small-holding dominate over 80% of the Nigeria palm oil production (Nigerian Institute for Oil Palm Research (NIFOR) - Commonwealth of Nations, 2020). Above 70 percent of the Nigeria's processing centres are non-operational and without capital and spare parts needed for maintenance, these sub-standard operations impact on the quality continuously.

4.2. Allocation of geographical areas for the production of food, feed, fuel, (oil palm) and access to land

The difference in the production efficiency, indicating the heterogeneity of climatic, soil, agro-ecology, and other factors, makes it paramount to allot a geographical region that may be dedicated to the production of a mixture of goods. The figure 26 below illustrates a prospective sketch of Nigeria into three geographic areas for the production of the mixture of food-feed-fuel, feed-food-fuel, and fibre-feed-food. These organized threesome signify the blend and classification of the belts for the production of the crops that are more adapted for the aim in each category. In the northern region of Nigeria, there is the Sahel, Sudan, and Guinea Savannah agro-ecological zones, that are appropriate for the production of cotton, guinea corn, ground nut, millet, and sugarcane. The mid-region is a derivative of the Savannah and the southern sector of the Guinea Savannah, and it is suitable for the production of melon, sesame, maize, shea nut, yam, cassava, and soybean etc.

The lower belt is made up of the humid forest largely and the derived savannah agro-ecological sectors, appropriate for producing **oil palm**, cassava, cocoyam, coconut, and rice, among others (Abila, 2012).

The sketch of the country into distinct regions is not automatically an established model. There are no strict characteristics between the agroecological areas, or the core climatic and soil quality that support a distinct group of crops. The bottom line is to alter the strategies, policies, and incentives outlined to improve production and productivity as well as to guarantee a balance in the realization of the food versus fuel nexus. Weather, nature of the soil, general food culture, and other unique related advantages may give one area an edge over the others in the production of a specific group of crops. Furthermore, focus on the goals may demonstrate that the need for reaching a particular target is important than others. The classification of geographical areas for crop production should also bear in mind the outlook for each goal and the native capacity to absorb the produce.

One of the obstacles faced in acquiring land for oil palm production is the continual nature of the crop. It takes around 36 months from the date of planting for an established plantation to produce any yield (Omereji, 2004). Due to Nigeria's low plantation culture (partially due to the land tenure system and as a result of the geographical spread of oil palm producers), it would be beneficial to reassess the Land Use Act and revise it to act as an incentive for supporting the development of a plantation practice for oil palm production (Small-Scale Palm Oil Processing Business in Nigeria; A Feasibility Study, 2020).

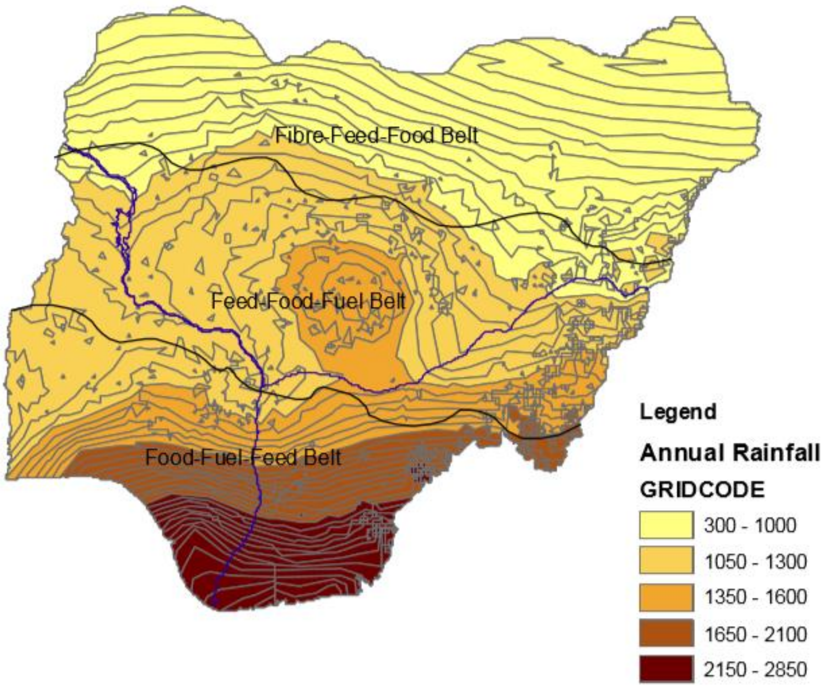


Figure 26. Proposition of geographical areas for the production of crops (oil palm).

Source: (Abila, 2012). Note: Rainfall in mm of precipitation.

4.3 Efficiency and Profitability of Production and Processing technologies

Nigeria's capacity to meet up with the surge in demand globally was reduced by the over dependence on traditional production techniques, too much tapping of the palm tree for palm wine, and the civil war between 1967 and 1970, which was fought in areas where palm oil production activities were high. The civil war brought about the destruction of small holder palm plantations as well as wild and semi wild palm plantations. During these time, palm oil production and the tonnes produced could not meet the surging demand globally and consumption. Between 1975 and 1995, production increased slightly from 640,000 tonnes to 898,000 tonnes (Small-Scale Palm Oil Processing Business in Nigeria; A Feasibility Study, 2020; Opeke, 2005). Traditional processing techniques have a low oil extraction rate, only able to extract nearly 24 percent of the oil in comparison to modern processes which extracts above 90 percent (2020b). An effective way of taking care of this issue rest on the small processing machines manufactured by the NIFOR. Although NIFOR has these machines available at reasonable costs, distribution to producers has been limited (Oyaide, 2004b).

The mechanised oil-palm processing equipment mentioned in the palm oil processing section of this thesis can be utilized to boost the efficiency and quality of palm produce. Smallholders can profit from actions to upgrade their production and processing technologies, get fair payment for the volume of their produce as well as increase the quality (Small-Scale Palm Oil Processing Business in Nigeria; A Feasibility Study, 2020).

Although the availability of inputs and labour are sufficient, smallholders have restricted access due to the excessive high costs for each. The prices of insecticides, herbicides, and fungicides are progressively high and above the capacity of the scanty earnings of small-scale producers. Therefore, to solve the problem of low input management, provision of credit for procuring inputs and for hiring labour could be made.

There is also a rise in the labour cost owing to decent accommodation needs and the high risks concerned with harvesting (many smallholders still climb to harvest, which places the harvester at risk of death or injury, and which sometimes results in damaged pods). Therefore, the provision of mechanised harvesting tools is crucial.

An important aspect of vulnerability rest on the unpredictability of the source of some of the seedlings sold to producers**.** Persons looking for individual income usually approach producers with supposed high quality seeds**,** which are actually fake replicas**.** It is necessary therefore to intensify the interdependence between oil palm seed and seedling production and distribution to check this illegal activity.

Nigeria was ruled by military governments previously, so there was little interest in agriculture development and much less in the oil palm industry. In essence, even private sector interests in driving agriculture were generally hindered, as politicians sought personal gain from the petroleum boom**.** Hence, there was poor maintenance of the support industries and infrastructure for agriculture, which translated into the degeneration of numerous sectors.

Although the current government has taken up severe measures to boost agricultural production, smallholders will always be susceptible to changes in the political arena, as new system coming to power may have contrasted preferences that could curb the growth of the oil palm industry. If the government does not support the required interventions for establishing a robust industry, the funding designated will be insufficient, as will be the other factors of production(Small-Scale Palm Oil Processing Business in Nigeria; A Feasibility Study, 2020).

4.4 Ethics of biodiesel (Implication for policy)

Simultaneously, various non-governmental organisations (NGOs) and social movements have asserted that the utilization of edible oils for biodiesel production is the main factor responsible for the market price increment of food worldwide. Currently, proof that biodiesel drives food price increases is only inconclusive. Alternatively, a lot of reasons have been indicated to have substantially created the price increase like the law of supply and demand, fast growth of the global population, income growth, increased production cost, increased price of other oils (soybean and rapeseed oils), natural disasters, climate change, and political instability (Lam et al, 2009; 2020k). As stated by Koizumi (2015), changes in the price of edible palm oil in Malaysia and Indonesia provoked by an increase in biodiesel demand are uncertain. Furthermore, different analysis on improved planting strategies, specific fertilizers, and advanced crop biotechnology as well as cloning have been recommended to enhance the palm oil production in an environmental-friendly and economical way to ensure a proportionate role of palm oil in food and fuel supply for a sustainable future(Lam et al, 2009).

The likely danger to environment, biodiversity and biological resources has been a major concern in the argument over biofuels sustainability**.** Nigeria's primary forest resources and delicate ecosystems should not be threatened any farther by biofuels development. A basic prospect of the biofuels (biodiesel) implementation policy should be the opportunity to completely utilize the current underused agricultural lands and controlling notable ecological challenges like deforestation, charcoal production etc. The production of biofuels as substitutes for sustenance and meeting the basic energy needs such as lighting and cooking is crucial as the Nigerian economy enters into a green energy era.

Worth or value is requisite to explain, particularly in the biodiesel context. As stated by Elkington (1999) in his triple bottom line approach to accounting, posits that the methods by which investors determine the value of a venture should include social and environmental measures in addition to the economic. In this framework, biodiesel can be considered to hold more worth than its fossil counterpart through the intrinsic value of the product. The intrinsic value (value without reference to market worth) of biodiesel is placed in the socio-environmental benefits that exist in its production and utilization. An environmental advantage via a minimization in net greenhouse gas emissions and social benefit through impacts to the human environment support the position of biodiesel within the economy. Additional evaluation and analysis of Nigeria's oil palm production and biodiesel processing can be predicated on the three particular concerns on which biodiesel feedstock and biodiesel production are significant as stated by von Braun's (2007) are (1) Economic change, (2) Environmental change, and (3) Socio-political change.

4.4.1 Economic change

Planning of economic growth that is dynamic and durable arising from the development of biofuels (biodiesel) sector is vital for sustainability. Although the Automotive Biomass Programme for Nigeria (Ohimain, 2013) was established to promote the improvement of biofuels, the utilization of the scheme requires combining and preserving the natural and man-made benefits for pushing biofuel innovation. To secure economic sustainability of the biofuel advancement in Nigeria requires the support of vital resources like land, capital, and labour to be assessable for other significant sectors. The development of the biofuel economy should not be at the expense of transport, health, and manufacturing, or other sectors of the economy. The implementation of the biofuels sector should also vitalize the growth of other relevant sectors. Exploiting the non-payment linkage between biofuels production and other sectors is fundamental. The biofuels advancement mediation and stimulus should be well established within the bigger economic improvement scheme linked to other sectors.
For example, the Nigerian government has earmarked two projects in Cross river state, Nigeria for biodiesel production using oil palm as feedstock with projected economic benefits as presented in figure 24 below. The locally accessible crude palm oil has been thought out as a sustainable feedstock to produce biodiesel.

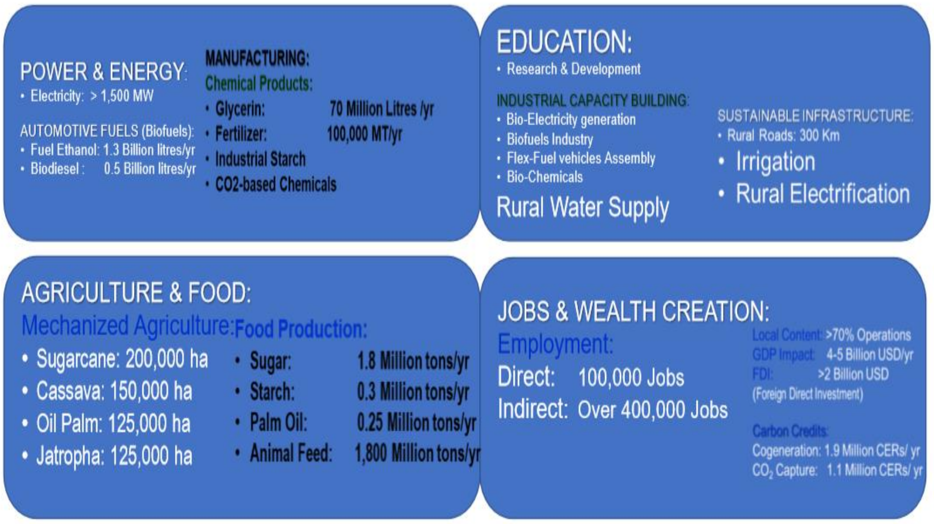


Figure. 27. Earmarked projects and assumed benefits for biofuel (biodiesel) production in Nigeria (Source:2020j).

Expected Benefits

- 2500 direct and 15,000 – 20,000 indirect jobs will be generated
- Increased food and energy production in terms of sugar, animal feed and electricity

- Improved rural economy for small businesses that will spring up along the entire value chain of the venture
- Increased revenue for the state
- Reduction of youth restiveness, drug abuse and crime
- Enhanced agricultural practices through the out-growers scheme
- Improvement in basic amenities such as water, schools, roads, and healthcare facilities in the form of Corporate Social Responsibilities (CSR)
- Prevent the high rate of the rural-urban drift

4.4.2 Environmental change

Presently, there are environmental issues such as flooding and erosions affecting the urban areas across Nigeria. Land pollution from oil spills in the Niger delta and along fossil fuels and fossil products delivery pipelines crossing the nation affects crop production throughout the country. Extended drought, water and desertification pose challenges. Formerly, arable lands turned insignificant with minimal or no appropriateness for valuable food production and agricultural investment. The designing and utilization of a scheme for oil palm production and employing the broad-spectrum biomass, and bioenergy potentials in Nigeria, provides a solution to some of the current environmental challenges. Insignificant lands emanating from the prevalent environmental issues can be recovered for the production of non-edible biofuels (biodiesel) feedstocks. The availability of water may not cause complications but handling the effluents from biodiesel processing can be a problem necessitating thorough and absolute conversion technologies and supervisory framework. Nigeria also needs to enhance its capacity and technology for gauging the advantages and profitability of adopting biodiesels, regarding carbon sequestration (Abila 2012).

4.4.3 Political and social change

The techniques employed in environmental governance turns into positive social changes necessitating the setting of comprehensible goals in designing and utilizing of feasible frameworks. Environmental issues include many collaborators. According to Stewart and Jones (2003), there should be policies, frameworks and methods which can allow the handling and strategizing of stakeholders decision making and promoting the growth of a set of shared values about the matter under consideration which is the utilization of palm oil feedstock for biodiesel production in Nigeria in this context. The favourable ratification of biodiesel in the country will build on collaborative decision-making processes, designing and implementation policies and governance directed at utilizing the accessible biodiesel potential of the country. This is fundamental to guarantee that benefits stream down to farmers and the others at the bottom of the supply chain of the production of biodiesel. An inclusive mitigation of negative impacts is necessary as well. A combination of peace and security in the volatile communities of the Niger Delta region is needed to tackle biodiesel production potentials as a substitute source of livelihood (Abila 2012).

The fifty years of fossil fuels exploration can be considered to have neglected the social aspect; thus, the emergence of a developing biofuels sector must guarantee the re-occurrence of such a trend. A redistributed value chain for the production of biofuels and supporting a reasonable participation of the small scale farmers is essential for establishing social sustainability. Therefore, the drive to boost the production of feedstocks should not lead to taking on of small farm holdings by the bigger large-scale investors. The out-grower practice described in the biofuels policy for Nigeria is to promote the arrangement between farmers and biofuels (biodiesel) plants for the cultivation of feedstocks (palm oil), it should be amended to protect small scale and female farmers and ensure that they are not deprived. Coordinated farming systems that will permit the farmers with small landholdings to merge and adjoin their farmlands to meet the basic farm size stipulation to be eligible under the out grower scheme should be put in place.

4.5 Certification of palm oil

Certification is the process whereby compliance to a set standard is assessed and validated with a certificate and/or a label. Sustainability standard models in agricultural production includes principles and criteria concerning legal compliance, environmental protection, good agricultural practices, land rights, community relations, human rights, and labour circumstances (RSPO Certification Systems, 2020). Moreover, certification schemes may either be private or public. The public standards are progressive and stimulated by the government although stakeholders such as NGOs and businesses determine the principles, criteria, and verification prerequisites generally in private scheme (RSPO Certification Systems, 2020). The Roundtable on Sustainable Palm Oil (RSPO) and the International Standard for Carbon Certification (ISCC) are the two domineering private certification systems in palm oil production (RSPO Homepage, 2020). RSPO is a multi-stakeholder initiative employed for sustainable palm oil. There are 3,583 RSPO members globally from diverse sectors in the palm oil supply chain. About 19% of palm oil production globally and nearly 3 million hectares are RSPO certified. The RSPO objective is to stimulate the production, application, and utilization of Certified Sustainable Palm Oil (CSPO), where a progress report (ACOP - Annual Communications of Progress) must be submitted yearly. There are various preconditions to become a member, and there are three levels of membership:

• Ordinary membership is for organizations / businesses that are directly involved in the palm oil supply chain.

• Supply Chain Associate membership is for companies that have supply chain activities but who buy or make use of less than 500 tonnes of palm oil or palm oil products annually.

• Affiliate membership is for organizations that are not directly concerned in the palm oil supply chain.

RSPO categorizes four peculiar chain of custody models: Book & Claim, Mass Balance, Segregation, Identity Preserved (RSPO Homepage, 2020).

• Identity Preserved (IP), where sustainable palm oil could be traced directly to the individual manufacturer. The oil is kept separate throughout the supply chain.

• Mass Balance, where the certified (CSPO) oil is mixed with conventional oil (not certified) but where accounting is kept of how much certified palm oil is accessible in the "System".

• RSPO credits/Book and Claim. Here the supply chain is not regulated with respect to the content of CSPO - sustainable palm oil. Production companies and oil dealers can buy credits directly from certified growers, oil mills or smaller producers.

• Segregated or SG – this means that certified palm oil is kept separate round the supply chain.

There are few RSPO-certified plantations in Africa (7 plantations). Siat Nigeria Limited (SNL) received its certificate in October 2019 and became the first RSPO-certified company in Nigeria**.** This certificate demonstrates the commitment of the Siat Group to produce palm oil responsibly. To obtain these two certificates, one that covers plantation and mill and one for the crusher, SNL complied with all the requirements of the standards: RSPO Principle and Criteria (P&C) and RSPO Supply Chain Certification Standard (SCCS), (Nigeria, 2020).

There are two supplementary certification schemes, RSPO NEXT and RSPO RED:

RSPO NEXT comprises of the following:

• No deforestation

• No planting on peat soil

ISCC is a requirement mostly employed in the bioenergy sector. It was established for companies to heed to the Renewable Energies Directive put into action by the European Union in 2009. ISCC is a certification scheme for biomass and bioenergy industries, aimed at the reduction of greenhouse gas emissions, sustainable land use, protection of the natural biosphere, and social sustainability. ISCC separates two chain of custody models (Mass Balance and Segregation), and in so doing creates the traceability requisites of the EU Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD) (RSPO Homepage, 2020).

4.6 Nigeria's competitive advantage

The Location of the Nigerian palm oil industry is its major advantage**.** Located in West Africa, it is advantageous due to its juxtaposition to the large markets in Europe and Africa, particularly in comparison to its principal competitors: Malaysia, Indonesia, and Latin America. This relatively reduces transportation costs and may provide a means to increasing the export market share once Nigeria's productivity and quality levels increase (2020b).

A comparison of the Nigerian Oil Palm Industry to that of Malaysia as illustrated in the table below focuses on the advantages of the Malaysian counterpart and demonstrates areas for development in the Nigerian oil palm industry.

Characteristic	Nigeria	Malaysia
TECHNOLOGY	Dominant technology: smallholder Production with traditional processing	Dominant technology: largescale plantations with modern mills
Farm-level	Oil palm inter-cropped with other food crops; semi-wild varieties with little or no modern inputs	Intensive monoculture; high degree of specialization, HYV's and modern inputs, mechanization
Processing	Manual; low volume; low extraction rate (20-50%)	Well-integrated; capital intensive, high volume; high extraction rate (90%)
Management Structure	Decentralized management processing and marketing	Single management control
Environment Production	80% of national production Structure from smallholders	Over 90% of production from large-scale plantations
Research	Public research (NIFOR only)	Collaboration between public (PORIM) and private research
Institutions	Separate land and tree tenure System, Land use decree of 1978	Consolidated land holdings; vertical integration; quality control standards
Supporting Infrastructure	Negligible; some government mills or plantation	Nurseries, credits, refinery mills established trading system
COORDINATION		
Inputs	Little use of modern inputs and extension service	Provided internally (e.g. seedlings from own nursery) or from markets
Output Market	Previously controlled by monopoly Marketing board: market Liberalization in 1986	Vertical integration; contacts; markets. PORLA provides market information, standard and quality control
PERFORMANCE		
Productivity	Low	High
Quality of Oil	High fatty acids, for local use only	Export quality
Adoption of modern Inputs	Low	High
Access to information	Slow	Fast (partial internal flow)
Impact on Environment	Low	High

A Comparison of the oil palm industry in Nigeria and Malaysia (2020).Source: (2020b).

4.7 Limitations

This report has been influenced by the unavailability of adequate data, which is a fall out of the COVID-19 pandemic since the inability to perform pre-scheduled skype interviews and access to first hand data from major industry players posed some challenges in obtaining current results on the state of the art of palm oil production and the implementation of biofuels (biodiesel) in Nigeria respectively. This inferred with drawing comparisons between the scanty literature accessed online to first-hand information from key actors in the industry. The statistics on palm oil production in Nigeria and the importation of palm oil to augment the need for consumption (food) were determined based on the available FAOSTAT database on Nigerian palm oil. The gap in terms of the deficiency in supply for food which is made up for by importation were also accessed from FAOSTAT. General assumptions were made based on similarities that could be drawn from the global palm oil industry particularly regarding biodiesel production and the use of the remnant streams for closing the loop in an attempt to foster the circular economy principle in the system. However, this method of evaluation does not capture the current palm oil production status in Nigeria especially the total amount of production from small scale farmers who play a key role in the palm oil business. Lastly, there was the limitation of working from home in view of the global lockdown thereby having access to limited databases.

4.8 Future Perspective

After digging into the field of the Nigerian oil palm industry and outlining the country's challenges to meet its capacity to produce palm oil as food and feedstock to implement biodiesel production, coupled with the upgrade of remnant waste streams to valorise the entire process thereby closing the loop and fostering the circular economy principle the following have been observed. What has come across as remarkably important also through the limitation, is the role of the government and stakeholders in the provision of modernized agricultural techniques, subsidy on fertilizers which can lead to an increase in productivity and production at reduced costs per unit area. Provision of incentives to the smallholders who are major players in the oil palm industry will go a long way to revamp the oil palm industry in Nigeria hence increasing the production of palm oil in Nigeria which will satisfy the need for consumption and the feedstock requirement thereby balancing the food vs fuel nexus.

An organization like RSPO or local certifications can be a key driving force to ensure sustainable production of palm oil which currently has only one member in Nigeria. The newest initiative from RSPO is a credit system, that creates one type of economic incentive, in which the producer gets a premium for certified palm oil, when consumers buy these credits (RSPO Certification Systems, 2020). Arguably, implemented credits is a short-term perspective, as the premium paid to the producer can have an immediate impact. Looking at a long-term perspective, it is necessary to encourage the production of sustainable palm oil. As such, an enhanced focus on education would be an option to provide producers with better preconditions for increasing yield per hectare in cultivating their land more efficiently.

Specifically, influencing the production through education can add value in several ways, but a potential outcome may be fundamental: an increasing transparency through the chain, and creating the conditions for reciprocal, beneficial relations between companies/organizations and smallholders. Although, this is a challenge with structural durability and complexity of implementation, the value is tied to partnerships.

Presently, the worldwide production of 65 million tonne palm oil needs cultivation of 15 million ha which are effectively less than the 194 million ha required to produce precisely 87 million tonne oil from oilseed crops like soybean, rapeseed, and canola (IBEST - The Institution of Biorefinery Engineers, Scientists and Technologists, 2020). Thus, regarding total oil yield per hectare, oil palm is more than 6.5-fold more productive than the average mixed yields of other crops. If oil palm is not considered, around 130 million ha more land will be required to produce the same volume of oil (IBEST - The Institution of Biorefinery Engineers, Scientists and Technologists, 2020). Oil palm is the most generative source and cheapest of vegetable oil for biodiesel. RSPO authorized over 13 million tonnes of RSPO Certified Sustainable Palm Oil produced from over 3 million hectares production area globally. This amount elucidates 20% of the worldwide CPO production certification so far (IBEST - The Institution of Biorefinery Engineers, Scientists and Technologists, 2020). The RSPO standard was advanced by stakeholders from around the globe, which enables the criteria to cover from legal, economic, social to environmental aspects of oil palm production**,** yet recognizing that the standard is to assist the upgrade of present-day operations, and not designed to close down the industry. The guideline proffers room for producers to commence on the learning process hence promoting the theory on factors that provide efficient approach**.** The standard may establish the assumption for approval of palm oil as biodiesel in other countries not producing it thereby sending economic flow to the countries like Nigeria who produce it. The NNPC and other relevant stakeholders should invest on more R&D by creating more foreign partnerships that can foster the technological transfer for biodiesel production to Nigeria.

It is expected that more research will emanate from this work. Key areas for future research include using modelling technique to investigate questions like estimating the prospects of biodiesel demand, evaluation of the impact of biodiesel implementation on the Nigerian populace.

Modelling to obtain a balance on the food, fuel and value added products potential is an outlook worthy to analyse, as the experimental trial on biodiesel implementation in Nigeria develops.

Chapter 5

Conclusion

In conclusion, we return to the key questions i.e. as to what extent can the circular economy principle be adopted into Nigeria's biodiesel and to what extent does palm oil as a feedstock represent a strategic market opportunity?

To achieve this aim and to answer our research questions, the conceptual framework was first developed by literature reviews. The data for Nigeria's palm oil production and the imported fraction to fill the consumption demand gaps were extrapolated from FAO statics database.

The data categorizes palm oil and its fractions into three main classes based on usage: palm oil, palm kernel oil and oilcake. This data with particular emphasis on palm oil was utilized to estimate the amount of palm oil produced in Nigeria currently as a measure to its availability for use as a feedstock for the Nigerian biodiesel sector. The assessment revealed that there is a shortfall in the amount needed for consumption which is the present driver of palm oil production in Nigeria. The country accounts for 1.5 million tonnes production yearly and imports 0.9 million tonnes to fill its consumption gap. The unavailability of recent data hampered the precise calculations of the current palm oil production status in Nigeria considering the flow from small holders production. As a consequence, the actual results were probably lower in light of various shortcomings due to insufficient data to calculate these parameters accurately. There is a potential for the rehabilitation and sustainability in the palm oil supply chain in Nigeria.

The technological readiness for the processing of palm oil for biodiesel production is still at the inception stages in both R&D and infrastructure. The sustainable production of biodiesel and valuable co-products from palm oil feedstock in Nigeria is dependent on the feedstock availability, and adequate technology utilization. The co-processing of biodiesel with petroleum diesel in conventional refinery infrastructure is dependent on a number of factors, which includes, the energy capacity, the capital cost of integrating the biomass pre-conversion facility to the existing conventional refinery infrastructure in comparison to the cost of a stand-alone biorefinery, the location of the petroleum refinery, the market availability for the consumption of these products and technology transfer. The transformation of Nigeria to a biobased economy will replace crude oil. This can materialize if the identified research gaps, policy shortfalls and sustainability issues are addressed. The realization of the 10% biodiesel blend in the nation's refineries to 100% domestic biodiesel production at the long run will be attainable if the availability of the palm oil feedstock, adequate machineries, technology, infrastructure, processing routes, and sustainability issues are well established.

In spite of the urgent need to promote energy security and low-level greenhouse gas (GHG) emission, Nigeria has made little progress towards developing her biofuel (biodiesel) industry alongside many hindered policies. By way of direct comparison, Nigerian oil palm industry has been suggested to have a prospect for a commercial scale biofuel (biodiesel) production that can work as both affordable clean fuel for her people and also as a source of export revenue to the country. Oil palm has been estimated as having the capability of becoming a valuable commodity that can meet the demand globally as edible oil and simultaneously supply to energy security globally hence balancing the food-fuel nexus.

The Federal government of Nigeria and relevant stakeholders can clamp on the energy prospect of oil palm bioresources to contribute to solving her energy challenges. An effort to revive the Nigeria oil palm sector after many years of neglect will promote the industry both as a source of food and a feedstock for biodiesel production. After 1962, Nigeria lost her place in international oil palm export market, even though there have been numerous oil palm policies issued as well as presidential oil palm initiatives toward an effort to improve the sector.

This study evaluated the extent to which palm oil as a feedstock for biodiesel production represents a strategic market opportunity and how the circular economy principle can be adopted to close the loop. The challenges that threaten the sector consists of; the control of the industry by smallholders who mostly utilize hand-operated tools for processing, poor approach towards work and insufficient government policies, changes in political regimes, substandard infrastructures, and poor access to credit facility. Regardless of the drawbacks, numerous opportunities exist for the sector such as the availability of arable cultivable hectares of land, workforce, upgraded varieties, applicable climatic and soil conditions. Hence, the reactivation of the oil palm industry will be valuable, and the country can leverage on the oil palm industry to implement its biodiesel sector.

This review examines Nigeria's capacity to produce palm oil and the capacity to utilize this resource to meet the nation's biodiesel demand. With the increasing need for clean energy and frequent fuel scarcity, Nigeria requires an alternative fuel source and the boosting and utilization of natural resources. Biodiesel is an appealing substitute for petroleum diesel. Nigeria is clearly an oil importer of transportation fuel. This makes the country susceptible to unpredictability in fuel prices globally and relies upon foreign exchange to satisfy its domestic energy requirements. The target then is to cut down the high reliance on imported petroleum by maximizing domestic biomass resources (palm oil) for biodiesel production. Nevertheless, this may be realized sustainably with minimal environmental and socio-economic impact which can be achieved by integrating palm oil processing technologies whereby remnant streams from each section of production of biodiesel is utilized and upgraded to close the loop in the circular economy model and sold to generate additional revenues for both the nation and the populace. Alongside the location of the existing petroleum refineries in the Niger Delta region of Nigeria, and the numerous abandoned oil palm plantations available in the same area, it is appropriate for the NNPC to analyse as part of its biofuels programme the production of refined biofuels (biodiesel). It should determine if it is preferable to construct new biorefineries and transport the products to existing refineries for blending, or alternatively for current refineries in the country to be extended to process raw biomass (palm oil) into biodiesel for blending.

The initial market for biodiesel in the near to long-term future is presumably to be used as a blend stock in petroleum diesel. Therefore, it is crucial that a comprehensive knowledge of biodiesel implementation from palm oil feedstock and fuel properties of the resultant biodiesel, such as exhaust emissions, low temperature operability, oxidative stability, water content, kinematic viscosity, and lubricity are attained. Nigeria has chosen palm oil for biodiesel production; the country presently produces significant amount of palm oil for food consumption alone and still imports a considerable amount of palm oil to make up for cooking. The utilization of palm oil as biodiesel feedstock should be extremely assessed and validated alongside the utilization of remnant waste streams for the production of valuable co-products to close the loop. Alternatively, the utilization of inedible oil sources from the processing of oil palm biomass and palm oil feedstock such as palm press fibre oil, palm kernel oil and raffia palm oil etc. may be employed for biodiesel production. Stakeholders and the respective governmental bodies in the Global North and Global South could be complementary by collaborating and combining their respective strengths to enhance the production of certified sustainable palm oil. The above strategies elucidate areas for development to improve the capacity of palm oil production in Nigeria thereby changing the narrative which invariably provides the needed feedstock (palm oil) for the biodiesel industry. It is important that interest in certified sustainable palm oil production takes the spotlight as there is no better substitute to palm oil presently.

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