Analysis of Biofuel Potential in Nigeria

By

Ndukwe Agbai Dick
(B.Agric.Tech. Hons. Agricultural Economics & Extension,
M.Sc. Environmental and Resource Management)

Thesis submitted for the Degree of **Doctor of Philosophy**

School of Agriculture, Food and Rural Development (SAFRD)

Newcastle University, Newcastle Upon Tyne, NE1 7 RU

United Kingdom

September 2014

Declaration

The contents of this thesis are my original research work and have not been presented elsewhere for any other award. I confirm that the word length is within the stipulated word limit for my school (AFRD) and faculty (SAGE) as recommended in the 'Guidelines for the Submission and Format of Thesis' document. In addition, I wish to state that there is no collaborative or jointly-owned work in this thesis, whether published or not. Every form of support received in the course of this study and all cited works have been duly acknowledged.

Ndukwe Agbai Dick

Abstract

Energy security is a priority for most countries as a pivot for economic development. However, Nigeria, despite being a major oil producer, is plagued by energy insecurity in addition to long-standing food insecurity. Nigeria spent 4% of its GDP (~ US$5B/year) importing refined petroleum products (RPP) for its transport sector between 2005 and 2009. In addition, an annual average food import of 3 million metric tonnes has existed for almost a decade.

To combat these energy and food insecurities, the Nigerian government plans to produce bioethanol from its major staple food (sugar and starch) crops in order to increase its transport fuel supply and ameliorate the negative impacts of the on-going import of motor fuel to its economy; given substantial uncultivated arable land, unemployed labour and suitable climatic and soil conditions. The dilemma between the apparent benefits of biofuels versus its potential impacts on food security needs to be analysed in order to articulate and implement a feasible ethanol policy.

This study develops and applies a sectoral Energy-Food Model (EFM) to: 1) analyse the supply capacity of the feedstock and food suppliers (the farmers in Nigeria) for ethanol; 2) estimate the bioethanol production potential in Nigeria; 3) identify the regional potential 'best' feedstock; and 4) assess the impacts of the potential feedstock and bioethanol demands and supplies on the national energy and food securities.

The programming model is based on farm production data from relevant national agencies and on Nigerian energy supply, food consumption, commodity export and import and commodity prices from international and national official databases such as EIA, FAOSTAT, IMF, World Bank, and Nigerian Bureau of Statistics databases.

Results show that Nigeria has the potential to produce sufficient feedstock and food crops required to meet the domestic ethanol and crop consumption requirements without reducing domestic food supply or increasing domestic commodity prices. Further, cassava is identified as the best feedstock for ethanol production in all the regions under current production and price conditions. Domestic ethanol production/supply to the local market for blending would generate and add a gross profit of US$2,725M per annum (including the potential co-products revenue) to national income. Also an annual production of 5.14 billion litres of ethanol from all the regions is feasible, and this can substitute 514 million litres of gasoline (4% of the annual average domestic RPP demand) at 10% ethanol blending, and save about US$36B per annum at US$70.33 per litre of the imported RPP. The changes in labour

and land use were substantial, but without associated increase in the prices of labour and land, reflecting existing un- and under-employment and stocks of uncultivated arable land. The impacts of ethanol production from the first generation feedstock on food supply and food prices are practically absent in a country with sufficient land and production resources.

Dedication

I dedicate this thesis to my late parents (Mr. and Mrs. Dick Agbai), especially my mum who saw the great potentials in me early enough and invested words of wisdom in me!

Acknowledgements

I am very grateful to my supervisors (Prof. David R. Harvey and Dr. Lionel Hubbard) for their immense and relentless support throughout my study. Their quick and insightful feedbacks expedited my research.

I also appreciate the Dr. Eric Ruto for his supports as my internal assessor during the annual students progression review while he was in Newcastle University.

I wish to appreciate Prof. Paul Wilson (Nottingham University) and Dr. Philip Dawnson (Newcastle University) for their interest, willingness and acceptance to be my external and internal examiners, respectively. I enjoyed every bit of your rigorous viva examination drill.

I also wish to acknowledge Prof. Bruce McCarl from the Department of Agricultural Economics, Texas A&M University, USA; for organising GAMS training course for us and reviewing my initial model formation.

I am also grateful to Mr. Maxwell Brown (a PhD Student and Research Assistant at Colorando School of Mines, USA) for his review and useful comments on the initial version of the model I developed and applied in this study.

I also wish to thank the former Head of School (Dr. Alan Younger), the AFRD Post-graduate Research Coordinator (Mr. John Gowing) and the administrative staff of AFRD (especially, Mr. Steve Hall, Mrs. Shell M. Wood and Mrs. Yvonne Turnbull) for their supports in procuring GAMS license for my study, assistance in travel arrangement and paying for my GAMS training course in the USA as well as for their financial supports for a conference in the USA and field trip in Nigeria. My postgraduate colleagues, with whom I shared my study experience, are also acknowledged.

I wish to express my profound gratitude to Nigerian government, through Petroleum Technology Development Fund (PTDF) for sponsoring this study.

Appreciation is also accorded to the heads and managements of these agencies (NBS, NNPC, NNPCRED, CBN, Ministry of Agriculture and Rural Development, state ADPs, Ministry of Works, Lands and Housing) for providing relevant data and information during my field trip in Nigeria. In particular, I wish to thank the following people: 1) the Head, Crop Production Unit Abia State Agricultural Development Programme (Mrs. Nnenna Uche) for the providing useful information about Nigerian cropping calendar and the cost of some farm operations; and the staff of NBS: Mr. Ugwu, Mr. Babalola, Mr. Ichedi and Mr. Leo for their supports in providing relevant statistical data on different areas. Mr. Ogba Chima (NNPC) is exceptionally appreciated for the various assistance he offered me during my data collection trip to Nigeria.

My special appreciation goes to my wife (Mrs. Chidinma Favour Ndukwe), children and siblings for their patience, understanding, prayers and unquantifiable supports throughout this study. Also the supports of my uncles (Mr. Okoroafor Agwu, Felix C. Okorie and late Mr. Peter Agwu) in laying the foundation of my education are highly recognised and appreciated. Further, the encouragements of my friends, prayers from my pastors and supports from brethren are deservedly appreciated.

Above all, I thank God Almighty, for keeping me alive and safe, granting me good health throughout my study period and giving me the inspiration and motivation that I need to successfully complete this study.

Ndukwe Agbai Dick

Acronyms

ADP	Agricultural Development Programme
AEZs	Agro-Ecological Zones
AFDC	Alternative Fuels Data Centre
AFRD	Agriculture, Food and Rural Development
AR	Assessment Report
ARCN	Agricultural Research Council of Nigeria
ARS	Agricultural Research Service
BR	Base-year Resources
Btu	British Thermal Unit
CBN	Central Bank of Nigeria
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CH_4	Methane
CHAC	Name of Mexican Sector Model
CF	Conventional Fermentation
CGE	Computable General Equilibrium
CIA	Central Intelligence Agency
CIF	Charges, Insurance and Freight
Cons.	Consumption
CO_2	Carbon Dioxide
CO_2SF	Carbon Dioxide Saving Factor
CPI	Consumer Price Indicator
D-20	Twenty Percent (20%) Bio-Diesel Blending with 80% Fossil Diesel
DCD	Domestic Consumption Demand
DCP	Domestic Crop Production
DDGS	Distillers' Dried Grains with Soluble
DED/DETD	Domestic Ethanol Demand
DP	Domestic Price
DPR	Department of Petroleum Resources
E-10 or E10	Ten Percent (10%) Ethanol Blending with 90% Gasoline
E-20 or E20	Twenty Percent (20%) Ethanol Blending with 80% Gasoline
EERE	Energy Efficiency and Renewable Energy
EFM	Energy-Food Model
EIA	US Energy Information Administration

EMSEX	Ethanol Minimum Selling Price for Export
EMSIM	Ethanol Minimum Selling Price for Import
EP	Ethanol Production
EPA	US Environmental Protection Agency
EPF	Ethanol Production Factor
EREV	Ethanol Revenue
ERS	Economic Research Service
ESMAP	Energy Sector Management Assistance Programme
ETB	Ethanol Blending
EU	European Union
EXD	Export Demand
EXP	Export Price
FAO	Food and Agricultural Organisation of the United Nations
FAOSTAT	Statistical Database of the Food and Agricultural Organisation of the United Nations
FEMARD	Federal Ministry of Agriculture and Rural Development
FOB	Free On Board
FoodandWaterWatch	Food and Water Watch Organisation
GAMS	General Algebraic Modelling System
GATT	General Agreement on Trade and Tariffs
GCE	Gran Conversion Efficiency
GDCGE	Global Dynamic Computable General Equilibrium
GDP	Gross Domestic Product
GFDS	Grain Feedstocks
GHGs	Greenhouse Gases
GL	Giga Litres (same as Billion (10^9) Litres)
GM	Gross Margin
GNI	Gross National Income
GTAP	Global Trade Analysis Project
GEM	General Equilibrium Model
$GtCO_2eq$	Gigatonnes of Carbon Dioxide Equivalent
HAPY	Name of Egyptian Sector Model
HFCs	Hydrofluorocarbons
IC	Input Cost
ICE	Internal Combustion Engine

ICS-Nigeria	Information and Communication Support for Agricultural Growth in Nigeria
IEA	International Energy Agency
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
IMF	International Monetary Fund
IMD	Import Supply
IMP	Import Price
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	The Inter Governmental Panel for Climate Change
IRR	Internal Rate of Return
LP	Linear Programming
LULUCF	Land Use, Land Use Change and Forestry
MAPD	Mean Absolute Percentage Deviation
MBtu	Million (10^6) British Thermal Unit
MC	Marginal Cost
MIP	Mixed Integer Programming
MMT	Million Metric Tonnes
MP	Mathematical Programming
MR	Marginal Revenue
MT	Metric Tonnes
N_2O	Nitrogen Oxide
NACR	National Calorific Requirement
NAERLS	National Agricultural Extension and Research Liaison Service
NBS	Nigerian Bureau of Statistics
NC	North Central
NE	North East
NEFM	Nigerian Energy-Food Model
NIFOR	Nigerian Institute for Oil-Palm Research
NIG	Nigeria
NLC	Nigerian Labour Congress
NLP	Non-Linear Programming
NNPC	Nigerian National Petroleum Cooperation
NNPCRED	Nigerian National Petroleum Cooperation Renewable Energy Division

NNPCSTAT	Statistical Database of the Nigerian National Petroleum Cooperation
NPC	National Population Commission
NPV	Net Present Value
NW	North West
OECD	Organisation for Economic Cooperation and Development
OC	Opportunity Cost
PAD	Percentage Absolute Deviation
PBP	Payback Period
PED	Price Elasticity of Demand
PEM	Partial Equilibrium Model
PFCs	Perfluorocarbons
PMP	Positive Mathematical Programming
PTDF	Petroleum Technology Development Fund
RE	Resource Endowment
RegTransC	Regional Transportation Cost
RES	Residues
RC	Resource Cost
R&D	Research and Development
RFA	Renewable Fuels Association
RHS	Right Hand Side
RPP	Refined Petroleum Products
RPPIMRS	Refined Petroleum Import Revenue Saving
RRR	Regional Resource Requirement
RTFO	Renewable Transport Fuel Obligation
ROI	Return on Investment
SE	South East
SF6	Sulphur Hexafluoride
SLSF	Simultaneous Liquefaction, Saccharification Fermentation
SPM	Summary for Policymakers
SS	South South
SSF	Simultaneous Saccharification and Fermentation
SW	South West
TASM	Turkish Agricultural Sector Model
TCI	Total Capital Investment
TPEC	Total Primary Energy Consumption

UN	United Nations
UNDP	United Nations Development Programme
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Convention on Climate Change
UNDF	Undefined
UNU	United Nations University
USA	United States of America
USDA	United States Department of Agriculture
USDA-ARS	Agricultural Research Service of the United States Department of Agriculture
USDA-ERS	Economic Research Service of the United States Department of Agriculture
VCG	Variable Cost of Production from Grains
VCR	Variable Cost of Production from Residues
WB	World Bank
WBSTAT	World Bank Statistical Database
UNSTAT	United Nations Statistical Database
WHO	World Health Organisation
WRT	With Respect To
WTO	World Trade Organisation

Table of Contents

Contents **Page**

List of Tables

List of Figures

Chapter 1. Background of the study

1. Introduction

Recently, development of alternative environmental-friendly sources of energy (renewable energy) has become a global concern, partly due to the emission of anthropogenic greenhouse gases (GHGs) such as CO_2 from the production and use of fossil fuels, and partly because of concerns about energy security. The Inter Governmental Panel for Climate Change (IPCC, 1992) has described GHG emissions, especially CO_2, as responsible for the increase in global temperature (global warming) from 0.3 to 0.6°C witnessed over the last 10 decades (Houghton et al., 1992, IPCC, 1993, and IPCC, 2001). A recent report - IPCC's Fourth Assessment Report (AR4), Summary for Policymakers (SPM), IPCC (2007, p. 3), reports that the global emissions (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) have increased by 70%, from 29 to 49 Gigatonnes of carbon dioxide equivalent ($GtCO_2eq$) between 1970 and 2004. In particular, CO_2 emissions have increased by 80% over the same period and by 28% from 1990 to 2004, accounting for 77% of the total anthropogenic GHG emissions in 2004. In addition, the report suggests that the growth in direct GHG emissions from the transport sector between 1970 and 2004 is the second highest (120%), coming after the energy supply (production) sector (145%), compared to growth in the industry (65%) and land use, land use change, and forestry (LULUCF) (26%). The GHG emissions evidence from the most recent IPCC's Assessment Report (the Fifth Assessment Report – AR5) (IPCC, 2014, p. 6) is stronger and raises more concern. According to the report, annual GHG emissions increased by 1.0 $GtCO_2eq$, representing 2.2% annual GHG emissions growth rate, from 2000 to 2010 against 0.4 $GtCO_2eq$ (1.3%) per annum from 1970 to 2000. In addition, CO_2 emission is reported to be accounting for 76% of the total anthropogenic GHG emissions in 2010 (49 $GtCO_2eq$), with annual fossil fuel-related CO_2 emissions reaching 32 $GtCO_2eq$ in 2010. The SPM indicates that the transport sector contributed 14% of the total CO_2 emissions in 2010 (37.2 $GtCO_2eq$) (IPCC, 2014, p. 8) and used 27% of the total global energy used in this period (IPCC, 2014, p. 22). The evidence that CO_2 emissions have increased significantly within a very short time (three years of the first assessment report) and are still increasing supports the broadly accepted scientific consensus that GHG emissions have a relationship with climate change. Global warming is believed to underlie at least some adverse climate effects such as droughts, floods and desertification, which are currently impoverishing the globe, especially the developing countries (IPCC, 2007). Tsunamis (except when caused by earthquakes) in Asia, hurricanes in North America, Cuba and Asia, and severe drought and desertification in Africa (Kenya, for example) are a few of the recent challenges illustrating the potential consequences of climate change.

In addition, energy security, relating to increasing dependency on imported energy supplies, especially in the context of consistent increase in the price of fossil fuel recorded in the recent past, has made great impact in securing public support for the global development of renewable energy. Fossil fuels are finite and non-renewable, which means that development of alternative sources of energy is a necessity, not an option.

Finally, socio-economic and developmental pressures to promote rural development and boost rural economies by creating rural jobs through linking agriculture to energy production are major drivers of renewable energy (specifically biofuels) development especially in developing countries.

In response, the Kyoto protocol prescribed biofuels such as bioethanol and biodiesel, made from biomass, as one of the renewable energy alternatives mitigating the adverse impacts of climate change and providing an alternative source of fuel and energy (UNFCCC, 1998). In fact, the SPM from the most recent IPCC's Assessment Report (AR5) (IPCC, 2014, p. 26) recognized the importance of bioenergy in achieving sustainable energy supply, and in reducing GHG emissions and mitigating against adverse climate change impacts by stating that "bioenergy can play a critical role for mitigation" even though several concerns about GHG emissions from land, food security, resource use competition (e.g. water), livelihoods and loss of biodiversity still remain.

Biofuels receive substantial attention as a substitute for fuel in the transport sector on a global scale, due to a combination of factors as listed above. In addition, biofuels offer the major current alternative energy source for the current infrastructure and physical capital dependent on the internal combustion engine. Other alternative energy sources require substantial re-investment or retro-fitting of existing transport systems. Efforts to develop biofuels have come in various forms, such as drafting, review and amendments of energy policy acts; and legislation on energy (ethanol) consumption market share targets. For example, the US Energy Policy Act of 2005, provides (among others) for 28.4 billion liters consumption of bioethanol by 2012 via its Renewable Fuels Standard. This target was further increased to 57 and 136 billion liters by 2012 and 2022, respectively in 2008 after the passing and signing into law the

Energy Independence and Security Act of 2007 (USA, 2005, Wong, 2007, Balat and Balat, 2009). In the same vein, the European Union (EU) via the biofuels directive (E.C., 2003) requires all member states to ensure that a minimum of 5.75% of the total consumed gasoline and diesel fuels by the transport industry come from biofuels by 2010. In 2008, EU further proposed a binding 10% share of bioethanol market share from the 20% renewable energy market target by 2020 (Balat and Balat, 2009). Other developmental measures include the mandatory policy directives (blending laws – EU member state directive, for example), subsidies (– PRACOOL in Brazil, Renewable Transport Fuel Obligation (RTFO) in UK, etc.), tax incentives such as tax refunds and tax holidays (as in China, India, Thialand, EU, etc.), market liberalization (free import and export duties as in China, India, Thialand, Philippines, etc.) and so on (see Berg, 2004, Ranola et al., 2009, Gnansounou, 2010, Qiu et al., 2010 for other forms of incentives and policy directives).

World bioethanol production and consumption is currently dominated by the USA and Brazil, accounting for 84% of the world´s production, with 50.3b and 23.7b litres (GL) respectively. Europe and China rank the 3rd and 4th largest bioethanol producers according to RFA (2013). The EU is leading global biodiesel production, with Germany as the major producer using rape seed, while Malaysia and Indonesia rank 2nd and 3rd respectively, using palm oil (RFA, 2008). Among developing countries, Brazil is leading bioethanol production using sugarcane as feedstock, with China following, using maize, wheat, sweet sorghum, sugarcane, sweet potatoes, and cassava. Others include India, Thialand, Indonesia, Colombia using a range of different feedstocks, as in China (RFA, 2008).

Currently, Nigeria, like other developing countries, is investing to become a bioethanol producer, even though she is the tenth largest crude oil exporter to the world market as of 2008 (EIA, 2011). The motivation to invest in renewable energy, specifically bioethanol and biodiesel production, is primarily to: (1) generate more energy that will help Nigeria meet her local energy needs and avoid becoming a net energy importer in future; (2) diversify her fossil oil-dependent economy and revitalize her agricultural sector by exploiting the link between agriculture and bioenergy, and (3) contribute to the global efforts to reduce GHG emissions (CO_2) and possibly accumulate carbon credit points for investing in and implementing clean development mechanisms.

1.2 Statement of Problem

Nigeria faces the challenges of providing enough energy both for reliable electricity supply and other uses, and also reducing poverty and providing sufficient food for her citizens. Renewable and sustainable energy alternatives (e.g., biofuels) which have been recognized (Onwuka, 1984, Nwachukwu and Lewis, 1986, and Ikeme, 2001) as having the potential of increasing Nigerian total energy production and consumption are presently not in the Nigerian energy equation (except for the inadequate hydropower generation and unsustainable traditional wood fuel consumption). The current director of the Nigerian Energy Commission (Sambo, 2009) acknowledged that the Nigerian energy sector needs urgent attention in terms of infrastructural development and investment as well as diversification into renewable energy alternatives especially bio-energy (biofuel – ethanol and diesel) in order to supplement the current energy production and meet Nigerian energy needs.

In addition, the Nigerian government spends a substantial amount of the total national revenue for the importation of refined petroleum products (RPP) due to the fact that some of the existing refineries are not functional while the functional ones are under-performing because of a lack of proper maintenance (NNPC, 2011). NNPC (2011) shows that the Nigerian government spent an average sum of US$4.8 billion per year between 2005 and 2009 and imported an average quantity of 6.5 million metric tonnes of RPP per year over this period. This petroleum import expenditure represents about 4% of the yearly nominal GDP over this period. Nonetheless, the Nigerian energy profile from EIA (2011) further highlights that Nigeria has the largest proven natural gas reserve in Africa (185 trillion cubic feet as at January, 2010), ranking her as the 8^{th} natural gas reserve holder in the world; yet Nigeria imports refined petroleum products and her per capita total primary energy consumption has remained very low. A further and more detailed analysis of Nigerian energy and food security situation is provided in Sections 2.1.1 and 2.1.2 below.

ESMAP (2005) states that energy security is a priority for most countries (Walter et al., 2007), since it occupies the centre piece for national economic development and growth as well as infrastructural development. Nigeria's population (about 175 million people, with a current growth rate of 1.97 (World Factbook, 2013)) alone suggests the real need to address these problems urgently, despite the major fossil fuel reserves. Of course, the present Nigerian population figure and its growth rate translate into an increasing pressure on the national resources (e.g. utilization of fossil oil reserves), infrastructures and utilities (energy for example).

Furthermore, the United Nations (UN) member countries, including Nigeria, agreed in 2001 to achieve the Millennium Development Goals by 2015, while the IPCC has called for pragmatic global cooperation and compliance in efforts to reduce GHGs and mitigate adverse climate change effects which are likely to affect developing nations, especially Africa more substantially than the current developed world (UNDP, 2001, IPCC, 1990, 92, 95, 01 and 07). The United Nations Foundation (UNCTAD, 2006), through its Biofuels Initiative, launched in June 2005 to promote the sustainable production and use of biofuels in developing countries, states that "biofuels have the potential to alleviate poverty, create sustainable rural development opportunities, reduce reliance on imported oil, and increase access to modern energy services".

The agricultural sector and food security situation in Nigeria indicates the need to tackle the fundamental problems (energy and food security) of the nation. This research aims to make a significant contribution to evidenced-based policies that can help alleviate these energy and food security problems. Historically, agriculture was the most important sector to the Nigerian economy (Babatunde and Oyatoye, 2005, Abdulkadri and Ajibefun, 1998). However, agriculture becomes less prominent following the discovery and first large scale production of oil in 1958 and 1960 respectively (NNPC, 2011). Nigerian agriculture suffered and is still suffering neglect and abandonment since the discovery and exploitation of oil. The oil boom led to a mass exodus of farmers and farm workers from the rural areas and villages to the townships/cities in search of well-paid white collar jobs (greener pastures) and this resulted to the decline in agricultural share of the total labour force and GDP. Although agriculture still makes a significant contribution to the Nigerian GDP compared to other sectors (NBS, 2009), its present contribution is less than that of the early 1960s. Also a comparison with other primary sectors such as education, health, and defense in terms of government's budget allocation and share in total budget allocation suggests that agriculture has been and is still being neglected.

In terms of food security, previous studies (Akinyele, 2009, NBS, 2008, Okolo, 2004, Nwajiuba, 2000) reveal that food supply (production) in Nigeria has fallen short of the demand (consumption) for many years. For instance, food deficit (food supply (production) minus food demand (consumption)) grew yearly by 3.3% on the average from 1994 to 2001 (Okolo, 2004). Available data show that Nigeria spent an average sum of ₦100 billion (approximately $660 million at the exchange rate of $1 = ₦152.25) per year, importing an average quantity of 3.3 million metric tonnes of food to make up for the domestic 'food deficit' from 1994 to 2001 (Okolo, 2004). This food import expenditure represents 19% of the total national expenditures over this period. The food security problem is not only related to food availability and affordability but also in terms of providing the nutritional requirements of the citizens. Nutritional requirement of the citizens means the ability of the citizens to obtain their daily per capita FAO/WHO calorie requirement of 2,360 kcal (assuming a man with a weight of 70 kg (FAO/WHO, 2002)) from the food they eat. This nutrition requirement figure (referred to as "national average apparent food consumption" by FAO/WHO expert Consultative Committee) translates to a national food consumption requirement of 1.30*10^14 kcal per annum assuming a population of 151 million Nigerians. Analysis of the available data from NBS (2008) based on eleven (11) major staple foods in Nigeria shows that the current national crop production output (in metric tonnes) is greater than the total metric tonnes equivalence of staple food crops required to satisfy the national annual calorific requirement, thus suggesting that Nigeria might not be food insecure in this perspective. Nevertheless, Nigeria's food security problem in terms of food consumption deficit (i.e. national food consumption being greater than national food production) is well-established to have been existing for a long time.

In response to these energy and food security challenges, attempts are being made to address these problems. In 2005, the Nigerian government through the Nigerian National Petroleum Corporation (NNPC) created a department known as Nigerian National Petroleum Corporation Renewable Energy Development (NNPCRED) and mandated it to investigate and advise the government on the possibility of generating biofuels, particularly bioethanol and biodiesel, from local resources. NNPCRED preliminary investigation identified sugar and starchy crops: maize, rice, sorghum, wheat, millet, sugarcane, and cassava; and their residues as well as oil crops (e.g. oil palm) as potential biofuel (bioethanol and bio-diesel) feedstocks in Nigeria based on the climatic and soil conditions favouring their production in different regions (and states) of the nation. Subsequently, six national biofuel pilot projects were proposed in six different regions: North East (NE), North West (NW), North Central (NC), South West (SW), South East and South South (SS), based on feedstock or crop-input production comparative advantage in each region (NNPCRED, 2007).

Nevertheless, an underlying important question needs to be answered for a sound ethanol policy to be drafted, implemented and for the perceived accruable benefits of the project to be realized. "How can Nigeria produce biofuel from (or in competition with) her major staple food crops amidst a long history of established food insecurity in the country"?

Ikeme (2001) and NNPCRED (2005) have predicted some potential benefits (such as creation of jobs, diversification of economy, revitalization of agriculture, community development) that Nigeria will reap by investing in renewable energy (bioethanol, biodiesel and others).

However nothing has been said about the particular ("best") feedstock (energy crop) or the actual feedstock combination(s) that will or should be used to optimize bioethanol production in order to reap these benefits. In addition, adequate research information on how the feedstock should be cultivated amidst our world of scarce resources and limited availability of land and funds is lacking. In fact, information on the profitability of feedstock production which will be very valuable to the farmers is missing. Information of this kind will be necessary if private investors and farmers are to be motivated to invest in the cultivation of feedstocks. At the same time, this information will give insight of what type of feedstock to produce, how to produce it in a cost-effective manner and how much of it is to be produced in order to maximize profit which is one of the underlying targets of every producer or investor, including farmers. On the other hand, the thought of using the nation's major staple food materials for energy purposes (biofuel production) raises a big question and aggressive debate in the context of food insecurity and malnutrition problems that have existed for some time in Nigeria. Therefore, there is a clear need for analysis of crop production and resource use strategies that can help resolve this energy-food dilemma. This study - "Analysis of biofuel potential in Nigeria" - aims to meet these needs.

1.3 Study Objectives

The major objective of this research is to develop and apply a sectoral Energy-Food Model (EFM) for the production of biofuel feedstocks and staple food crops in six different regions of Nigeria, in order to assess how biofuel production can contribute to energy and food securities in Nigeria. Specifically, this study intends to answer the following research questions:

a. Is it technically feasible and economically sensible for Nigeria to achieve "self sufficiency" in both energy and food, given the available production resources?
b. What is the potential biofuel (bioethanol) production in Nigeria from the local feedstocks and their residues?
c. Which feedstock(s) is/are the best for bioethanol production in each region?

d. How much foreign exchange could Nigeria save from the biofuel produced from these feedstocks per annum, based on the current refined petroleum products (RPPs) import expenses?
e. What are the potential impacts of the feedstock and bioethanol demands and supplies on the national energy and food securities?
f. What policy implications and/or recommendations does this research offer in terms national development?

1.4 Study Hypotheses

The following hypotheses shall be tested in the course of this study:

a. Biofuel production potential in Nigeria is significant.
b. It is technically feasible to achieve energy and food security (self sufficiency) in Nigeria via feedstocks and biofuel production
c. It makes economic sense for Nigeria to embark on biofuel production given available resources.

1.5 Justification/ Significance of the Study

Adequate and informed planning is necessary for the success of the biofuel projects and the realization of its objectives and benefits. However, in Nigeria, there exists little or no research on how the feedstocks (which is the starting point of biofuel development) can be produced profitably by local farmers using available resources, despite the perceived accruable benefits of investing in biofuel development. In addition, existing research (Ikeme, 2001, NNPCRED, 2005, Sambo, 2009) has not identified which feedstock or combination of feedstocks offer the greatest potential. Existing research has also failed to analyze the profitability of biofuel production, while the Nigerian government has done little to promote and stimulate more research and capacity development in the field of agro-energy (bio-energy) development.

This study: "Analysis of biofuel potential in Nigeria"; aims to fill these gaps.

It will add to the renewable energy development knowledge, at least in the study area; and possibly stimulate government action in funding research on the use of biomass for biofuel production; while benefiting policy formulation.

1.6 Thesis Structure

This thesis is organized into six chapters. Chapter one deals with the background of the study, covering the global motivation and/or rationale for renewable (bioenergy) energy development, statement of problem, study objectives and justification of the study. Chapter two provides a review of the Nigerian energy consumption situation, the Nigerian agricultural sector, discussing Nigerian food security status as well as the agro-ecological zones of Nigeria with emphasis on its role in food production across the six administrative regions of Nigeria. Further, it discusses briefly the history of biofuels and the global debate on biofuels' impact (both positives and negatives) in addition to the status of bioethanol development in Nigeria. It also highlights some existing studies on bioethanol feedstocks and the theoretical framework surrounding the analytical model employed in this study and finally concludes with a review of mathematical programming (MP) models as a sectoral modelling tool, with some illustrations of programming models used for policy analysis in previous studies. Chapter three describes the specific research methodologies employed in this study, while Chapter four presents and discusses the results from the developed and applied analytical model for this study. Scenarios and sensitivity analyses of the study are laid out in Chapter five. Finally, some important study conclusions, recommendation and suggestions for future research are offered in Chapter six.

Chapter 2. Literature Review and Theoretical Framework

This chapter offers an overview of some important issues on energy and food security in Nigeria, which are very important to the broader contextual understanding of this study. Specifically, the review of current energy and food security in Nigeria is presented in Section 2.1. In addition, the global debate on biofuels and the Nigerian biofuel development status are discussed in this section. Section 2.2 highlights the theoretical framework for the analytical model chosen for this study, while Section 2.3 considers mathematical programming (MP) as a sectoral modelling tool. Finally, some programming models used in policy analysis previously are discussed in Section 2.4.

2.1 Literature Review

2.1.1 Review and Analysis of Energy Security Situation in Nigeria

Energy consumption data (Table 2.1), adapted from the US Energy Information Administration database (EIA, 2011) and UN Food and Agriculture Organization (FAO, 2005, 2010) reveal that Nigeria has consumed less energy than South Africa from 2005 to 2010. Table 2.1 further indicates that the Nigeria's total primary energy consumption (TPEC) shows a declining annual energy consumption trend unlike other neighbouring West African countries (Ghana and Ivory Coast) that have little or no oil and gas resources and gained their independence at almost the same time as Nigeria. Table 2.1 shows that the TPEC consumption trend of these countries with respect to (WRT) their 2005 figures are consistently increasing while that of Nigeria is decreasing. The annual average percentage decrease in the Nigerian TPEC between 2008 and 2010, relative to its 2005 value, is substantial (15%) given the importance of energy to every economy, and therefore underscores the real energy insecurity challenge in Nigeria. Conversely, Ghana's change in TPEC from 2008 to 2010, relative to its 2005 level, shows a significant annual increase by 51%. Further, Figure 2.1 indicates that Nigeria has a lower per capita total primary energy consumption (9 MBtu) as at 2010 compared to Ghana (23 MBtu) and South Africa (115 MBtu) who are poorer in terms of oil and gas resources endowment. The figure further also shows that Ivory Coast had a higher per capita total energy consumption compared to Nigeria (12 MBtu as at 2010), despite the fact that Nigeria is Africa's primary oil producer and has the second largest oil reserves in Africa (36.22 billion barrels, following after Lybia with 41.46 billion barrels as at 2008), ranks 15th in world crude oil production, 10th in crude oil net exports to the world market (EIA, 2011) as noted earlier; and therefore earns much more foreign exchange revenue from oil and gas than the above named African countries. NNPC (2011) further shows that the annual expenditure for the importation of refined petroleum products (RPP) relative the 2005 import expenditure increased by an average of 47% between 2008 and 2010 while the quantity of RPP imported increased 5% over the same period (see Table 2.2). Table 2.2 also indicates that the quantity of RPP imported per annum increased from 2005 to 2009 except in 2008, where it decreased probably due to the negative effects of global economic crises which affected commodity demands and prices, including oil. However, the import expense for the RPP increased from 2005 to 2009 without the expected resultant decrease in 2008 since the quantity imported declined in 2008. From Table 2.2, the annual average percentage increase in the quantity of RPP imported between 2008 and 2010 is negligible while the annual average percentage increase in the import expenses over the same period is 3% -suggesting an increasing inflation rate over this period or increase in the cost of importing the RPP. The annual average RPP import from 2008 to 2010 from Table 2.2 is about 6.4 MMT, equivalent to 345,262 litres[1]; and this corresponds with the Nigerian RPP import figure from EIA (344,982 litres). However, a wide discrepancy exists between the Nigerian total RPP consumption figure (i.e. sum of the petroleum, gas and biofuels consumptions) from EIA and that from the Nigerian National Petroleum Cooperation statistics (NNPCSTAT). Table 2.3b from NNPCSTAT (2011) shows that Nigeria consumed an average of 13,322 million litres per annum from 2008 to 2010, which yields an equivalence of 12,314 quadrillion (10^15) Btu[2] per annum; whereas the Nigerian total energy consumption from petroleum, gas and biofuels (including the annual imported RPP) from EIA as reflected in Table 2.3a indicates that Nigeria consumed an equivalence average of 1.15 million litres per annum (equivalent to 1.1 quadrillion Btu) within the same period. For the purpose of this review, EIA's TPEC is utilized since it has the advantage of showing the comprehensive energy sources in Nigeria. However, to quantify the total domestic RPP demand (consumption) employed in the Nigerian Energy-Food Model developed and applied in this study, NNPC domestic RPP consumption data are preferred and utilized as it is the basis for which

[1] 1 MT of RPP is equivalent to 8.53 barrels of oil, whereas 1 barrel of oil is equivalent to 0.0063 litres; for details on the conversion units, see the following links:
http://www.eia.gov/cfapps/ipdbproject/docs/unitswithpetro.cfm
http://bioenergy.ornl.gov/papers/misc/energy_conv.html

[2] To convert 1 litre to 1 barrel, the given litre is multiplied by 158.9825 since 1 barrel of oil is equivalent to 0.0063 litres; while a million barrel of oil is multiplied by 0.005814 in order to convert to quadrillion Btu since 172 million barrels is equivalent to 1 quadrillion Btu (see the above websites for further details).

NNPCRED estimated the potential bioethanol market demand in Nigeria (see NNPCRED (2007, p. 6) and Ohimain (2010, p. 7162) for details).

Table 2.1, Total Primary Energy Consumption for Nigeria, South Africa, Ghana and Ivory Coast (in Quadrillion Btu); source: compiled from country data, FAO forest product and EIA databases.

Country/year	2005	2006	2007	2008	2009	2010	Annual Ave from 2008 to 2010
Nigeria TPEC	1.70	1.66	1.62	1.67	1.31	1.37	1.45
Annual % change in consumption	0	-3	-2	3	-21	4	-5
Annual % change in consumption WRT 2005 values	0	-3	-5	-2	-23	-19	-15
South Africa TPEC	5.24	5.41	5.54	5.93	5.75	5.71	5.80
Annual % change in consumption	0	3	2	7	-3	-1	1
Annual % change in consumption WRT 2005 values	0	3	6	13	10	9	11
Ghana TPEC	0.36	0.49	0.48	0.51	0.54	0.58	0.54
Annual % change in consumption	0	35	-1	6	7	6	6
Annual % change in consumption WRT 2005 values	0	35	34	41	51	61	51
Ivory Coast TPEC	0.20	0.20	0.21	0.22	0.22	0.21	0.22
Annual % change in consumption	0	1	3	7	-2	-3	1
Annual % change in cons. WRT 2005 values	0	1	4	11	9	6	9

Figure 2.1, Per Capita Total Primary Energy Consumption in 2010, adapted from Table 1 and World Bank Population data from http://data.worldbank.org/indicator/SP.POP.TOTL/countries?display=default

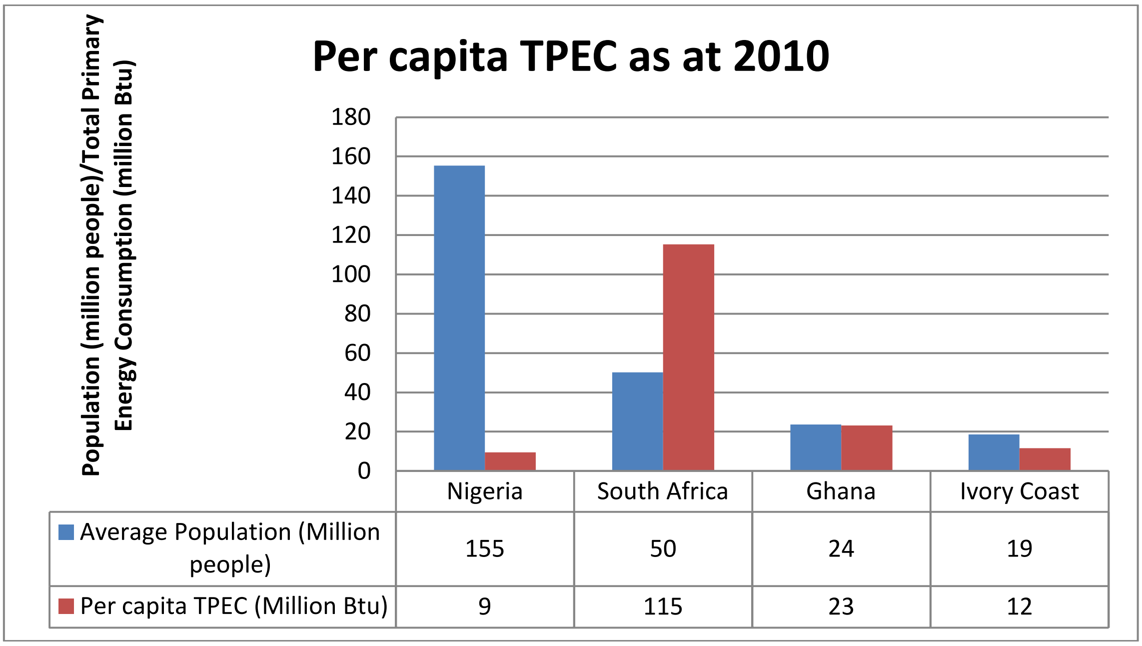


Table 2.2, NNPC Refined Petroleum Products (RPP) Import Statistics (2005 – 2010), Source: NNPC Oil and Gas Annual Statistics Bulletin, accessed from: http://www.nnpcgroup.com/PublicRelations/OilandGasStatistics/AnnualStatisticsBulletin/MonthlyPerformance.aspx

Item/Year	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	Annual Ave from 2008 to 2010
Quantity imported (MMT)	6.15	6.58	7.13	5.51	7.16	6.64	6.43
Annual % change in RPP import	0	7	8	-23	30	-7	0
Annual % change in quantity imported WRT 2005 figure	0	7	16	-11	16	8	5
Import value (USDM)	3,626	4,497	5,111	5,661	4,841	5,454	5,319
Annual % change in RPP import expenses	0	24	14	11	-14	13	3
Annual % change in quantity imported WRT 2005 value	0	24	41	56	34	50	47

Table 2.3a, Nigerian TPEC (in Quadrillion Btu) by Energy Sources, from 2005 to 2010; source: extracted and modified from country data, FAO forest product and EIA databases.

Energy Sources	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	Annual Ave from 2008 to 2010
Petroleum Consumption	0.6311	0.5744	0.5434	0.5709	0.4827	0.4866	0.5134
% contribution to TPEC	36	33	32	32	32	34	33
Natural Gas Consumption	0.3831	0.4038	0.3919	0.4539	0.2668	0.1812	0.3006
% contribution to TPEC	22	24	23	26	18	13	19
Coal Consumption	0.0002	0.0002	0.0006	0.0008	0.0009	0.0010	0.0009
% contribution to TPEC	0	0	0	0	0	0	0
Electricity Consumption	0.0578	0.0507	0.0657	0.0619	0.0603	0.0695	0.0639
% contribution to TPEC	3	3	4	3	4	5	4
Renewable (Hydro) Net Electricity Cons.	0.0769	0.0615	0.0609	0.0558	0.0438	0.0616	0.0537
% contribution to TPEC	4	4	4	3	3	4	3
Current Biofuels Consumption	0	0	0.0006	0.0006	0	0	0.0002
% contribution to TPEC	0	0	0	0	0	0	0
Wood Fuel+ Charcoal Cons.	0.6224	0.6260	0.6297	0.6337	0.6378	0.6421	0.6379
% contribution to TPEC	35	36	37	36	43	45	41
TPEC (Quadrillion Btu)	**1.77**	**1.72**	**1.69**	**1.78**	**1.49**	**1.44**	

Table 2.3b, Domestic Refined Petroleum Products (RPP) Consumption, adapted from NNPC Oil and Gas Annual Statistics Bulletin, accessed on from: http://www.nnpcgroup.com/PublicRelations/OilandGasStatistics/AnnualStatisticsBulletin/MonthlyPerformance.aspx

Year	NNPC RPP consumption in million litres
2005	13,215
2006	11,625
2007	11,402
2008	13,714
2009	12,501
2010	13,751
2011	13,211
2012	13,084
Average RPP Consumption from 2008 to 2010	**13,322**
Average RPP Consumption from 2010 to 2012	**13,349**

From Table 2.3a, energy consumption from the traditional biomass resource (wood fuel + charcoal) made the greatest contribution to the TPEC from 2005 to 2010, supplying an average of 0.64 quadrillion (10^{15}) British Thermal Unit (Btu) per annum from 2008 to 2010. This represents 41% of the annual TPEC between 2008 and 2010; thus, justifying previous studies' (Nwachukwu and Lewis, 1986, and Sambo, 2009) findings that the majority of Nigerian energy consumption comes from wood fuel. Following wood fuel in a descending order of contribution magnitude are: energy consumption from petroleum; natural gas; electricity; and coal. As shown in Table 2.3a, energy from biofuels consumption currently accounts for the least share of the TPEC. Further, Sambo (2009) observes that the Nigerian energy sector needs an urgent attention in terms of infrastructural development and investment as well as diversification into renewable energy alternatives especially bio-energy (biofuel – ethanol and diesel) in order to supplement the current energy production and meet Nigerian energy needs. The foregoing arguments clearly support the Nigerian energy consumption data (Table 2.3a), buttressing the fact that an urgent and alternative energy solution needs to be sought for in order to boost Nigerian energy supply and substantially reduce wood fuel as a major energy supplier in Nigeria, if deforestation and desertification and their consequent adverse effects must be averted.

In terms of economic impact, fossil oil accounts for about 80% and 90% of the Nigerian economy (total national income) and the total exports respectively, yielding about 95% of the total foreign exchange revenue of the country (Ikeme, 2001). An earlier study from Onwuka (1984) reports that only about 10% of the oil produced in Nigeria that is utilized in the country, while the rest (90%) goes for export. In addition, Nwachukwu and Lewis (1986) remark that over 90% of the country's foreign exchange earnings comes from oil and gas exports. Also available GDP data from NBS (2010a) corroborate the findings of previous studies that the oil and gas sector is contributing more to Nigerian economy than any other sector (see Tables 2.4 and 2.5). However, it is necessary to remark that while the positive contribution of the oil and gas sector to the Nigerian economy is desirable, it also highlights the over-dependence of Nigerian economy on oil and gas and the need for investments in other sectors in order to diversify the economy.

2.1.2 Review of Agricultural Sector and Food Security Situation in Nigeria

A review of the agricultural sector and food security situation in Nigeria is necessary to illustrate clearly the fundamental problems (energy and food security). Historically, agriculture has been one of the most important sectors in Nigerian economy. It employed about 71% of the country's labour force as at 1960 and its contribution the gross domestic product (GDP) averaged 56% from 1960 to 1969 (Abdulkadri and Ajibefun, 1998). Adegboye (2004) reports that agriculture accounted for more than 70% of the non-oil exports and provided more than 80% of the food needs of the country even up to late 1950s (Babatunde and Oyatoye, 2005). Helleiner (1996) opines that food production in Nigeria was at a self-sufficient level despite being subsistence between 1950 and 1960 (Babatunde and Oyatoye, 2005). However, agriculture becomes less prominent after the discovery and first large scale production of fossil oil in 1958 and 1960 respectively (Encyclopedia, 2011, NNPC, 2011, and Metz, 1991). The agricultural share to the total labour force reduced to about 55% in 1979 and further to about 52% in 1985, while its contributions to the GDP declined to about 24% on the average between the period of 1970 and 1979 and varied between 21% and 23% from 1980 to 1985 (Abdulkadri and Ajibefun, 1998). Nevertheless, more recent data from NBS (2008) show that the contribution of agriculture (crop farming) to the total labour force in Nigeria grew from 75% to 92% between 1995 and 2006 (based on 2010 total labour force figure – 48.33 million people reported in World Factbook, (2011)). In addition, agriculture is reported to have employed more than 70% of the total Nigerian workforce in 2010 (UNSTAT, 2011, WBSTAT, 2011, and World Factbook, 2011). On the contribution of agriculture to the national GDP, NBS (2008) show that the percentage contributions of agriculture to the national gross domestic product (GDP) (though decreased from 45% to 33% between 2003 and 2007) is still higher than that of the manufacturing sector which decreased from 6% to 3% within the same period. The current low per capita energy consumption in Nigeria might well be associated with the low industrial and manufacturing sector development in Nigeria, which in turn is resulting to the meager contributions of this sector to the national economy in comparison with agriculture. Recent studies, (NBS, 2009, NBS, 2010a) show that crude oil and gas has contributed more, in real terms, to the national GDP from 2003 to 2007 compared to agriculture, which in turn has contributed more than other sectors (see Tables 2.4 and 2.5)[3]. Although, the recent employment data indicate an increasing agricultural share to the total labour force in Nigeria, they tend to illustrate the fact that agriculture still has the potential to regain its pre-oil era pivotal role to the Nigerian economy if proper attention is given to the sector in terms of policy, research, investment, and management.

GDP deflators used in Table 2.4 are as given in the Key below:

Key for Table 2.4; source: World Bank Development Indicator (WDI, 2011), accessed from: http://data.worldbank.org/country/nigeria?display=default

Year	2003	2004	2005	2006	2007
GDP deflator	111.2	134.3	160.8	192.2	201.5

[3] The sudden jump in the 2007 mining and quarrying sector data in Table 2.4 suggests probably an inconsistency, possibly a typographical error during data entry, although this cannot be verified nor explained by the researcher since the data is from a secondary source. Also note that the World Bank GDP deflator for year 2002 is 100, implying that 2002 is the base year.

Table 2.4, Nigerian Gross Domestic Product (₦M) by Sector at Current and Constant Basic Prices from 2003 to 2007, Source: NBS, (2009, 2010a)

Sector	**Real GDP$_i$ = Nominal$_i$ GDP/(GDP deflator$_i$/100), i = respective year value from 2003 to 2007, GDP deflator$_i$ = World Bank GDP deflator estimates for Nigeria**									
	2003 Nominal GDP	2003 Real GDP with 2002 as base year	2004 Nominal GDP	2004 Real GDP with 2002 as base year	2005 Nominal GDP	2005 Real GDP with 2002 as base year	2006 Nominal GDP	2006 Real GDP with 2002 as base year	2007 Nominal GDP	2007 Real GDP with 2002 as base year
Agriculture	3,231,444	2,906,091	3,909,759	2,912,432	4,773,198	2,968,938	5,794,306	3,014,486	6,757,868	3,354,449
Mining And Quarrying	9,970	8,966	13,038	9,712	17,286	10,752	23,631	12,294	7,564,497	3,754,841
Crude Petroleum & Natural Gas	4,113,905	3,699,704	4,247,716	3,164,181	5,664,883	3,523,567	6,702,123	3,486,778	7,929,282	3,935,912
Manufacturing	444,209	399,484	321,382	239,402	375,167	233,355	501,189	260,744	520,883	258,554
Public Utility	23,589	21,214	26,830	19,986	29,387	18,279	31,641	16,461	268,422	133,238
Building & Construction	118,558	106,621	166,078	123,714	215,786	134,219	271,535	141,266	266,464	132,267
Transportation	214,375	192,791	348,839	259,855	366,878	228,199	464,017	241,405	473,445	235,007
Telecom	16,064	14,447	20,454	15,237	38,194	23,757	69,585	36,202	246,226	122,221
Wholesale And Retail Trade	1,094,638	984,426	1,484,422	1,105,766	1,868,251	1,162,056	2,495,751	1,298,414	3,044,774	1,511,355
Hotel And Restaurants	26,835	24,133	35,250	26,258	46,080	28,662	56,778	29,538	72,839	36,156
Finance and Insurance	81,081	72,917	102,953	76,691	130,749	81,326	165,980	86,351	340,908	169,219
Real Estate and Business	395,347	355,542	164,280	122,374	828,026	515,034	942,001	490,076	925,594	459,444
Community, Social and Personal Services	78,693	70,769	99,835	74,368	126,267	78,538	159,704	83,086	204,615	101,566
Producers of Government Services	25,736	23,145	28,827	21,474	32,865	20,442	37,468	19,493	193,425	96,012
Total (GDP)	**9,874,444**	**8,880,252**	**10,969,664**	**8,171,450**	**14,513,020**	**9,027,124**	**17,715,708**	**9,216,592**	**28,809,243**	**14,300,242**

Table 2.5, percentage contribution of the economic sectors to Nigerian GDP from 2003 to 2007 (calculated from Table 4).

Economic Sector	% sector contribution to real GDP in 2003	% sector contribution to real GDP in 2004	% sector contribution to real GDP in 2005	% sector contribution to real GDP in 2006	% sector contribution to real GDP in 2007
Agriculture	32.7	35.6	32.9	32.7	23.5
Mining & Quarrying	0.1	0.1	0.1	0.1	26.3
Crude Petroleum & Natural Gas	41.7	38.7	39.0	37.8	27.5
Manufacturing	4.5	2.9	2.6	2.8	1.8
Public Utility	0.2	0.2	0.2	0.2	0.9
Building & Construction	1.2	1.5	1.5	1.5	0.9
Transportation	2.2	3.2	2.5	2.6	1.6
Telecommunication	0.2	0.2	0.3	0.4	0.9
Wholesale & Retail Trade	11.1	13.5	12.9	14.1	10.6
Hotel & Restaurants	0.3	0.3	0.3	0.3	0.3
Finance & Insurance	0.8	0.9	0.9	0.9	1.2
Real Estate & Business	4.0	1.5	5.7	5.3	3.2
Community, Social and Personal Services	0.8	0.9	0.9	0.9	0.7
Producers of Government Services	0.3	0.3	0.2	0.2	0.7
Total	100.0	100.0	100.0	100.0	100.0

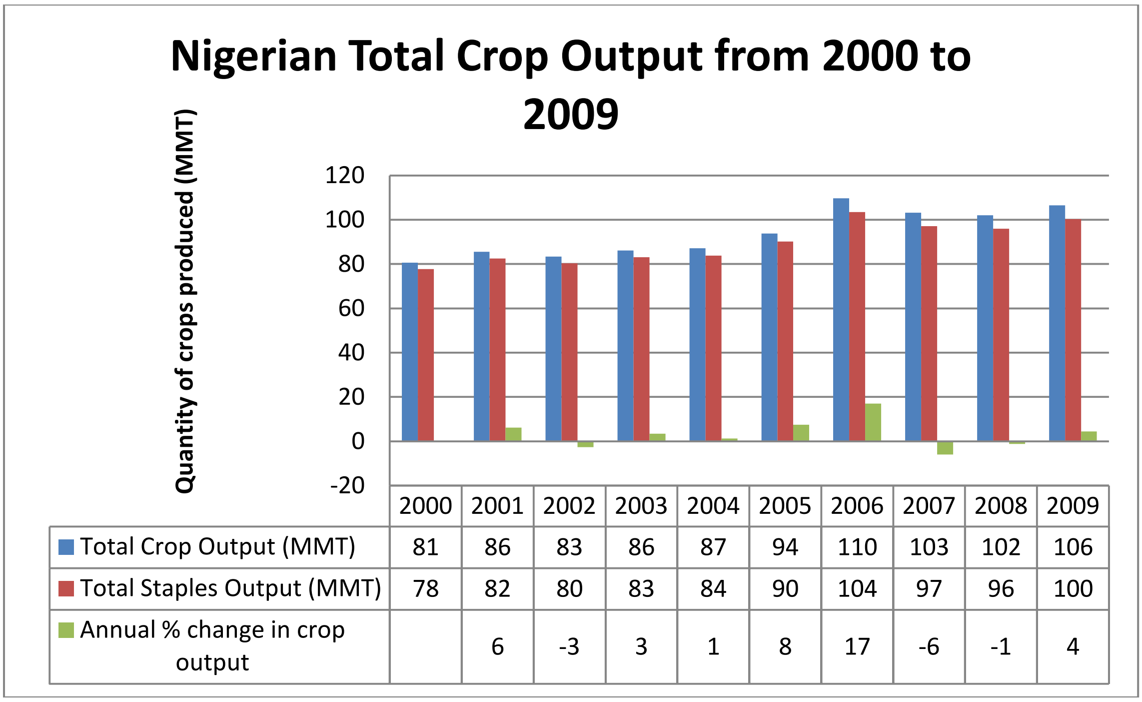
Although recent studies (e.g. NBS, 2009) show that agriculture still makes a significant contribution to the nation’s GDP, its present contribution has declined compared to that of the early 1960s.

As remarked earlier, previous studies (Akinyele, 2009, Okolo, 2004, NBS, 2009, Nwajiuba, 2000) reveal that food supply (production) in Nigeria has fallen short of the demand (consumption) for many years. For instance, food supply fell short of food demand from 1994 to 2001, resulting into a yearly average food deficit of 3.3 million metric tonnes (Okolo, 2004; see also Table 2.6). These food deficits were supplemented through food imports which cost on average a sum of ₦100.4 billion per annum ($659.4 million) for 3.30 million metric tonnes (MMT) equivalent of average imported food within this period (Okolo 2004). Analysis of the data provided by Okolo (2004) – Table 2.6, shows that food production and consumption (on the average) grew yearly by 2.3% and 3.0% respectively over this period (1994 – 2001) while food deficit and food import values grew yearly on the average by 3.3% and 65.9% respectively over this same period. However, analysis of the recent Nigerian crop production data from 2000 to 2009 (Figure 2.2) suggests that total crop output grew on average by 3% over this period and by 9% from 2004 to 2006, but declined by 1% between 2007 and 2009. Similarly, the harvested land area (Figure 2.3) indicated an average growth rate of 4% from 2000 to 2009, 9% from 2004 to 2006 and 1% between 2007 and 2009. Note that crop production data for potato, plantain and wheat were obtained from FAOSTAT as they were not available from the national (NBS) crop production data. In addition, potato and sweet potato data are combined for simplification purpose.

Table 2.6, Food Security Situation in Nigeria from 1994 to 2001 (adapted from Okolo, 2004)

Year	Food consumed (demanded) in million metric tons	Food produced (supplied) in million metric tons	Food gap (deficit/surplus) in Million Metric tons (MMT)	Food imports in Billion Naira	Average food import cost per MT (MT/Billion Naira)
1994	86.7	87.2	-0.5	16.8	100.4/3.3 = 30.5
1995	89.3	89.6	-0.3	88.3	
1996	93.4	96.3	-2.9	76.0	
1997	95.6	99.1	-3.4	100.6	
1998	98.7	101.9	-3.1	102.2	
1999	100.4	104.6	-4.2	103.5	
2000	102.1	107.5	-5.3	120.1	
2001	103.9	110.4	-6.5	195.8	
Total	**796.4**	**770.1**	**-26.5**	**803.2**	
Average	**99.6**	**96.3**	**-3.3**	**100.4**	

Figure 2.2, Nigerian Crop Production (Output) Trend, adapted from NBS (2010b) and FAOSTAT: http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor

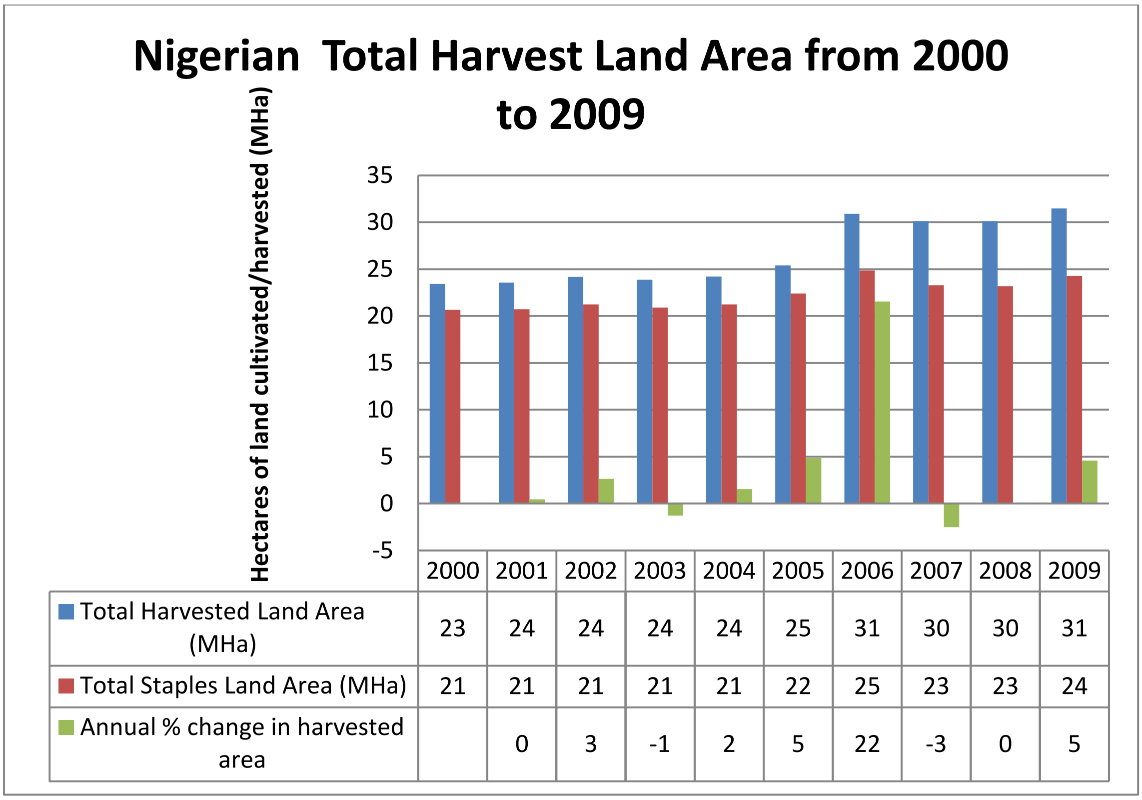


	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total Crop Output (MMT)	81	86	83	86	87	94	110	103	102	106
Total Staples Output (MMT)	78	82	80	83	84	90	104	97	96	100
Annual % change in crop output		6	-3	3	1	8	17	-6	-1	4

Note that Nigerian staples are defined as the major food crops that are consumed in the six different regions of Nigeria, namely: maize, cassava, potatoes (including sweet potatoes), yam, cocoyam (taro), plantain, beans, sorghum, rice, wheat, millet and sugarcane.

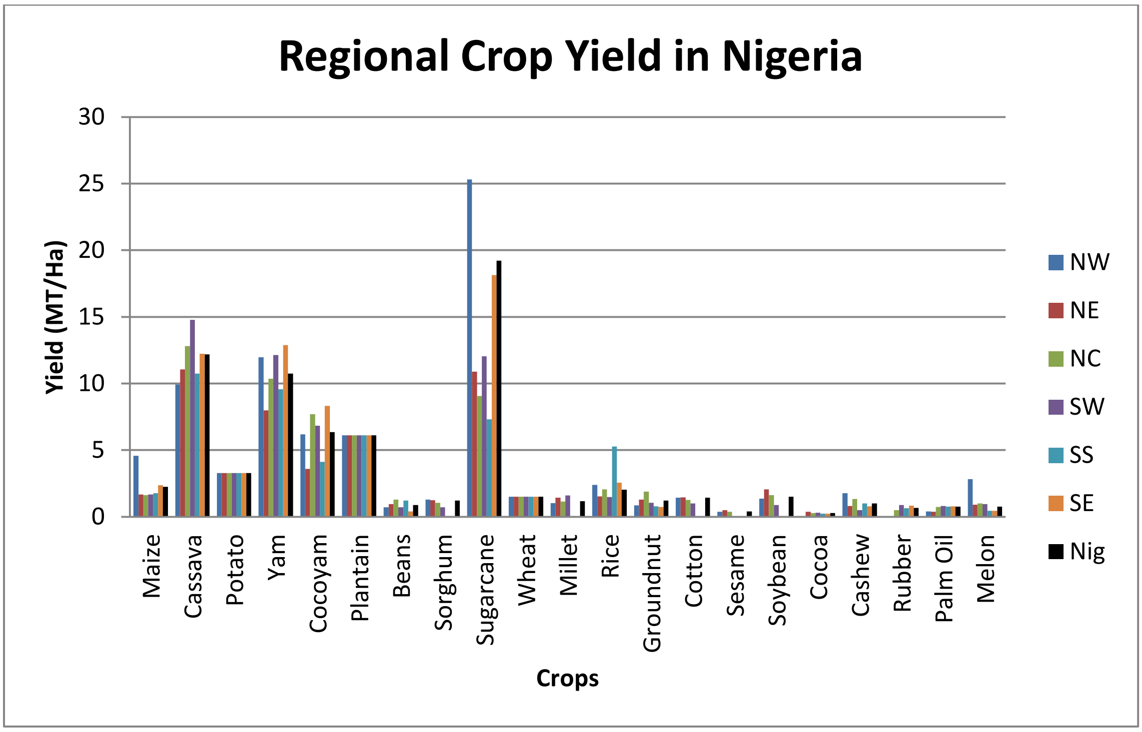
Figure 2.4 shows the per hectare average regional yield of the crops considered in the models from 2008 to 2010. Figure 2.4 illustrates the region with the highest crop production advantage, which is very useful for potential investors and farmers in the crop farming system of Nigeria.

Figure 2.3, Nigerian Harvested Land Area Trend, adapted from NBS (2010) and FAOSTAT: http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total Harvested Land Area (MHa)	23	24	24	24	24	25	31	30	30	31
Total Staples Land Area (MHa)	21	21	21	21	21	22	25	23	23	24
Annual % change in harvested area		0	3	-1	2	5	22	-3	0	5

Figure 2.4, Per Hectare Average Regional Crop Yield from 2008 to 2010



Source: Nigerian farm survey data, NBS (2010b) and FAO crop production data, FAOSTAT, (2010) A further investigation to examine the recent food gap (food deficit or surplus) based on FAO data (due to unavailability of recent comprehensive national data)[4] reveals a more alarming food gap (deficit), hence, a more critical food security problem in Nigeria. The investigation considered and collected crop production and consumption data (from 1990 to 2007) of 13 major staple food crops in Nigeria: yam, cassava, maize, beans, millet, plantain, rice, cocoyam, sorghum, groundnut, sweet and non-sweet potatoes, wheat and sugarcane, as identified by previous studies (Akinyele, 2009, Okolo, 2004, NBS, 2008, Nwajiuba, 2000). Okolo (2004), for instance, considered all the staple food crops listed, except wheat and sugarcane. However, in this study, consideration is also given to crops that can serve for food, feed and energy purposes in terms of providing food, raw material and biofuel feedstock, hence, the inclusion of wheat and sugar cane. These data reveal that food production and consumption, on the average, grew yearly by 4.1% and 4.2% respectively over this period (1990 – 2007) while food deficit grew yearly on average by 88.6% (see Table 2.7). The available data on food import value from 1990 to 2001 from CBN (Table 2.7) shows a yearly average food import value of ₦70 billion for an equivalent food deficit of 36.3 MMT per annum over the same period. These figures imply that 1 MMT of imported food costs a sum of ₦1.9 billion ($1.3 million equivalence). A linear projection of food production, food consumption, food gap and food import cost until 2020 using their respectively growth rates stated above, shows that the food gap will be unimaginably wide (a total of 908.1 MMT from 2007 to 2020, with a yearly average of 64.9 MMT) if food production and consumption continued under a business as usual scenario. This will in turn incur a total import cost of ₦1.8 trillion, equivalent to $1.2 billion from 2007 to 2020 and a yearly average sum of ₦125.3 billion ($0.82 billion equivalence). Based on FAO data, further analysis suggests that food deficits and their consequent food imports will be eliminated in five years if annual food production growth rate is 20.8% (see Table 2.8 for details). However, how to achieve such a high production growth rate remains uncertain given the peasant system of farming practiced widely across different regions in Nigeria.

[4] The challenge of complete lack of data or lack of comprehensive and/or reliable data in developing nations is well-known and has been recognised by other studies (see for example, Hazell and Norton 1986, p. 126)

Table 2.7, Food Security Situation in Nigeria from 1990 to 2007
Sources: FAOSTAT: http://faostat.fao.org/site/609/DesktopDefault.aspx?PageID=609#ancor and Central Bank of Nigeria, Various Issues, 2003 (Okolo, 2004)

Year	Food consumed (demanded) in million metric tons	Food produced (supplied) in million metric tons	Food gap (deficit/surplus) in million metric tons	Food consumption growth rate (%)	Food production growth rate (%)	Food imports in Billion Naira
1990	54.3	29.8	-24.4			3.5
1991	65.8	35.6	-30.2	21.3	19.2	7.8
1992	72.8	39.1	-33.6	10.6	10.1	11.8
1993	76.1	41.2	-35.0	4.6	5.2	14.0
1994	78.1	42.5	-35.5	2.5	3.3	16.8
1995	81.2	43.8	-37.3	4.0	3.0	88.4
1996	83.1	44.8	-38.3	2.3	2.1	76.0
1997	85.4	46.3	-39.1	2.9	3.4	100.6
1998	87.3	47.3	-40.0	2.2	2.2	102.2
1999	90.3	49.1	-41.2	3.4	3.8	103.5
2000	90.4	49.3	-41.1	0.1	0.4	120.1
2001	88.5	49.3	-39.2	-2.1	-0.1	195.8
2002	93.8	46.8	-47.0	5.9	-5.1	
2003	99.4	48.6	-50.7	6.0	4.0	
2004	99.5	51.1	-48.5	0.2	5.0	
2005	106.5	53.7	-52.8	7.0	5.2	
2006	116.0	56.5	-59.5	8.9	5.2	
2007	106.4	57.9	-48.4	-8.3	2.4	
Total	**1574.7**	**832.9**	**-741.8**			**840.2**
Average	87.5	46.3	-41.2	4.2	4.1	**70.0**

Table 2.8, Projected Nigerian Food Security Situation from 2007 to 2020, using 2007 as base year and assuming constant increase in food consumption and production using the current average production and consumption growth rates of 4.1% and 4.2% respectively.

Year	**Projected food consumed (demanded) in million metric tons**	**Projected food produced (supplied) in million metric tons**	**Food gap (deficit/surplus = imported/exported food) in million metric tons**	**Food gap rate (%)**	**Sustainable food production rate (%)**
2007	106.4	57.9	-48.4	-83.7	Average food gap rate divided by average current food production rate: 85.1/4.1 = 20.8
2008	110.8	60.3	-50.6	-83.9	
2009	115.5	62.7	-52.8	-84.1	
2010	120.4	65.3	-55.1	-84.3	
2011	125.4	68.0	-57.5	-84.5	
2012	130.7	70.7	-60.0	-84.7	
2013	136.2	73.6	-62.6	-85.0	
2014	141.9	76.6	-65.3	-85.2	
2015	147.9	79.8	-68.1	-85.4	
2016	154.1	83.0	-71.1	-85.6	
2017	160.6	86.4	-74.2	-85.8	
2018	167.4	90.0	-77.4	-86.1	
2019	174.4	93.6	-80.8	-86.3	
2020	181.8	97.5	-84.3	-86.5	
Total	**1973.6**	**1065.6**	**-908.1**		
Average	**141.0**	**76.1**	**-64.9**	**-85.1**	

It is important to remark that food security problem is not only related to food availability (i.e. food production being equal to food consumption) and affordability, but also to the provision of nutritional requirements of the citizens. Nutritional requirement of the citizens means the ability of the citizens to obtain their FAO/WHO/UNU recommended minimum/maximum daily per capita calorie requirement of 2650/3050 kcals respectively, (assuming the most active and consuming set of a population- a man from the age of 18 to 30 years with a weight of 70 kg) (FAO/WHO/UNU, 2001, p.41) from the food they eat. The maximum nutrition requirement figure referred to as "national average apparent food consumption" by FAO/WHO/UNU expert Consultative Committee translates to a national food consumption requirement of $1.94*10^{14}$ kcals per annum assuming a population of 175 million Nigerians. To assess Nigeria food security in terms of nutritional requirements, Table 2.9 has been compiled from the United States National Nutrient Database (USDA-ARS, 2013). It shows the calorific content of each staple food crop in Nigeria. The table indicates that the total calorific content of one metric tonne of all Nigerian staples summed together is 28.2 million kcals while the maximum annual per capita energy/calorie requirement is 1.1 million kcals. The figures imply that total calories obtainable from one metric tonne of all the Nigerian staples will provide the maximum energy requirement of 25 men in one year (i.e., 28.2m/1.1m). Therefore, an approximated total of 7 million metric tonnes equivalence of all the staples combined will be needed (from production and/or imports) to provide and/or satisfy the maximum national energy requirement of 1.9 trillion kcals. Comparing the estimated equivalence metric tonnes of food required to meet the nation's maximum energy requirement (7 MMT) with the observed metric tonnes of staples produced in Nigeria (Figure 2.2 – an average of 98 MMT per annum between 2007 and 2009) suggests that Nigeria is producing more than enough staple food crops to meet the energy requirement of her citizens. This result supports the findings of a USDA-ERS food security assessment study (Shapouri and Rosen, 1997, pp. 12 -13, 66), which assessed and projected the food security situation in 37 Sub-Sahara African (SSA) countries (including Nigeria) and other regions across the globe from 1997 to 2007. USDA-ERS study projected that Nigeria's nutritional gap would be equal to zero in 2007 and concluded that Nigeria's domestic food production will be adequate to meet minimum nutritional standard, given the rate of domestic food production growth then (3%). A recent USDA-ERS study (Rosen et al., 2008, pp. 10 - 12), though focused mainly on regional food security analysis instead of country analysis like the previous study, does not indicate any food security challenge in Nigeria despite its remark that 21 out of the 37 SSA countries have 80 – 100 percent of their populations consuming below the required nutritional target, and a damming conclusion that SSA is the world's most food-insecure region. It is worthwhile to mention that USDA-ERS studies utilized the minimum daily energy requirement (2,100 kcal) of a population who does not participate in exercise for their estimation while this study employed the maximum daily energy requirement for the most active population set (3050 kcal). Hence, food security challenge in terms of meeting the required national energy requirement does not seem to exist since the national maximum energy requirement in metric tonnes equivalence has been surpassed by domestic production by a wide margin as illustrated above. However, food deficit or food gap, i.e. the difference between domestic food production and consumption which leads to the spending of considerable amount of national foreign exchange on food import remains as demonstrated above.

Table 2.9, Calorific Content of Major Staple Food Crops in Nigeria; adapted from the US Nutrient database: source: http://ndb.nal.usda.gov/ndb/search/list

Crops	Staple calorie content (kcals/mt)	Staple Share (%) of the total staple calories	Staple MT equivalence required to actualize NACR	Per capita annual maximum calorific requirement (kcals)	National annual calorific requirement (NACR) in kcals
Maize	3,710,000	13	908,254	Daily maximum per capita calorific requirement (3050) multiplied by 365 days in a year	National population (175 million people) multiplied by the maximum per capita calorific requirement (3050) multiplied by 365 days in a year
Cassava	1,600,000	6	391,700		
Potatoes: white, flesh & skin, raw	690,000	2	168,920		
Yam, raw	1,180,000	4	288,878		
Taro, raw (Cocoyam)	1,120,000	4	274,190		
Plantains, raw	1,220,000	4	298,671		
Beans: snap, raw	310,000	1	75,892		
Sorghum	3,390,000	12	829,914		
Sugar, granulated (Sugarcane)	3,870,000	14	947,424		
Wheat, germ, crude	3,600,000	13	881,324		
Millet, raw	3,780,000	13	925,390		
Rice, white, glutinous, raw	3,700,000	13	905,805		
Total	**28,170,000**	**100**	**6,896,362**	**1,113,250**	**$1.94271*10^{14}$**

2.1.3 Review of the Nigerian Agro-Ecological and Geographical Zones

Understanding the agro-ecological zones (AEZs) in Nigeria is paramount to the understanding of the indigenous and potential exotic crops that can be grown in the country. In other words, knowledge about AEZs helps potential and current farmers in crop selection - making choice about the type of crop to grow in each zone/region in Nigeria. It can also help in making an intelligent estimate of the expected (potential) yield of the crop(s) grown since it is one of the factors that affect crop yield, being an important element of soil fertility (soil organic matter content) and a product of soil and climatic factors (temperature, rainfall and humidity) interactions (Oyenuga, 1967, and Iloeje, 2001).

Various classifications of Nigeria's vegetative/agro-ecological zones exist. Oyenuga (1967) grouped Nigeria into nine agro-ecological zones: (1) the mangrove forest and coastal vegetation, (2) the freshwater swamp communities, (3) the tropical high forest zone, (4) the derived (distorted high forest zone) Guinea savanna with relict forest, (5) the southern Guinea savanna zone, (6) the northern Guinea savanna zone, (7) the Jos plateau, (8) the Sudan savanna, and (9) the Sahel savanna. Iloeje (2001) divided Nigeria into two main vegetative zones (forest and savanna), and further divided each of the zones into three: (a) Salt-water swamp, (b) Fresh-water swamp and (c) High forest - for the forest zone; and (d) Guinea savanna (e) Sudan savanna and (f) Sahel savanna for the savanna zone. Climatic factors and rainfall variations in particular dictate the formation and nature of natural vegetative zones which in turn influences the type of indigenous plants that can grow as well as alien plants/crops that can be successfully introduced into the country (Aregheore, 2005).

Administratively, Nigeria was first divided into two protectorates – northern and southern protectorates - from 1900 to 1914 by the British colonial masters. The southern protectorate was later (after 1914) split into two regions (south-western and south-eastern), resulting into three main regions of Nigeria (Northern, Western and Eastern regions) based on topographic, climatic and cultural similarities (Metz, 1991). In terms of rainfall patterns, the south has a longer rainfall than the north leading to the formation and existence of forest vegetative zone in the south and savanna vegetative zone in the north (Aregheore, 2005, Oyenuga, 1967, Iloeje, 2001, and Metz, 1991). The more humid climate in the southern region supports the existence of a tropical forest zone and fosters the cultivation of cash (tree) crops such as oil palm, rubber, cocoa, coffee and most staple (food) crops such as yam, cocoyam, rice, cassava, beans, sweet potatoes, melon, plantain, groundnut, maize, etc. (Aregheore, 2005, Oyenuga, 1967, Iloeje, 2001, and Metz, 1991).

The south-western and south-eastern parts of Nigeria are now split into the South West, South South regions and South East. Both western and eastern parts of the southern region have great potential for the production of plantation and staple crops. The South South is mainly the delta area, lying close to the coast of Atlantic Ocean and is associated with the salt- and fresh-water swamps/vegetative zone; while the South East is associated with high forest vegetative zone according to Iloeje's vegetation classification. The northern region comprises of the area presently known as the North West (NW), associated with Sahel savanna vegetation; North East (NE), associated with Sudan savanna; and the middle belt, presently referred to as the North Central (NC) is associated with Guinea savanna (Aregheore, 2005). However, the North Central regional has both the climatic and soil conditions that are relatively similar to that of the far-north region (NW and NE) and the southern part of Nigeria. This distinctive dual regional climatic and soil characteristic of the NC provides it with the advantage of growing almost all the staples that are grown in the southern and northern parts of Nigeria. The major commercial crop of the NC is sesame (benniseed), though they also grow staples like yam, cassava, cowpeas, millet, sorghum, maize, etc. (Metz, 1991). The North West climate, being the driest of the three zones in the northern region, supports the growth of drought loving crops such as sorghum, millet, corn and wheat; with groundnut and cotton as major commercial crops. The North East area is relatively drier than that of the North Central, favouring the cultivation of some staples, especially cereals and tuber crops (Aregheore, 2005, and Metz, 1991).

For the purpose of this study and model development in particular, Nigeria is divided into six main agro–geographical regions namely: 1) North West; 2) North East; 3) North Central (Middle belt); 4) South West; 5) South South and 6) the South East geographical areas. The North West is made up of 7 states: Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, Zamfara, while the North East is made up of 6 states, namely Adamawa, Bauchi, Borno, Gombe, Taraba, Yobe; and the North Central consists of 6 states: Benue, Kogi, Kwara, Plateau, Nasarawa, Niger, plus the Federal Capital Territory (FCT), Abuja. Similarly, the South West consists of 6 states: Ekiti, Ogun, Ondo, Osun, Oyo, Lagos; whereas the South South consists of Akwa Ibom, Bayelsa, Cross River, Delta, Edo and Rivers (6 states); while the South East comprises of 5 states: Abia, Anambra, Ebonyi, Enugu and Imo. A justification for dividing Nigeria into 6 major regions reflects the existing (current practice) administrative blocks or regions upon which resources, governance and/or political powers are shared in Nigeria. Hence, it will be easier to adopt and implement directly (without modification) research findings and/or policy recommendations achieved from research designed using this existing administrative regional structure than those from different research design. It also seems to be a sensible way of reducing aggregation bias since producers (local farmers) in each region share the same or almost the same culture in terms of agricultural management practices and language as well as similar agro-ecological and climatic conditions; which directly or indirectly affect their yield. Further, previous research (Diao et al., 2010 and, Diao et al., 2009) also employed the same regional division to examine the agricultural growth and investment opportunities for reducing poverty in Nigeria. The uniqueness of the North Central region, for example, calls strongly for a departure from a division into 3 major regions as reported in other studies (Metz, 1991 and Okolo, 2004) to a more beneficial administrative or agro-ecological region as done in this study. It is expected that this regional recognition and classification will aid in specifying the model, making the generated model results more realistic, accurate and applicable.

2.1.4 Brief History of Biofuels (Bioethanol)

The history of fuel ethanol dates as far back as the origin of the automobile industry. The use of ethanol in the internal combustion engine (ICE) of automobiles was invented by Nikolas Otto in 1897 (Rothman et al., 1983). Demirbas (2005, 2007), Balata et al (2008) and Demirbas and Balat (2006) state that fuel ethanol blends are successfully used in all types of vehicles and engines. For instance, the Quadricycle (model T) built by Henry Ford in 1908 was designed to use bioethanol. Ford was quoted to have had a vision to "build a vehicle affordable to the working family and powered by a fuel that would boost rural economy" (Kovarik, 1998). Ethanol is also said to have played a remarkable role in making up for the short supply of fossil fuel during the Second World War, especially in USA and Brazil (Rosillo-Calle and Walter, 2006). However, ethanol production and use declined in the 1930s due to the low cost of oil (Akpan et al., 2005 cited in Balat et al., 2008). Ethanol was re-established as an alternative fuel with the oil crises in 1970s (Bothast and Schlicher, 2005); and has been considered as alternative fuel in many countries since the 1980s (Balat et al., 2008). The word bioethanol is conventionally used to distinguish ethanol produced from biomass from that produced industrially (e.g. as a synthesis or derivative of petroleum products).

Ethanol suitability as fuel is accredited to: 1) its oxygen content (35%) which reduces particulate and NO_x emissions from combustion, 2) its high octane numbers (108) – octane number being a measure of gasoline quality, 3) broader flammability limits, 4) higher flame speed and 5) higher heat of vapourization. These properties permit a higher compression ratio, shorter burn time and cleaner burn engine; making it theoretically more efficient than gasoline in ICE. Bioethanol is criticized because of its lower energy density than gasoline, its corrosiveness, low flame luminosity, low vapour pressure (making cold start difficult), miscibility with water and toxicity to ecosystem (MacLean and Lave, 2003); however, R&D and technology advances mean that these shortcomings have and can be overcome (Lal, 1995).

Currently, the USA is leading the production of bioethanol using starch biomass (corn) while Brazil leads in the use of sugar biomass (sugarcane). According to RFA (2013), USA and Brazil produce 13,300 and 6,267 million gallons of bioethanol, equivalent to 50.3 and 23.7 GL, respectively. On the other hand, EU (Germany in particular) is leading the global production of biodiesel using rape seed, while Malaysia and Indonesia are in the second and third positions, respectively; using palm oil (FoodandWaterWatch, 2008). The afore-cited literature have in general adopted a literary review approach, considering the past, current trend and prospects of bioethanol production. However, they did not pay attention to the feedstocks production planning, implicitly assuming farmers´ perfect knowledge in allocating farm resources for the feedstocks production.

Biofuels (bioethanol, biogas and biodiesel) are made from biomass and are used to supplement fossil oil and gas in the transport industry (bioethanol and biodiesel) and for electricity and heat supply (biogas). Biomass presents an interesting and attractive source of bioenergy as an alternative to fossil energy because it is more evenly distributed across the globe and can be tapped using environmental-friendly technologies compared to fossil energy sources which are selectively distributed (Lal, 2005). Biomass is basically plant material which contains sugar in the form of simple sugar, complex (polysaccharide) or very complex sugar (see, for example, EERE, 2014, Lal, 2008, Lal, 2005). While biodiesel can be made from oil crops such as rape seed and palm oil, bioethanol can be produced from any sugar-contained material. Hence, biofuel feedstocks abound depending on the environment and the technology available for the harnessing of it for biofuel production. Bioethanol feedstocks include sugar biomass such as sugarcane, sugar beets and so on; starch biomass such as maize, sorghum, rice, cassava and so on; and cellulosic biomass which include agricultural residues such as maize husk; forestry wastes such as chips and sawdust; municipal solid wastes such as household garbage, food processing and other industrial wastes such as black liquor, and energy crops (fast growing tress) specially grown for the production of bioethanol (AFDC, 2014, Lal, 2008, Kim and Dale, 2004). Research is on-going on a number of feedstocks, particularly the cellulosic materials such as algae; however, only sugar biomass (e.g. sugarcane or molassess in Brasil) and starch biomass (e.g. corn in USA) are currently used as bioethanol feedstocks (AFDC, 2014, EERE, 2014, Rosillo-Calle and Walter, 2006). EERE (2014), AFDC (2014), Rosillo-Calle and Walter (2006), Lal (2005, 2008) and Kim and Dale (2004) among others, have identified and described the kind of biomass (feedstocks) that can be used for bioethanol production, presently and in future. Nevertheless, they did not discuss how resources can be allocated for the production of these feedstocks which has the potential of assisting interested farmers in the production of these feedstocks.

2.1.5 Global Debate on Biofuels (Bioethanol)

There exist strong growing global debates in the area of the impacts of biofuels on land use, food and feed prices and/or biodiversity loss witnessed since the recent acceleration of biofuels development.

Hazell and Pachauri (2006a) present an overview of the pros and cons in bioenergy development and production. In the context of challenging global oversupply of most agricultural commodities in the world market, they remark that channelling some agricultural resources into bioenergy production reduces the costs and market distortions of existing farm support policies in developed nations, which is about US$320 billion per year for Organisation for Economic Cooperation and Development (OECD) countries as at 2006. For instance, diverting excess maize supply into bioethanol production in the United States helps in stabilizing the price of maize, thereby reducing the need for and the cost of price compensation and export subsidies (Hazell and Pachauri, 2006a). In addition, the literature reports that expanding biofuel production increases farmers' income through feedstock cultivation and provides more employment and basic infrastructures (e.g. road), especially where the processing is done in a small scale and in rural areas. They also add that it will lead to cheaper energy prices for the rural poor dwellers. Hazell and Pachauri (2006a) further suggest that biofuel production, especially from the second generation feedstocks (such as fast-growing trees, shrubs and grasses) and some first generation feedstocks (like sugarcane), has positive carbon and energy balances due to the fact that some of the feedstocks can grow in marginal lands (unfertile lands that cannot support food nor feed production) and require little cultivation after establishment. On the cons, they argue that expanding bioenergy production will lead to higher food and feed prices across the globe and especially in poor developing countries if the major food exporting countries like United States, European Union and Brazil divert their excess agricultural resources into bioenergy production. This is because bioenergy production requires the use of land, water and labour, hence, competing with food and feed production. Therefore the increase in the demand of these fixed production resources for the production of ethanol feedstock will drive their prices up thereby increasing the cost of food/feed production. From these arguments, Hazell and Pachauri (2006a) clearly present the dilemma that exists in reconciling the impact of biofuel production on energy and food security, environmental, social and economic sustainability; suggesting the need for every country to conduct a biofuel development impact analysis prior to implementation, as this study proposes to do in the Nigerian case.

In addition, Hazell (2006) admits that biofuel production has unquestionable benefits for the agricultural sector but cautions that a careful analysis is needed to assess the pros and cons of large-scale biofuel production with respect to competition for land and water for food production and potential pressures on food prices since each country is case specific.

In the same vein, Ugarte (2006) underscores the positive impact of biofuel development on rural development and poverty alleviation. The study reports that increase in biofuel production, starting with feedstock production, will create more jobs and wages in the agricultural sector while increasing the infrastructural development of the rural areas, since it will be economically rational to site, construct and operate refining facilities where the feedstocks are produced, given the weight and bulky nature of most biomass feedstocks. Further, he argues that the effect of higher food prices on the poor, resulting from the diversion and conversion of surplus food crops (such as maize) into biofuel production by the major global food exporters (e.g. US), can be offset in a long run by the higher income and employment generated through growth in agricultural activities (employment and income) in the rural areas. In addition, Ugarte (2006) suggests that the observed land use effects (reductions in land allocated for food production) in some ethanol producing nations (e.g. 15 – 30 million acres in the US) might be mitigated by the possibility of cultivating special and fast-growing energy crops (like grasses and trees which require very little inputs) on marginal soils.

Rosegrant et al. (2006) concluded that large scale bioethanol production using cassava as a feedstock, without adequate technology change that will bring about conversion of cellulosic feedstocks into ethanol as well as an increase in crop productivity, might have negative effects on the well-being of the poor people in developing countries where cassava is consumed as a major staple food.

An IFPRI study by Joachim von Braun (2008) argues that rapid expansion of biofuels has led to new food security risks and poses new challenges to the poor, particularly when competition to available resources have resulted to trade-offs between food and biofuel production as well as rising food prices. von Braun cautions that a thorough assessment of the impacts of technologies, products and feedstocks should be examined before contemplating on further expansion of biofuels.

Rosegrant (2008) predicts that rapid expansion of biofuels will cause food prices, especially those used for biofuel production, to rise. Rosegrant (2008) estimated that increased biofuel production has led to a 30 percent increase in the weighted average grain prices between 2000 and 2007; accounting for 39, 21 and 22 percent in real prices of maize, rice and wheat, respectively; within this period. Nonetheless, the study also acknowledges that biofuel production is not the root cause of rising food (grain) prices but a combination of other factors such as bad weather (drought) in major grain producing areas (Australia and Ukraine); rising oil prices, which have increased cost of production and transportation (and also raised the profitability of biofuels); poor government policies (grain export bans and import subsidies) as well as speculative trading and a consequent hoarding behaviour of some marketers. Other higher-price-triggering factors according to Rosegrant (2008) include stronger economic growth in Sub-Sahara Africa since late 1990s, leading to increased demand in wheat and rice in the region; faster income growth and urbanization in Asia; and growing demand for meat and milk in many developing countries, which has raised the demand for coarse grains (e.g. maize) used as feed; in addition to underinvestment in agricultural research and technology and rural infrastructures such as irrigation.

FoodandWaterWatch (2008) also argues that bioethanol production has led to a substantial hike in the food and feed prices, including diary and related products, while OECD/FAO (2008) shows that the entire blame is not on bioethanol.

OECD/FAO (2008) argues that factors like severe drought in the major grain/cereal producing areas like Australia, Japan, Agentina and others cannot be left out among the causes of the escalating food prices. In addition, the study blames speculative activities of some market makers, and some unfavourable agricultural export policies of most of the major grain producers. Japan for example, placed a very high export tariff, well above the world market price, on rice, thereby discouraging exports and encouraging hoarding of these products in their own country. This of course, contributed to the increase in global food demand above its supply, thereby driving rice prices up. Although most studies admitted that biofuel contributed to the food crises, the blame is not wholly on biofuel. There are also predictions that food prices would come down (although not to their original prices), due to producers' response to the present food crises and high food prices (OECD-FAO, 2008). It is believed that many countries now (even in Africa) have been alerted and are cultivating more land for staple foods like rice, maize and so on. For example, Malawi and Tanzania are among African countries that have embarked on remarkable agricultural development and food production programmes (Gallagher et al., 2003). Another important remark on this issue (the impact of biofuel on escalating food prices or food crises) is on the focus of biofuel with respect to the kind of biomass that is expected to be used in producing biofuel in the near future. There is on-going research on the development of cellulosic biomass (which is the plant material which is largely indigestible as food or feed, and hence is not directly competitive with food and feed markets and uses). For example, the United States Energy Department, Energy Efficiency and Renewable Energy (EERE, 2014) under Biomass Programme is working on the development of this cellulosic biomass which is expected to replace the use of food and feed feedstock materials being used today by 2020. On the other hand, as a case specific, biofuels production in Nigeria is expected to boost food production and security in Nigeria given the availability of attractive government biofuels policy and incentives which extends to all biofuel stakeholders including farmers (feedstock producers), a substantial spare capacity in arable land (47 million hectares), and enough unemployed labour (8m people) according to CIA World Factbook (2013). The logic is that many farmers and even non-farmers will look in the direction of feedstock production and invest in order to benefit from the biofuels policy incentives, thereby making room for the production of enough food crops that will serve both purposes (self-food sufficiency and biofuels production) in the country. The availability of sufficient key production resources (land and labour) would likely lead to a reduced or no competition in resource use which is likely to reduce the price-rise effect of using staple food crops for bifouel production while producing sufficient food crops to the domestic energy and food market. Using local food crops as feedstocks for ethanol production might also make food more affordable in the event of an increase in food prices since the poor farmers are likely to be compensated through higher crop prices caused by increases in the market demands for the crops that they produce. Competition for farm resources (e.g. soil water) is expected, although Nigerian seasonal rainfall is sufficient to support plant growth and performance in most parts of Nigeria (Aregheore, 2005, Iloeje, 2001, Oyenuga, 1967). As a conseqeunce, biofuels production in Nigeria might not exert much negative impact on food prices nor increase hunger and poverty among the poor Nigerian citizens in general. Nevertheless, post-biofuels studies might help to assess the extent to which biofuel projects impacted on the economy holistically while achieving these envisaged desired effects. Besides, one of the main objectives of this study is to analyze the potential impacts of biofuel introduction on the domestic energy and food security (food availability and food prices) using the revealed shadow prices on land, labour and product demand-supply equilibrium from the applied Energy-Food Model developed in this study.

FoodandWaterWatch (2008) and OECD/FAO (2008) among others clearly present the on-going debate on the impact of bioethanol development on the prices of agricultural and related commodities. However, the studies focused on continental/regional and global scale and did not examine national (Nigerian) case specific effects as recommended by Hazell (2006) and as proposed by this study.

On the impact of biofuel on land use, IPCC (2014, p. 26) observes that the scientific debate on the overall land use impacts of certain bioenergy alternatives on climate change are yet to be resolved. Gallagher et al. (2003) predict that bioethanol development in the USA will impact significantly on the production structure of USA, predicting that more land will be allocated towards maize production while land for the production of wheat and other crops will decline. They remark that land is a major constraint for crop production in the United States, hence, their re-allocation finding. Similarly, Qiu et al. (2010) report that bioethanol expansion in China will not only affect significantly the prices, production and trade of those crops being used as feedstocks for bioethanol production but will also affect available land for agricultural production. Other research (Smeets et al., 2007, FAO, 2008 p. 33) shows that the degree of the land use problem or impact varies substantially among different countries across the globe, or among different continents, and/or between developed and developing countries like Nigeria. Smeets et al. (2007) conclude that there is a larger potential for bioenergy production due to availability of land either due to surpluses or current inefficient agricultural production systems in Sub-Sahara Africa, the Caribbean and Latin America. Walter et al. (2007) observe that developing countries have a good potential for biofuels production due to availability of land, better weather conditions, and availability of cheap labour force. In fact, as at 2008, Nigeria only cultivated about 41 million hectares of land out of 88 million agricultural land available, from the total land mass of about 91 million hectares according to FAO (2011). From FAO statistics, only about 46% of the total agricultural land has been cultivated, leaving 54% uncultivated and available for future cultivation. Further, data analyzed from a national farm survey by the Nigerian Bureau of Statistics (NBS, 2008) reveals that there is probably more available uncultivated agricultural and arable land (agricultural land minus forest area) in Nigeria. It shows that an average of 23 million hectares (26%) of the available agricultural land (88m ha) were cultivated between 2004 and 2006. Therefore, the conflict and/or competition in land use may not apply to Nigeria.

The conflict between developmental projects and biodiversity loss is a major issue. One of the ways of reconciling this dilemma might be to estimate or value the net-environmental gain of the project (although, not easily estimated) and the initial purpose of establishing such project – whether it is to help 'save' the environment or not. Estimating the net environmental change might consider valuing the negative impact of losing biodiversity to the society in comparison with the adverse effect of climate change through continual emission of CO_2 from the use of fossil fuels, assuming renewable energy (biofuel) is not developed. It is strongly believed that it is relatively easy to endure and adapt to the loss of some biodiversity than to endure and adapt to the negative impacts of climate change such as flooding, desertification, drought and so on, which the world has started to experience. Furthermore, the original idea behind the development of bio-energy (biofuel) is to save the environment including biodiversity. In fact, the contribution of Working Group III from the most recent IPCC's Fifth Assessment Report (AR5), Summary for Policymakers (SPM) (IPCC, 2014, p. 5) states that the basis for assessing climate change policies is sustainable development and equity; implying that sustainable development and equity in terms of eradicating poverty and bridging the gap between the poor and the rich should be adequately considered in adopting and/or implementing climate change mitigating policy measures. The summary also observes that some mitigation efforts could undermine actions aimed at promoting sustainable development, eradicating poverty and achieving equity, despite the fact that mitigating climate change effects is necessary to bring about sustainable development and equity, including poverty eradication. According to the predictions of previous studies (Sambo, 2009, UNCTAD, 2006, Ikeme, 2001) and Brazil's experience (Goldemberg et al., 2004), biofuel production is expected to contribute to poverty eradication in Nigeria through rural economy empowerment, i.e. by creating additional market for the farm produce and in contributing to rural community development via the associated developmental project that might accompany the establishment of bioethanol refinery in the rural areas, since the rural poor farmers are going to grow the required feedstock. In addition, going by the earlier projections of the Supplementary Report to the IPCC's First Assessment Report (AR1) (Houghton et al., 1992), more biodiversity might be lost if adverse climate change effects prevail, than what will be lost in terms of land use for the biofuel (bioethanol) projects. Comparison of the socio-economic benefits of the project in question and biodiversity value with respect to the area concerned (Africa/Nigeria being a region/country of under-developed and significant number of poor and hungry people, according to UN development indicator), might be another way of viewing the impact of biofuel production on biodiversity. In general, these varying opinions emphasize the need for detailed biofuel impact analyses in Nigeria which this study targets.

2.1.6 Status of Bioethanol Development in Nigeria

Presently, the state of biofuels technology in Nigeria is at the initial (planning) stage, with policy, legal, regulatory frameworks, and market incentives being developed. In terms of the policy/legal framework, the Nigerian government through the Department of Petroleum Resources (DPR) of NNPC, recommended through the "Official Gazette of the Nigerian Bio-fuel Policy and Incentives" for 10% bioethanol blending with gasoline and 20% blending for biodiesel in the selected three (3) major cities: Lagos, Abuja and Kaduna, starting from 2007. The two biofuel laws are known as the E-10 and D-20 regulations, respectively. The bioethanol and biodiesel market is projected to increase from 1.3 billion litres (GL) and 480 million litres (ML), (the present annual requirements based on gasoline and diesel demand), to 2GL and 900ML, respectively; by 2020 (NNPCRED, 2007, p. 6). The annual national demand for bioethanol has been estimated at 5.14 billion liters, broken into 1.3 billion liters for E-10 gasoline blending (NNPCRED, 2007), 3.75 billion liters for household cooking and lightening in replacing paraffin (kerosene) (Azih, 2007) and 0.09 billion liters for the manufacturing sector as industrial raw materials, solvent, chemicals, wine, pharmaceutical, etc., (Awoyinka, 2009) in Ohimain (2010). To ensure the implementation of the blending policy directive and the biofuel projects in general, a lot of incentives have been rolled out to encourage private investors both in terms of feedstock production and bioethanol production, distribution and marketing. These include: 1) free import and export duties of bioethanol, its equipment and/or services, for an initial period of 10 years with the possibility of 5 years extension; 2) 10 years tax holiday for all registered businesses engaged in activities concerned with biofuels production and/or feedstock production; 3) exemption from withholding tax on interest on foreign loans, dividends and expatriates' services related to biofuels, 4) waiver on valued-added tax for biofuels; 5) long term preferential loans, serviced by an "Environmental Degradation Tax" charged on Oil & Gas upstream operations; 6) insuring all activities related to biofuel development and 7) government last resort buy-back guarantee of all (100%) locally produced biofuels at a negotiated price between the producer and the government based on the prevailing market price valued at its cost of production (NNPCRED, 2007, pp. 12 - 15). The Nigerian biofuel programme is broadly divided into two phases. The first is seeding the market phase, where bioethanol will be imported from outside (possibly from Brazil) to satisfy the ethanol demand for the E-10 blending law, while investments in capacity building, infrastructure and research are being undertaken to ensure smooth and successful migration to the production phase. This is the current bioethanol development phase in Nigeria. The second phase is expected to commence immediately following the first, and this has to do with establishment of feedstock plantations, building of bioethanol refineries and production of bioethanol.

2.1.7 Some Existing Studies on Bioethanol Feedstocks

Several studies exist on the different materials or resources that can be used to produce bioethanol. However, the existing studies focus on locations different from the study area of this research (except for the recent studies from Iye and Bilsborrow, 2013), suggesting the need to conduct this research in order to provide stakeholders, decision makers and interested individuals with research-oriented information they need to invest, produce and/or make decisions.

Iye and Bilsborrow (2013a) estimated the quantity of cellulosic feedstock required to meet the E-10 blending mandate from the Nigerian biofuels policy. However, the study did not analyse the economics of producing ethanol from the cellulosic materials and the production technology that can be employed to make cellulosic ethanol production in Nigeria competitive, despite several findings that cellulosic ethanol production is not yet cost effective (see, for example, (Gnansounou, 2010, Balat et al., 2008)).

Kim and Dale (2004) estimated the global and regional annual potential bioethanol production from major crops: corn, barley, oat, rice, wheat, sorghum and sugar cane; considering only wasted crops (which they defined as crops lost in distribution), residues and sugarcane bagasse as feedstocks. The objective of their study was to statistically highlight some perspectives on the size of bioethanol feedstock resource and to assemble relevant data that could be useful to researchers and/or to ethanol producers. In general, the study reveals that carbohydrates comprising of starch, sugar, cellulose, hemicelluloses and lignocelluloses (crop residues) are the main potential feedstocks for bioethanol production. The study specifically reports that the global total potential bioethanol production from crops residues and waste crops is 491 billion litres (GL) per year, which is capable of replacing 353 GL of gasoline (corresponding to 32% of the global gasoline consumption as at 2004) when bioethanol is used in E85 (mixture of 85% ethanol with 15% of gasoline) fuel for a midsize passenger vehicle. Kim and Dale focused on the global and/or regional scale, rather than individual country (ies) in estimating the potential of using crop residues and wasted crops for bioethanol production and also considered the ethanol potential from cellulosic materials due to the feared-conflict between food and fuel, neglecting the fact that some countries (Nigeria, for example) might have enough of the most-limiting resource (land) for the production of crops both for food and fuel. In addition, the study is clearly not meant to show how these crops can be profitably produced by rural farmers in order to yield the exciting potential bioethanol.

Sriroth et al. (2010) studied the promise of a technology revolution in cassava bioethanol in Thailand. They described the state of bioethanol technology in Thailand and showed how the operational government ethanol policy (E10 and E20) in addition to the implementation of a good cultural practices such as planting of improved varieties, weed control, have increased cassava productivity from 14.0 tons/ha to 21.6 ton/ha from 1995 to 2008, respectively. The study further gave an elaborate description of the three major processes (Conventional Fermentation (CF); Simultaneous Saccharification and Fermentation (SSF); and Simultaneous Liquefaction, Saccharification Fermentation (SLSF)) presently used in converting cassava chips to ethanol in Thailand and enumerated many desirable cultivation characteristics that made cassava a promising feedstock for bioethanol production in Thailand. However, the study considered only one feedstock – cassava and did not consider other crops (potential feedstocks) such as sweet sorghum, maize, sugarcane, rice, that have been identified and/or being used already for bioethanol production in other countries (e.g.

US and Brazil for maize and sugar cane, respectively). In addition, the study was not meant for planning or advisory purposes. Consideration of other potential feedstocks will no doubt provide a better alternative for choice of what type of feedstock to grow, thereby reducing fierce competition on farm resources such as planting material among farmers in the region.

Ranola et al. (2009) evaluated the viability of cassava feedstock for bioethanol production in Philippines using cost-benefit analysis. They first adopted a theoretical approach to determine the best practice for feedstock (cassava) production, technical, manpower and cost requirements for setting up bioethanol processing plant as well as the best processing performances adaptable in Philippines. The study further employed financial investment and sensitivity analyses (covering internal rate of return - IRR, payback period – PBP, return on investment - ROI and net present value – NPV) to evaluate the feasibility and potential of cassava as a bioethanol feedstock, taking into consideration the existing ethanol policy and incentives, existing and potential ethanol market, cost and productivity of cassava production, production technologies, feedstock supply arrangement and processing schemes (corporate farming and joint venture) and the potential areas designated for growing cassava in Philippines. Under the corporate farming scheme, the ethanol processing company leases land from landholders for a period of 10 – 25 years, employs the landholders and their immediate relatives and then farms the land for the production of the feedstock. The joint venture involves a partnership arrangement where farmer cooperatives provide land and labour for the feedstock production while processing company provides the technical support, planting materials, agro-chemicals and other inputs, with the farmers earning 30% of the profit from the partnership while the rest is retained by the company. Their results show that economies of scale are important in ensuring the viability of cassava production as feedstock for bioethanol production as a large corporate farming scheme indicated a better business model than the joint venture, in terms of feedstock supply arrangement (a key aspect in ethanol production), due to the better efficiencies associated with large scale production. Among others, they notably conclude that the sustainability (consistent availability) of feedstock supply is one of the key determinants of viability and therefore, recommend that feedstock production should provide satisfactory income and economic activities for the feedstock producers in order to ensure continued supply of feedstock. This study examined the viability or profitability of cassava feedstock production only without any comparison with other potential feedstocks. It is also country specific, focusing only on the prevailing biofuel market and policies in Philippines.

Recently, several biofuel production and/or expansion impact studies have been conducted using Partial Equilibrium or Computable General Equilibrium (CGE) Models. Rosegrant et al. (2006) investigated the impact of national (using Brazil, China and India), regional (using US and EU) and global aggressive expansion of biofuels, using crops (cassava, maize, oilseeds, sugar beet, sugarcane and wheat) as feedstocks, on global food prices from 2010 to 2020; under three scenarios: a) aggressive biofuel growth without change in technology, b) with change in technology (assuming commercial breakthrough of cellulosic ethanol technologies only) and c) with technology change that results in both cellulosic ethanol and crop productivity change (increase in crop yields). They employed the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) as their analytical tool and their results show that the price impact on cassava (for example) will be highest, higher and high (moderate) in 2020 under scenarios a, b and c, respectively. Based on these results, they concluded that a contemplation of aggressive large-scale biofuel production using cassava as a feedstock, without the commercialization of cellulosic ethanol technologies and meaningful investments on technology, research and innovation that will increase crop yield, will adversely affect the price of cassava and consequently the poor population in developing countries (e.g. Sub-Sahara Africa) where cassava is a major staple food. Nevertheless, the applied model has an obvious drawback of not allowing for substitution among different feedstocks used for biofuels production and also excludes trade activity (market) for biofuel products. Allowing for feedstock substitution and an inclusion of the market for the biofuel products might show a considerable change (decrease) in the feedstock cost (price).

Another recent study was conducted by Qiu et al. (2010) on bioethanol development in China and its potential impacts of China´s agricultural economy and food security using the Global Trade Analysis Project (GTAP) model. The study examined maize and wheat, sweet sorghum, cassava, sweet potatoes and sugarcane as potential bioethanol feedstocks with focus on the impact the use of these crops will have on their prices and related products, production and trade (both locally and globally). Qiu et al. state that China has developed an ambitious long-run biofuel programme with many financial and institutional supports. However, they report that China´s expansion programme will have little impact on overall agricultural prices on a global scale, but significant impact on local prices, production and trade of those energy crops given the fact that land is a major constraint for bioethanol production in China, even though, utilization of marginal lands (reclaimable lands) has been assumed. Qui et al. (2010) have conducted part of the required biofuel development impact analyses using the GTAP model (which is a General Equilibrium Model- GEM with focus on global trade analysis); nevertheless, the region or country (China) studied is different from Nigeria. This study assesses the impacts of biofuel production on Nigerian domestic crop production, food security (food availability and food prices) and economy (trade) using a Partial Equilibrium Model (PEM), since each country is unique and has different resource endowments. In this study, the PEM is preferred to GTAP due to its marginal impact analysis advantage on activities considered in the model against the whole sector or aggregate impact analysis from GEM. Also Qui et al. restricted ethanol production to come from maize only at the baseline scenario (S0) and assigned a pre-determined ethanol production percentage share to different potential feedstocks based on their pre-determined market forces (demand and supply situation and prices), thereby ruling out some potential feedstocks (e.g. sugarcane) from being considered as feedstock for ethanol production in the model in the first scenario (S1). Such specifications would clearly not allow the model to freely evaluate all the specified market conditions and production costs and make an unrestricted decision about the best feedstock to use for ethanol production.

Timilsina et al. (2011) studied the relationship between oil prices, biofuels and food supply using a global, multi-country, multi-sector, recursive dynamic, Computable General Equilibrium (CGE) Model, implemented using adapted GTAP database; and found that increase in fossil oil prices would increase biofuel expansion and decrease agricultural output. The decrease in crop production and consequently food supply is due to re-allocation of food crop land to the production of biofuel feedstocks as well as diversion of food crops for biofuel production. However, their results represent estimates of long-term impacts and do not explain the possibility for and reasons for short-term rise in food prices, such as the one witnessed in 2008. Another study from Timilsina et al. (2012) investigated the impacts of biofuel targets on land use change and food supply using Global Dynamic Computable General Equilibrium model (GDCGE). The study found that a considerable expansion of biofuel production would have a moderate impact (less than 5%) on agricultural commodity prices, with the exception of sugar whose impact is between 7% and 10%. Their results also indicate that food supply and food prices are moderately impacted by a considerable expansion of biofuel production. Considerable expansion according to them is defined as the announced ethanol targets and a double of the announced targets from the countries considered in their model. Further, Zilberman et al. (2013) reviewed several existing studies analyzed using CGE model and other methods with focus on two broad aspects of literature: first on the relationship between fuel and food prices and second on the impact of the introduction of biofuel on commodity food prices. They observe that food and fuel prices affect ethanol prices throughout the globe, while the relationship between ethanol prices and food prices is weak when CGE model is employed. They argue that the weak relationship between ethanol prices and food prices does not mean that the introduction of biofuels has little impact on food prices, but rather that the impact of biofuel on food prices are not fully captured using the analysis between fuel and food prices. More importantly, they concluded that the introduction of biofuel has much lesser impact on food commodity prices when biofuel production is not competing with food crops for production resources such as land, labour and water. In addition, Rajagopal and Zilberman (2007, p. 45) reviewed the environmental, economic and policy aspects of biofuels, identifying different sector models that have been applied to study the impacts of biofuels on food supply and food prices to include models that focused on the impacts biofuel mandates at global and national levels as well as models that analyze the outcomes of carbon sequestration policies via agriculture. They observe that models with global/national focus (e.g. IMPACT) predict that aggressive increase in the production of biofuels without accompanying increase in crop productivity compared to the current level would lead to significant increase in food prices.

This study therefore aims to fill the gap of biofuel potential impact study on food supply and food prices in Nigeria, as have been done in some other countries where bioethanol programme is contemplated and/or introduced.

2.2 Theoretical Framework

The theoretical background for sectoral production modelling is primarily based on the basic economic theory of production, cost, revenue and marginal concepts as explained in many economics and farm management textbooks, for example, Casavant and Infanger (1984). Sectoral production modelling usually involves financial objectives such as profit maximization (or cost minimization) which is the underlying assumption of production function (McCarl and Nuthall, 1982, Kay, 1986, Hazell and Norton, 1986, Manos and Kitsopandis, 1988). It also provides useful insights as to how the primary production questions of: “how much to produce, how to produce and what to produce in order to maximize profits” can be answered. In addition, it underlies important decision rules that are fundamental to production economics. To substantiate this fact, McConnell and Dillon (1997) state that planning decisions about what, how and how much to produce should be based on the basic rule of production economics: that is to say “that any activity should be taken up to and no further than the point where the marginal benefit of the activity is just balanced by its marginal opportunity cost”.

2.3 Review of Mathematical Programming as a Sector Modelling Tool

Traditionally, planning in agriculture was based on experienced judgments of farmers and/or comparisons with their neighbouring farmers. However, mathematical programming (MP) has replaced it in recent times (Manos and Kitsopandis, 1988, Glen, 1987, Hazell and Norton, 1986). This review provides the scientific justification for the suitability of Mathematical Progamming (especially non-linear programming-NLP) as the empirical and/or analytical model for this study. A review of LP’s characteristics, merits and demerits are first pursued in order to provide justification for the adoption and use of NLP as the analytical tool for this study.

Historically, MP emanates from Operations Research, specifically from the optimization theory. The first optimization technique, known as steepest descent was developed by a German mathematician called Johann Carl Friedrich Gauss (1777 – 23 February 1855). In the same historic line, a Russian mathematician Leonid Kantorovich invented linear programming. George Dantizig (American mathematician) in 1947 re-invented linear programming, specifically the Simplex method while John von Neumann (Hungarian-American) developed the duality theory in the same year (1947).

Ever since these landmark developments, different forms of mathematical programming have been further proposed and adapted to solving different problems. Examples include, mixed integer programming (MIP), parametric linear programming, quadratic programming, maximin programming (from game theory), and positive mathematical programming (see Arriaza and Gómez-Limón, 2003, Manos and Kitsopandis, 1988 for a long list). Progressively, traditional LP has been modified and adapted to capture farm system characteristics, farmer’s objectives and decision-making process in solving different problems in agriculture and especially agricultural economics (Hazel and Norton, 1986; Glen, 1987 and Arriaza and Gomez-Limon, 2003).

McConnell and Dillon (1997) observe that traditional LP form has been further extended in many ways and like non-linear programming, has become an appropriate mathematical programming tool for solving different problems in agriculture; as shown in Hazel and Norton (1986), for example.

Regarding the use of LP for regional or sectoral agricultural planning and/or policy analysis, especially when risks and uncertainties are involved (which is always the case in real life agricultural production), there are conflicting opinions. While some (Manos and Kitsopanidis, 1988, for example) criticize the use of LP in sectoral agricultural planning and/or policy analysis based on the linearity, divisibility, fixedness, finiteness and single value expectation assumptions; others (e.g., Hazel and Norton, 1986, pp. 33 - 34) explain that close approximations to non-linear relations can be easily accommodated or represented despite the restrictive assumptions; depending on the data used and experience of the modeler. Olayide and Heady (1982) add that in so far as LP is based on restrictive assumptions as stated above, that it has remained the most popular mathematical programming (MP) technique as observed by Anderson et.al. (1977) and has received wide application in agricultural planning problems (Jeffrey et al., 1992). Further, Nix (1979) in Glen (1987) states that LP models have been widely applied in crop and/or livestock production planning ever since Heady (1954) demonstrated the use of LP model to determine the allocation of arable land to two crops.

Austin et al. (1998) in Arriaza and Gomez-Limon (2003) examine the goodness-of-fit of alternative programming models to explain farmer´s decision making and concluded that nonlinear models do not give appreciably better performance compared to linear models.

Further, Barnett et al. (1982) conducted a study on the performance of goal programming (NLP) versus expected profit maximization (LP) and report that they did not find any substantial difference between the two.

Mohd (1984) cited in Arriaza and Gomez-Limon (2003) also did a comparative study of the expected profit model (LP) with the negative exponential utility and the market-based profit models (NLP) to explain farmer's decisions regarding crop selection. He shows through his results that expected profit maximization (LP) model outperformed the negative exponential utility and the market-based profit (NLP) models in predicting observed crop distributions.

Conversely, Manos and Kitsopanidis (1988) compared the performance of four mathematical programming models: LP, parametric, mixed integer, quadratic programming and game theory models (maximin) in farm planning for the determination of profit-maximizing enterprise combinations and concluded that quadratic and maximin (NLP) models gave a better stabilized-profit and farm income with lowest variability in face of risk and uncertainty and should be preferred to LP even though LP gave the highest profit.

Similarly, Alarcon et al. (1997) analyzed the performance of three models: classical LP, quadratic programming (following Baumol, 1963 risk formulation) and positive mathematical programming (PMP). Their results reveal that: 1) quadratic programming performs better than LP, and 2) that PMP performed best. However, they did not consider risk as important in their model.

Based on the balance of experts' opinions and LP's criticisms (rigidity characteristic in particular), a NLP model is favoured as the analytical model for this study. NLP draws from the positive characteristics of LP (LP's strength), while relaxing some of the linearity and rigidity (fixedness) assumptions.

2.4 Applications of NLP Models in Policy Analysis Studies

A large body of literature exists on the use of NLP models for agricultural, environmental, economic and policy analysis studies. Also different modelling and/or analytical approaches have been employed, ranging from global to national and/or regional perspectives, depending on the interests and/or targets of the researchers; see, for example, Rajagopal and Zilberman (2007, p. 45). In addition to the research cited in Section 2.1.3 (the debate of biofuels on food supply and food prices), a few studies (below) have been selected to further illustrate the suitability of NLP model as an analytical tool for sectoral agricultural policy analysis and to justify its choice as the analytical model for this study. Drawing from historic antecedents, the first sectoral NLP (PMP) model constructed for a developing nation, as documented in Secretaria de la Presidencia 1973 and 1983, and Bassoco et al. (1983), is the Mexican Model (CHAC), according to Hazell and Norton (1986, p 286). Following CHAC, Kutcher (1980) developed and applied a sectoral NLP model (HAPY) in order to analyze Egypt's agricultural production system with the aim of identifying ways to improve Egypt's agricultural production, domestic food supply and economy. Similarly, Bauer and Kasnakoglu (1990) analyzed the Turkish agricultural trade liberalization policy using a sectoral NLP model (TASM). Their results show the potential impacts of agricultural trade liberalization on Turkish economy, indicating which crops Turkey has export advantage on and could focus on in terms of exports. Others notable 'early days' sectoral NLP models are found in Hazell and Norton (1986, p. 286). For recent studies that employed NLP model as analytical tool to perform regional or sectoral agricultural, environmental, economic and/or policy analysis, see, for example, Heckelei et al. (2012, pp. 118 - 119). Also Heckelei and Britz (2005, p. 52) is another useful reference for sectoral or regional NLP models.

Chapter 3. Methodology

3.1 Introduction

This chapter focuses on describing the specific methods employed in this study. It starts with a concise review of the structural elements of a sector model in Section 3.2, which is followed by the general structure of a sector model in Section 3.3. In addition, data issues ranging from data type to data processing are described in Section 3.4, while Section 3.5 described the calibration method followed in this study. Further, procedures followed in developing and specifying Nigerian Energy-Food Model (NEFM) in GAMS platform are described in Section 3.6. Finally the algebraic structure or mathematical definition of the model is presented in Section 3.7.

3.2 Structural Elements of a Sector Model

To distinguish a sector model from a farm-level model, it is important to identify the unique fundamental elements of a sector model. A sector model contains all sources of supply and demand for the products in the sector, among other major characteristics. In summary and according to Hazell and Norton (1986, Ch.7, pp 136 – 137), every sector model contains the following five fundamental elements:

3.2.1 Description of Producers' Economic Behaviour

In terms of agriculture, it entails describing how farmers make decisions about output composition and scale. In other words, it relates to farmers' objective functions which may include profit maximization, risk aversion, self-sufficiency.

3.2.2 Description of Available Production Technology Sets to the Producers

This relates to yield and inputs and the need to show technology differentiation among farmers from different regions and the impact of technology differentiation in the crop yield.

3.2.3 Definition of Resource Endowments for Producers in each Region

Endowed resources mainly refer to land, family labour and irrigation supplies, as variation in resource endowments will result to varying farmer's response with regards to their output and combinations.

3.2.4 Market Specification

This entails specification of the market environment in which producers in each region operate in. It involves specifying market forms (competitive, monopolistic, oligopolistic, monopsonistic, etc.,) and the attached consumer demand, credit availability both from formal and informal sources, cost of marketing and processing agricultural products and the possibility for exports and imports.

3.2.5 Specification of Policy Environment (Policy Goals)

This involves quantifying the policy instruments or variables such as government subsidy, import and export quotas and tariffs.

3.3 Algebraic Structure of a Standard Non-Linear Programming Model

A simplified version of a constrained optimization problem for a standard sectoral non-linear programming model[5] with one production technology, multiple products (j) and one sector/region can be stated as give below:

$$Max\ Z = \sum_j \left(\alpha_j - \frac{1}{2}\beta Q_j\right) Q_j - \sum_j C(S_j) + P_j^e E_j - P_j^m M_j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

such that

$$Q_j + E_j - (S_j + M_j) \leq 0, \qquad \forall\, j \qquad [\pi_j] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\sum_j a_{kj} X_j = \sum_j (a_{kj}/y_j)\, S_j \leq b_{k,} \qquad \forall\, k \qquad [\lambda_k] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$E_j \leq \overline{e}_j, \qquad \forall\, j\ \ which\ are\ exportable \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$Q_{j,} S_j \geq 0, \qquad \forall\, j. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where

Z = objective function to be maximized, which is equal to the largest possible total gross margin from all activities, in currency units;

α_j = demand intercept for each product (crop produced), in currency units;

β_j = slope or gradient of the demand curve for each product (crop produced);

5 The above model is adapted from Hazell and Norton (1986, p. 166). The expanded structure and detailed of a sector model is also available from Hazell and Norton (1986, p. 152).

$Q_j =$ average quantity demanded (sold) in the domestic market for each product (crop produce), in MT;

$S_j =$ average quantity of each product supplied (produced) domestically, in MT;

$\sum_j C =$ total input cost (unit cost) of producing each product domestically, in currency units;

P_j^e = real export price of each product after adjusting for export (FOB) cost, in currency units;

$E_j =$ average quantity of each product exported (demanded or sold externally), in MT;

$\overline{e_J}$ = export quota for each product, in MT, representing the average quantity of each crop exported at the base year or the import quota of the receiving (importing) country;

P_j^m = real import price of each product after adjusting for import (CIF) cost, in currency units;

$M_j =$ average quantity of each product imported (supplied or bought externally), in MT;

$X_j =$ the level of jth production activity such as hectare of maize grown. If n denotes the number of possible activities, then $j = 1$ to n;

$y_j =$ per hectare average yield of each product, in MT;

a_{kj} = the quantity of the k^{th} resource (e.g.; ha of land or hours of labour) required to produce one unit of the j^{th} activity, in varying units depending on the resource in question, e.g., labour in man-hours, tractor in service hours, seed and fertilizer in MT, etc. In other words, it represents the technical coefficients of a production function. Letting m denote the number of resources, then $k = 1$ to m;

$b_k =$ amount of the k^{th} resource available or available resource endowments (RHS);

π_j = shadow price of each product at the commodity (market) balance constraint, in currency units, which is the same as the product price of each product;

λ_k = marginal opportunity cost of resource k, or the market valuation of resource k, in currency units. In other words, it is the increment in consumer and producer surplus that would accrue from the availability of extra unit of resource k;

Equations (2), (3) and (4) are the national commodity or market balance, resource use balance and export quota balance constraints, respectively; while equation (5) is the set of non-negative constraints.

3.4 Data Issues

3.4.1 Data Type

The analytical model employed in this study is compatible with the use of secondary data, covering the available historic and up to date Nigerian and regional physical and economic farm production data such as crop type, yields, prices, gross margin, labour requirement, inputs requirement (e.g. fertilizer, pesticide, seed, cash capital), in addition to the Nigerian energy consumption data and Nigerian food consumption and nutritional data.

3.4.2 Method of Data Collection and Data Integrity

Data collection was mainly undertaken through internet screening of recognized international and national official websites and databases such as IEA, EIA, FAOSTAT, IMF, World Bank, US nutritional database, NBS; published relevant literature, journals and national dailies as well as personal research visits to the government agencies such as State Agricultural Development Programme (ADP) agencies, ministries: agriculture, commerce, budget, finance, NLC, NNPC, CBN, NBS, NPC, research institutes, e.g. IITA, extension agencies, e.g. Information and Communication Support for Agricultural Growth in Nigeria (ICS-Nigeria) and a pioneer biofuel company in Nigeria. The essence of the personal research visits to these organisations was to collect additional up-to-date data that are not in the public domain and for the verification of some of the already collected data from public domain databases in order to ensure data integrity. For the biofuel company, the visit was intended to ascertain the status or stage of biofuel production in Nigeria – being the pioneer company and to collect ethanol production data (costs).

3.4.3 Data Sources

Different data sources and/or databases were employed in gathering the data used in this study as mentioned above. For the farm production data, two databases (NBS and FAOSTAT) were used complementarily as none of them is perfectly comprehensive. For example, NBS (2008, 2010) reported Nigerian and regional agricultural (crop farming) labour employment data from 1995 to 2010 which is not available in FAOSTAT, while FAOSTAT shows the comprehensive and up-to-date national crop production data of some crops which were not reported by NBS. However, NBS data is presumed to be more reliable (being a direct national database) and therefore preferred to FAO data. Nonetheless, FAO data is used where NBS data is not available. Getting accurate and reliable data, especially labour employed in the production of different crops either from government agencies or individual farmers was not possible due to lack of such data and the mixed cropping system of farming in many regions of Nigeria.

3.4.4 Data Processing

To apply the raw data from the databases into the NLP model, important transformations and/or processing were necessary. For example, the historic farmgate prices (from 1995 – 2010) of the crops used in the model for all the 36 states in Nigeria as reported by NBS (2008, 2010b), were transformed from a nominal price status to a real price status by dividing the yearly nominal price with a corresponding yearly consumer price indicator (CPI deflator) published by IMF in order to account for inflation while measuring the real price growth of the crops from 1995 to 2010. Other minor conversions such as converting real prices from naira per kg to naira per MT and conversion of naira per MT to US$ per MT using the exchange rate of ₦152.25 to US$1 were also done.

3.5 Model Calibration Method

Historically, mathematical programming (MP) models have been, among others, the best choice in solving agricultural sector and economic policy analysis problems. The first reason is because they can be constructed and implemented with a minimal data set, unlike econometric models (Hazell and Norton, 1986; Bauer and Kasnakoglu, 1990; and Howitt, 1995a). Second, they permit, in principle, an appropriate reflection of the multi-input and output relationships inherent in agricultural sector. For example, the complementary (between maize grain and maize flour production), the competitive (between maize and rice production) relationships and the linkages (between crop and livestock production via feed demand and supply), which are relevant features of agricultural production can be adequately represented and modelled using MP models (Bauer and Kasnakoglu, 1990). Third, the representation of specific agricultural technology process which is vital in agricultural economics and agronomy is made possible and easy using MP models. Fourth, MP approach to sector modelling provides different possibilities for the incorporation/implementation of different policy instruments such as trade and/or change in trade policies (both foreign and domestic), change in input and output demands and supplies, environmental impact policies, quota systems, input subsidies, domestic agricultural price and intervention policies, technology improvement measures and so on (see Bauer and Kasnakoglu, 1990, for a list of other application references). This is because the constraint structure of MP models are very suitable in characterizing resource, environmental and policy constraints (Howitt, 1995a). Fifth, most MP models exhibit Leontief production technology characteristics which intrinsically appeals in input determination during farm production modelling (Just et al., 1983). In particular, LP models have unique merits. LP models are preferable when modelling crop production with multiple inputs (Howitt, 1995a). Howitt (1995b) further remarks that LP models have been long and well-established in the regional analysis of agricultural production systems due to the following significant advantages: 1) can be constructed and implemented using available minimum data set, 2) can be used to explicitly show how resources are utilized, and 3) can be used to show and/or demonstrate the implications, impacts and/or effects of policy constraints. In contrast, LP, when applied for agricultural policy analysis, is criticized for not being responsive to slight changes in input costs, commodity prices or some policy instruments (e.g., commodity subsidy), making it ineffective for policy simulations, due to its linearity specifications (Howitt, 1995a, 1995b, Heckelei and Britz, 2005). In other words, small changes in input costs and product prices do not lead to changes in shadow prices (dual values) or output types (production pattern) except when such changes lead to a change in solution basis. LP models are also criticised of generating overspecialised optimal solutions due to the fact that the number of empirically justifiable (or available) resource constraints are usually lower than the number of observed activities. By design, the upper limit of the non-zero variables in the LP framework is usually set with the number of resource constraints, thereby enforcing overspecialisation by default (Heckelei and Britz, 2005, p. 51). The overspecialisation problem is reported to be more significant in aggregate (sectoral or regional) models (Howitt, 1995a, p 330) due to the facts that: 1) the number of empirically justifiable constraints in comparison with the number of observed production activities in aggregate models are usually smaller than that of farm level models; 2) important non-linearity specification that would enforce more production activities into the optimal solution are usually absent due to lack of data, time and computational difficulties; and 3) output price endogeneity and risk behaviour specifications which would ensure solution diversification tendency are mostly omitted due to the above reasons (lack of data, time and computational challenges). LP models are further limited in analyzing the interaction of agricultural policy and environmental implications due to their inherent linear responses as a result of their Leontief production technology characteristics, which make them unable to show the gradual substitution of inputs as their input costs or quantities are varied (Howitt, 1995b). In other words, LP models are criticized to be inflexible for policy analysis. Alternatively, Positive Mathematical Programming (PMP) as formalized by Howitt (1995a), builds on LP methodology and specification to develop non-linear terms which overcome the overspecialisation, irresponsive and/or inflexible limitations of LP and calibrate the model's agricultural production levels, input requirement levels, input costs and/or product supply levels and prices to the 'exact' base-year (observed) levels. This significant breakthrough has been long recognized as a methodological advancement in agricultural policy and economic analysis. As in econometric models where economic models are parameterized based on observed behaviour, PMP concept is intended to increase the reliability of a constrained optimization model by recommending the use of observed behaviour at the model's specification phase. PMP models have been modified, applied and extended in different agricultural, environment and policy areas such as in Turkish Agricultural Sector Model (TASM) (Bauer and Kasnakoglu, 1990). Nevertheless, PMP, as proposed by Howitt, still has some drawbacks which have been highlighted and addressed by Heckelei and Britz (2005). In this study, the alternative Positive Mathematical Programming (PMP) calibration approach by Heckelei and Britz (2005) - an update of the 'traditional' PMP calibration approach by Howitt (1995a) is followed in the calibration of the developed and applied models. The new PMP calibration approach recommends incorporating prior information such as crop supply elasticities or land rents in the calibration procedure and using the first order condition of every optimization model that is assumed to represent the producers' behaviour and satisfies the simulation needs of the analysts, without including the calibration constraints and using the initial generated shadow prices to calibrate the cost function in the objective function (i.e., by omitting phase 1 of the former procedure), to calibrate MP models (see, Heckelei and Britz, 2005, for details). In this study, crop demand elasticities for the different crops covered in the model as well as the observed/derived base year crop production resource demand (crop production input-output coefficients) were included in the model specification.

3.6 Description and Specification of the Nigerian Energy-Food Model

A non-linear mathematical programming (NLP) model is adopted here because of the greater usefulness of NLP in sectoral and/or regional agricultural policy analysis compared with LP (as noted in Section 2.3) and the numerous LP criticisms as earlier explained in Section 3.5. The principal limitation of LP models is their sensitivity to corner solution conditions in objective function values (prices and costs). The ability of NLP models to reflect the impact of small changes in agricultural production and/or marketing policies such as inputs supply and/or use levels, input/output prices, demand and supply quotas, subsidies and other policy instruments is important for sound and evidence-based policies. Therefore, the application of an NLP model, operationalised and implemented using GAMS, became necessary.

The General Algebraic Modelling System (GAMS) has been applied in various areas, sectors and/or projects/programmes to solve large and complex decision making, analytical and/or allocation problems since its invention (Kutcher, 1980, Kutcher and Scandizzo, 1981, Le-Si et al., 1982, Kutcher et al., 1988, Bauer and Kasnakoglu, 1990). In particular, it is designed to model linear, non-linear and mixed integer optimization problems (GAMS, 2013).

The methodology and procedures described below follow notable previous works (Howitt, 1995a, Bauer and Kasnakoglu, 1990, Kutcher et al., 1988, Le-Si et al., 1982, Kutcher and Scandizzo, 1981, Kutcher, 1980) on the development, application and extension of non-linear mathematical programming in solving complex optimization problems and sectoral or regional agricultural production and policy analysis. The Nigerian Energy-Food Models, called NEFM1 and NEFM2 for the Base-year and Ethanol Production Models respectively, were implemented using both MINOS and CONOPT solvers (Murtagh et al., 2012, Drud, 2012). There was no difference from the results obtained using either of the solvers.

In general, the structure of the Nigerian Energy-Food Models (NEFM1 and NEFM2) hereafter referred to as Model 1 and Model 2, are presented in five main category formats: indices; input data; decision variables; constraints and objective function; as recommended by Rosenthal (2012, pp. 5 - 15) and McCarl et al. (2012, pp. 28 - 36) to ensure compatibility and consistency with GAMS design. In GAMS terminology, indices are **sets**, input data are **parameters**, decision variables are **variables**, while constraints and the objective function are **equations**.

Sets declaration (Indices): this entails identifying, defining (code assignment), describing and grouping all the major activities of the model into different sets and defining or assigning members/elements to those sets. For example, in Models 1 and 2, set C represents a set of the crop production activities, which describes the various crops intended for production and considered in the models; and there are 22 crop members (elements) of this set. The elements of set C are maize, cassava, potato, yam, cocoyam, plantain, beans, sorghum, sugarcane, wheat, millet, rice, groundnut, cotton, sesame (beni seed), soybean, melon, cocoa, cashew, natural rubber, oil-palm, and the residues of starch and sugar crops. Other declared sets in the models include:

1) set E(C) – a subset of C, which describes a set of energy crops with 8 elements (maize, cassava, potato, sorghum, sugarcane, wheat, millet, rice) as members;

2) set B- representing a set of available production resources: land, labour, seed, fertilizer, pesticide, cash capital and tractors;

3) set R describes the six administrative, political and economic regional structures in Nigeria, comprising of NW – North West, NE- North East, NC – North Central, SW – South West, SS – South South and SE – South East;

4) set EP – is a set of 9 ethanol production factors employed in the process of converting the feedstock (both grain and cellulose) to ethanol, consisting of:

i) GCE - the published research estimates of grain conversion efficiencies (grain-to-ethanol production coefficients), used in quantifying the volume of ethanol produced from 1 MT of each grain feedstock;

ii) GFDS (an inverse of GCE), referring to the estimated quantity of grain feedstock required to produce 1 litre of ethanol from each of the grain feedstock in the energy crop set;

iii) RCE representing the published residue conversion efficiencies (i.e., straw-to-ethanol ratios or input-output coefficients) of each energy grain residue feedstock, used in estimating the volume of ethanol produced from the quantity of residues generated from the produced grain energy crops,

iv) RFDS (an inverse of RCE), denoting the estimated quantity of residue feedstock required to produce 1 litre of ethanol from each of the residue feedstock in the energy crop set;

v) SGR - the published straw-to-grain ratios of each energy grain feedstock, applied in estimating the quantity of residues produced from the quantity of grain energy crops produced;

vi) VCG represents the variable cost (in US$) of producing 1 litre of ethanol from each energy grain feedstock;

vii) VCR is the variable cost (in US$) of producing 1 litre of ethanol from each of the energy residue/straw feedstock;

viii) EREV is the ethanol domestic market price (pump price- revenue) in US$ per litre, adjusted with 10% domestic market price as marketing cost.

Typical formats and detailed explanation and other examples of GAMS Statements are contained in McCarl et al. (2012) and Rosenthal (2012).

In GAMS, input data are incorporated into the model using **tables** and/or **parameters**. In the two models (1 and 2) the same number and types of tables exist, except for table EPF used in defining input data to set EP (- the set of ethanol production factors) which is only relevant to and present in Model 2. Otherwise, there are 19 input data tables in the models. Specifically, Table Y(C,R), is a vector that defined the per hectare yield of each crop in each region for both models. The unit of the yield table is metric tonnes per hectare (MT/Ha). Table DP(C,R) is used to define and enter the value of the domestic real market price of each of the crops produced in different regions of Nigeria into the models. The domestic real market prices for all the crops produced are assumed to be the same in all the regions because the observed domestic real market prices obtained from the national (Nigerian) bureau of statistics are reported on a national scale and not disaggregated into regional prices. The unit of the table is in US$ per MT. Table DCP(C,R) is the estimated average regional crop production data from 2008 to 2010[6]. Tables EXD(C,R) and IMD(C,R) are the average crop/food export and import data, respectively, within the same period. The reference domestic crop demand (denoted by parameter DCD(C,R)) is defined to be equal to average quantity of crops produced (DCP) minus the quantity exported (EXD) plus the quantity imported (IMD). The reference crop demand (DCD) is therefore equivalent to the total quantity crops supplied and consumed within the regions at the base year. In terms of utility, it is the base year aggregate of crops which are consumed as food, feed, seed, stock and raw materials in the processing industry; and therefore represents the equivalence of the average quantity of each crop used to satisfy the human and animal food consumption needs in the base year. In essence, it serves as the food demand upper limit (constraint) which is required to ensure food security in each region and Nigeria at large. Alternatively, the national domestic food requirement (demand) for each crop was estimated using the upper range value (3050 kcals) for men (between 18 to 30 years) daily average energy requirement as recommended by (FAO/WHO/UNU, 2001 p. 41). These values are shown in Section 2.1.2. However, the estimated metric tonne

[6] Domestic Crop Production (DCP) was estimated by taking a three-year average of the regional quantity of crops produced from 2008 to 2010 as reported in NBS (2010b).

equivalence of each crop required to satisfy the national annual energy requirement based on the national population of 175 million people (Factbook, 2013) as recommended by FAO/WHO/UNU is much smaller than the computed reference crop demand. Therefore using these calorific-based crop demands as upper bounds of domestic food demand in the Base Model will cause the resulting regional/national crop production to be below the base year production level since crop production (a supply component) is directly linked to crop demand via the domestic crop consumption equation (the commodity/market balance constraint). Secondly, the calorific database covers only some of the crops considered in the model- mainly the major world staples; hence, using it will mean defining the Nigerian food basket as limited to such crops/foods, which is not consistent with actual practice. Table PED(C,R) defines the value of price elasticity of demand (PED) of the various crops considered in the model, and used to condition the objective function in the NLP format. The values often range from -0.4 to -3.0 according to Minot (2009, p.13). The Economic Research Service (ERS) of United States Department of Agriculture (USDA) (USDA-ERS, 1996) published the aggregate price elasticity of demand for the Nigerian food sub-group as -0.67924 while Le-Si et al. (1982) estimated elasticities for different crops (see Appendix 1.4 for details). In this study, Le-Si et al.'s estimates were preferable and used since they are available for specific crops. Hazell and Norton (1986, p. 276) remark that elasticities are frequently borrowed from studies of other countries because they do not differ substantially over countries for principal products or product groups and do not seem to influence sector models significantly when varied moderately. Sector models are reported to be much more sensitive to changes in wage rates and world market (export and import) prices. Table EXP(C,R) defines and inputs the regional real market export prices of the crops into the models. It is important to note that real export prices applied in the model were assumed to be the same with the real domestic prices of the crops due to the fact that the observed international trade data including export prices seem to be unreliable as they are over 400% higher than the real domestic prices and about 200% greater than import prices in some of the crops, suggesting an economic scenario of importing and re-exporting crops that are not produced but utilized locally within the accounting base year period. Similarly, the regional real market import prices were defined and input to the models using table IMP(C,R). Applied import prices are assumed to be 10% more than the domestic real market prices of the crops[7]. The

[7] Commodity import prices obtained from NBS trade department were about 200% higher than the domestic prices. Also commodity prices from World Bank, IMF and FAO did not cover all locally

assumed export and import prices are treated as the world market export and import prices. However, 20% of the export price of each crop is assumed as the transportation cost incurred in exporting each crop from the originating port to the port city of the receiving destination. Therefore the resultant export price implemented in the model for each crop subtracts the exporting (transportation) cost from the world market export price to ensure consistency with the free on board (FOB) concept in international trade. The reverse is implemented in terms of imports (i.e. the real import price implemented in the model for each crop is equal to the world market import price of that crop (10% increase in domestic price) plus its import charges/taxes/tariffs, insurance and freight (CIF)- which is assumed to be 20% of the world market import price of each crop, failing better data on these charges). These assumptions are necessary in the absence of reliable and meaningful export and import data and are subject to subsequent sensitivity analysis. Further, the assumption of the 10% increase in domestic price as the world market import price is based on the economic logic that keeping import prices lower than the domestic prices of goods and services of any economy will lead to flooding of domestic market with foreign goods and services and consequently kill the local industries since they will not be able to compete with established and technologically advanced foreign firms that are even supported with subsidies. A second rationale is that a country with ambition to reduce and/or substitute to a significant level the importation of essential food crops with locally produced crops (as Nigeria plans) is likely to put some 'anti-importation' policies in place which could be in form of high import tariffs. Nevertheless, the first rationale prevails in consideration of Nigeria's membership to The World Trade Organisation (WTO) and/or signatory to the General Agreement on Trade and Tariffs (GATT) which prohibits 'anti-importation' policies from member nations (WTO, 2013). The unit for the export and import prices is US$/MT while the export and import prices are taken to be the same for all the regions. To account for the international (export) demand, table EXD(C,R) defines the quantity of each crop exported by each region within the base year period (- base year taken as 2008 while its data represent 2008 to 2010 averages). Minot (2009, p.52) show that export and import can be regionalised to enhance model realism, while Hazell and Norton (1986, p.180) observe that it is more realistic to specify market-clearing (demand and supply equilibrium) behaviour by region instead of national. To actualise specification of market-clearing behaviour in a regional basis, all demand and supply

produced (and modelled) crops as reported by NBS. However, for the crops covered, the assumed commodity import prices compare closely to the assumed commodity prices implemented in the models.

elements, including exports and import would need to be regionalised. In this study, base year regional export demand is achieved through disaggregation of national crop export data considering the historic regional crop production data and using the estimated percentage regional average crop production to the total (national) average crop production. This is necessary to ensure that every region only has the potential to export crops that it produces and does not export crops that it does not produce. It also helps to determine the regional export comparative advantage on each crop exported. Regional crop export data is in MT per annum. Similarly, on the supply side, Table IMD(C,R) defines the quantity of crop imported by each region in Nigeria. In the base and simulation models, base year export demands and import supplies are implemented as the maximum export and import levels (upper bounds) to ensure reference crop demand and supply balance, as recommended and implemented in previous studies (Minot, 2009, Bauer and Kasnakoglu, 1990). In contrast to the regional export data, the regional import demand is calculated using the estimated percentage regional population data based on the last Nigerian official census data in 2006 (NPC, 2006) and in consideration of the regional crop production pattern. The rationale for using the percentage regional population and the regional crop production pattern data is to give every region the opportunity to import any good and/or service (crop in this case) that is culturally known and consumed by them since it is not likely that any region would import what it cannot consume or use. Inter-regional trade and/or re-sale of imported crop commodities seem to be logically reasonable for crops or commodities that are consumed by other regions. For example, sorghum and millet are purely northern crops and are neither known nor consumed in the southern part of Nigeria (except the southwest region). Hence, it is not likely that there will be significant market (demand) for them in the southern part that will push for their importation. Therefore culture (in terms of crop consumption pattern/preferences) was also considered in estimating the regional commodity imports. Table RE(B,R) denotes the average regional resource endowments. It defines the upper limits of the fixed and semi-fixed resources (land, labour and tractor) used in the production process of the crops and/or feedstocks considered in Model 2. For Model 2, the average regional land resource endowment represents the estimated total hectares of arable land (regional land area minus the built-up areas minus forest areas) available for agricultural use (NBS, 2010b, FAOSTAT, 2014a). While the average regional cultivated hectares of land from 2008 to 2010 as reported in NBS (2010b) denote the regional land resource endowments in the Base Model. On a national scale, only 37% of the available total arable land in Nigeria is currently being cultivated based on the Nigerian farm survey data (NBS, 2010b). From the NBS crop farming employment data, the northwest region employed the highest number of labour (36.3% of the total labour employed- about 50 million people between 2008 and 2010), followed by the southeast region (17.2%), and then the northeast region (15.8%). The north-central and the south-south employed relatively the same number of crop farming labours (12.4%), while the southwest employed the least number of labours (5.9%)- probably due the presence of important commercial cities like Lagos and Ibadan in the region, where people are more likely to be engaged in jobs other than farming. On the other hand, the SE has the highest percentage its population in crop farming (52.4%) while the populations of SS and SW in crop farming are 29.6% and 10.6%, respectively. This distribution seems to agree with the physical and real life situation in the southern part of Nigeria, where the southeast with probably the least number of industries possibly due to the destructive effects of the Biafran war (Achebe, 2012) and the favourable climatic and soil conditions engage more in farming as the major source of livelihood than other regions in Nigeria. In the north, the respective percentage regional population in crop farming based on their 2006 population data are 50.7% for the northwest, 41.7% for the northeast, and 30.4% for the north-central. Similar to the Base Model, the average regional labour endowment for the Simulation Model is the estimated average crop farming labour force in each region as at July 2013. To estimate these regional labour resource endowments, the percentage regional population relative to the last national census (population) data in 2006 are first utilized to quantify the current regional population, using the estimated national population figure of about 175 million people from The World Factbook (2013)[8]. Further, the percentage regional base year crop farming labour force in each region relative to their regional population data, as highlighted above, are then employed to estimate the current available crop farming regional labour forces. This is done by multiplying the estimated current regional population figures with the crop farming regional labour percentages at the base year, assuming constant labour employment share. Finally, the estimated regional crop farming labour forces are disaggregated into family and hired labours using the base year family and hired labour percentage shares in order to arrive at the available regional family labour (family labour RHS or upper bound) implemented in the Simulation Model (Model 2). The regional hired labours are unconstrained in the models, but attract a uniform hired wage cost. It is important to

[8] Current regional population is estimated by multiplying the estimated current national population figure from World Factbook with the regional population percentages.

note that the actual regional family labours available for crop production in the Base and Simulation Models are equal to the regional farm holders plus the regional employed family labours. Below are the regional percentage population and the disaggregated labour employment data used in the estimation of current available regional family labour force. According to NPC (2006), the SE has the least population (11.7%) while the NW has the highest population (25.6%) relative to the total Nigerian population figure of about 140 million people, as at 2006. Following the NW in a decreasing order of magnitude, is the SW with 19.7%, SS with 15.0%, NC with 14.5% and then the NE with 13.6% of the total Nigerian population in 2006. Also the base year regional crop farming labour force, disaggregated into farm holders (farmers), family (farmers' household) and hired labours indicates that the NW has the highest number of farm holders (31.6%), and utilized the highest number of family and hired labours – 29.9% and 61.1%, respectively, compared to other regions. In contrast, the SW has the least number of farm holders (9.1%), and employed the least number of family labours (5.3%) and hired labours (2%) during the same period, compared to other regions. The disaggregated regional crop farming labour for other regions are shown in Appendix 2. The cumulative percentage regional family labour distribution at the base year (i.e. % farm holder plus family labour) used in estimating the available family labour for the Simulation Model are 30.6%, 17.7% and 14.7% for the NW, NE and NC, respectively. In the southern part, the cumulative family labour percentages for SW, SS and SE are 6.8%, 13.0% and 17.2%, respectively. Tractors are also defined in table RE(B,R). According to the information from the Federal Ministry of Agricultural and Rural Development (FMARD) (2012), there are about 40,000 units of tractors in Nigeria but the regional distribution data are not available. The percentage regional farm holders' data were used to distribute/disaggregate the tractor units into the existing six regions. The north-west has the highest number of regional farm holders (31.6%), followed by the northeast (19.5%) and third by the north-central (15.2%), relative to the average total number of farm holders' that engaged in the production of crops considered in the models from 2008 to 2010. Following the north-central region, in a decreasing order of magnitude, are the south-south (12.7%), the southeast (11.8%) and the southwest (9.1%) - having the least percentage farm holders and crop production. Regional arable land area and farm holders' ratio would also influence tractor utilization in a region. From the regional farm size distribution (i.e. the total hectares of land cultivated in each region divided by the corresponding number of farmers (farm holders) that cultivated them), the NC has the highest farm size (2.57 ha/farmer), followed by the SW and NE with farm sizes of 2.04 and 2 ha/farmer, respectively. The farm sizes for the NW, SS and SE, in a decreasing order of magnitude, are 1.71, 1.36 and 1.07 ha/farmer, respectively. On a national scale, the average cultivated farm size in Nigeria between 2008 and 2010 is 1.80 ha/farmer based on the available NBS data. Hence, the northern part has a greater land-to-labour ratio and would likely have a greater potential to utilize tractor in their farming activities than the southern part (except for the SW). However, Hazzel and Norton (1986, pp. 254 - 255) recommend specifying more mechanised techniques to both bigger and smaller farms, allowing decision to use tractor service to be based on relative factor endowments and factor prices. Hence, in this study, the available national tractor units were regionally distributed using the regional percentage farm holders' data highlighted above in order to ensure relatively uniform tractor availability and access to all regions based on farmers' usage. The available regional tractor units are further converted into their equivalent service-hours, assuming 8 hours of service per day and 300 working days per year (excluding 65 days due to holidays and repairs). Therefore a tractor has an endowment of 2,400 service-hours in a year; computed by multiplying the per day service-hour of one tractor (8 hours) by the number of working days in a year (300 days). Other resources in Table RE(B,R) include seeds, fertiliser, pesticides and cash (working capital). Seed represents the total quantity of seeds available to satisfy the seed requirements of all the crops planted in each region. Hazell and Norton (1986, Ch.9, p.201) recommend that the supply of inputs such as seeds, fertilizer and other agrochemicals, except land, family labour and tractor, should be unconstrained in MP models since their supply is perfectly elastic at a specified cost, even in a short-run. Therefore, seed represents the unconstrained supplied seed variable in each region. The same applies to fertilizer and pesticide resource endowments. The cash resource endowment represents the monetary cost of performing all the necessary farm operations (including cost of purchasing all inputs and hiring services) prior to the sale of farm proceeds/produce. It is calculated as the sum of all the unit market prices of the required inputs multiplied by the corresponding quantities of those inputs required to cultivate all feasible hectares of such crops in the models. Similarly, its supply is not constrained in Models 1 and 2. Table BR(B,R) defines the average regional resource use in the base year (from 2008 to 2010). It denotes the upper limit constraints of the resources (resource endowments) used in the production of the crops considered in the Base Model (Model 1), meant for calibration purposes. Table RE(B,R) defines the upper bound of the production resources for policy and scenario simulations (when ethanol production is implemented). The numerical data of the resources in the base year- table BR(B,R) are estimated from the observed 2010 national farm survey data (NBS, 2010b). Finally, the units of the resources in Tables RE(B,R) and BR(B,R) are: 1) land in hectares, 2) labour in man-days or man-hours, 3) seed in metric tonnes (MT), 4) fertilizer in MT, 5) pesticide in MT, 6) cash capital in US$, and 6) tractor in hours.

Tables RRR(C,R,B) define the production input-output coefficients of the crops produced in each of the six regions as implemented in the two models (1 and 2). The input coefficients are derived by dividing the average quantity of each resource (labour, for instance) used between 2008 and 2010 with the average quantity/hectares of land cultivated within the same period. This assumption is necessary due to lack of the required marginal input-output coefficients. Recommended seed rates from research institutions such as IITA and extension agencies such as Information and Communication Support for Agricultural Growth in Nigeria (ICS-Nigeria/IITA, 2011) were used for some crops whose data (usage quantities) were not reported in NBS (2010b). Table RC(B,R) defines the average regional unit cost of the resources utilized in the production of the crops. For simplicity and due to lack of comprehensive regional per unit resource cost data for most the resources, the unit cost of the resources: labour, fertilizer, pesticide, cash capital cost and tractor renting given for one region is assumed to be the same across all regions. Land rent is assumed and implemented as zero US$.

To account for the existing internal trade among the regions, Table RegTransC(C,R) represents the assumed regional transportation cost incurred in transporting crops from one region to another during inter-regional trade of commodities/crops, in US$ per MT. Since actual inter-regional or inter-state trade data (inflows and outflows) do not exist, the models simply require total inflows to be equal to total outflows as recommended and demonstrated by Minot (2009).

Table EPF(E,R,EP) is the last table in model 2. It defines the ethanol production factors employed in Model 2 to account for ethanol production from the produced energy-crop feedstocks. Grain conversion efficiencies (GCE) implemented in Model 2 is as published by Mitchell (2010, p.17) and Johnston et al. (2009, p.4), and GFDS is an inverse of GCE. EERE (2014), Lal (2005, p. 578 , 1995), and Kim and Dale (2004, p. 363) have been useful in deriving, calculating and/or assembling SGR, RCE and RFDS[9]. The same applies to other ethanol production factors: VCG, VCR and EREV.

[9] Lal (2005) provides a mathematical formula for estimating crop residue volume from the grain yield as: residue production = grain production × straw/grain ratio; and the corresponding straw/grain ratios (estimates) for most cellulosic energy materials in his previous work (Lal, 2005), while Kim and Dale (2004) show the ethanol yield per kilogram of some cellulosic feedstocks using the US developed

Parameters are alternative means of defining and inputting data into GAMS. In the two models, the marketing cost of each crop produce is conceived as the cost of transporting 1 MT of that crop from the point of production (the rural areas/farms in different regions) to the point of sale ('central national market') and defined as specified in Table RegTransC(C,R). It is denoted by a Parameter called 'NatMktCost' and enters the objective function as a cost (with negative coefficient). It is implemented by multiplying of the cost of transporting 1 MT of each crop from each region to the marketing/processing centres by its regional total output. DED is the parameter defining the current estimated domestic ethanol demand (5.14*10^9 litres) in Nigeria which represents the minimum volume of ethanol (lower limit value) of ethanol required to satisfy the domestic/national ethanol demand as reported by Ohimain (2010). It is particularly relevant in Model 2. In GAMS, DED is a scalar parameter because it is defined in terms of magnitude only. ETB is another scalar parameter and defines the ethanol blending factor (10%) in Model 2. It is used to estimate the volume of gasoline substituted by the ethanol produced from the energy crops and their residues. Research (Balat et al., 2008, Demirbas, 2007, Demirbas and Balat, 2006, DemİRbaŞ, 2005) show that most car engines can run with 10% ethanol-blended gasoline without requiring additional engine modification.

To estimate the sustainability impact of the ethanol produced from Model 2, we first assume that the 'saved' CO_2 estimated below is equal to the volume of CO_2 absorbed by ethanol feedstocks while growing in field, and then employ another parameter known as the carbon dioxide sustainability factor (CO2SF). CO2SF is derived from the following arithmetic of biofuel production: 1 gallon (3.79 litres) of motor gasoline emits 19.37 pounds of CO_2 according to US Environmental Protection Agency (EPA, 2004, p. 2), implying that 1 litre of gasoline will emit 5.11 pounds (lb) of CO_2. In addition, 5.11 pounds of CO_2 is equivalent to 0.002318216 MT of CO_2 (the CO2SF – achieved by multiplying 5.11 by 4.5359*10^-4) based on the conversion factor advanced by U.S. EPA (2004, p. 1). It therefore implies that 3m litres of ethanol produced and blended with 30m litres of gasoline at the ratio 1:9 (10%:90%), for example, will displace 3m litres of gasoline and save about 7000 metric tonnes of CO_2. The little CO_2 emission during burning of the blended gasoline and/or during the production of the feedstock and processing of it into ethanol has been well-researched

---

theoretical ethanol yield calculator. To arrive at the residue estimates and ethanol yield per metric tonne of residue used in this study, EERE's ethanol yield estimates from residues, Lal's residue estimation method and Kim and Dale's estimates were utilized.

and reported to be less or equal to the volume of CO_2 sequestrated by the biomass feedstock during photosynthesis in the field at the growing stage of the feedstock (for details see Shapouri et al., 2010, Schmer et al., 2008, Shapouri et al., 2002b, Shapouri et al., 2001, Macedo, 1998). Similarly, parameter RPPIMRS is used to calculate import revenue savings from refined petroleum product that would have been imported if ethanol is not produced and if gasoline has been fully used to meet the national domestic energy (transport fuel) demand. To estimate RPPIMRS, we utilized the 2012 projected price of refined petroleum products (RPP) (motor gasoline) which is US$256 per gallon (3.79 litres) according to the U.S. Department of Energy, Energy Information Administration (EIA) (2012). From the EIA data, it implies that one litre of the RPP costs about US$70. However, Nigeria currently spends about US$5 billion per year, equivalent to about 4% of her GDP, importing this RPP. It therefore follows that Nigeria will be saving about US$211m per year if she replaces 3m litres of gasoline with 3m litres of ethanol under E-10 blending. It is important to remark that parameters CO_2SF and RPPIMRS are both scalar. To calculate the residues produced from the energy crops in all the regions, parameter RES(E,R) was employed as described below.

3.7 Model Definition

The model definition refers to the algebraic expression (structure) or mathematical equations used to define and implement all the structural elements (parameters) of the NEFM as given below.

The algebraic formula used to estimate the regional residues produced from the energy crops is as given in the equation below:

$$RES_{E,R} = 0.3 * \sum(EPF_{SGR} * Y_{E,R});\ Y_{E,R} \neq 0 ------------------(6)$$

where $RES_{E,R}$ is the quantity of residues collected for ethanol production from the total quantity of residues generated from the grain feedstocks, while EPF_{SGR} and $Y_{E,R}$ are as defined already. The 30% residue collection is only considered to ensure that all residues produced in the farm are not removed since they are needed for the maintenance of soil fertility, prevention of soil erosion and for other economic and cultural uses such as animal bedding (as straw) and roofing sheets in remote areas as done in northern part of Nigeria. Other regional parameters are defined and implemented as given below:

A. For the regional seed cost per hectare of each crop produced/cultivated:

$$SC_{C,B,R} = \sum\left(RRR_{C,SEED,R}/1000 * DP_{C,R}\right);\ DP_{C,R}, RRR_{C,SEED,R} \neq 0 ------ (7)$$

where

$RRR_{C,SEED,R}$ is the quantity of seed in kg required to grow a ha of each crop considered in the models in each region, and $DP_{C,R}$ is the regional real domestic price for a MT of each crop in US$.

$$SCT_{C,B,R} = \sum_{i=r1}^{r6} SC_i ------------------------- (8)$$

where

$SCT_{C,B,R}$ is the total cost of seeds required to grow a ha of each crop considered in the models in all the regions (Nigeria). R_1 = NW, R_2 = NE, R_3 = NC, R_4 = SW, R_5 = SS and R_6 = SE.

B. For the cash required to cultivate one ha of each crop produced in each region:

$$CR_{C,B,R} = \sum\left(RRR_{C,R,LAN,T} * RC_{LAN,R} + RRR_{C,R,FLAB,T} * RC_{FLAB,R} + RRR_{C,R,HLAB,T} * RC_{HLAB,R} + SC_{C,B,R} + RRR_{C,R,FERT} * RC_{FERT,R} + RRR_{C,R,PEST} * RC_{PEST,R} + RRR_{C,R,TRACT,T} * RC_{TRAC,R}\right);\ RRR_{C,B,R}, RC_{B,R}, \neq 0 --(9)$$

where

$RRR_{C,R,SEED,FERT,PEST}$ are the respective quantities of seed, fertilizer and pesticide (input resources with unlimited supply) required to grow a hectare of each crop considered in the models in each region. Similarly, $RRR_{C,R,LAN,T,LAB,T,TRAC,T}$ are the respective quantities of land, labour and tractor (input resources with limited and seasonal supply characteristics) required to grow a hectare of each crop considered in the models in each region. Subscript T denotes cropping season, representing the different periods of the year from January to December when specific farm operations are performed. $RC_{B,R}$ is the regional real domestic unit price for each of the resources employed in the production and $CR_{C,B,R}$ is the total cash (in US$) required to cultivate a hectare of each of the crops considered in the models in each region; while $SC_{C,B,R}$ is the cost of seed cost required to grow 1 ha of each crop.

$$TCR_{C,B,R} = \sum_{i=r1}^{r6} CR_i ------------------------- (10)$$

where

$TCR_{C,B,R}$ is the total cash required to grow a ha of each crop considered in the models in all the regions. The total cash required can also be defined as equal to the total variable cost.

C. For the cost of borrowed cash capital required to procure all resources required to cultivate 1 ha of each crop produced:

$$CC_{C,B,R} = \sum \left(CR_{C,B,R} * RC_{CASH,R}\right);\ CR_{C,B,R}, RC_{CASH,R}, \neq 0 - - - - - - - - - - (11)$$

where

$CR_{C,B,R}$ is the cash required to procure all the resources (land, labour, seed, fertilizer, pesticide and tractor) required to grow a hectare of each crop considered in the models in each region, $RC_{CASH,R}$ is the cost of borrowed cash (interest rate) required to finance the purchase of each of the resources employed in the production process and $CC_{C,B,R}$ is the total cost of cash (in US$) required to cultivate a hectare of each of the crops considered in the models in each region. $RC_{CASH,R}$ is the official and prevailing annual interest rate from Nigerian Central Bank in 2013 (CBN, 2013), which in this case is thirty percent (30%) of the total borrowed capital, and it is the same across all the regions in Nigeria.

$$CCT_{C,B,R} = \sum_{i=r1}^{r6} CC_i * RC_{CASH,R} - (12)$$

where

$CCT_{C,B,R}$ is the total cost of cash required to grow a ha of each crop considered in the models in all the regions, while $RC_{CASH,R}$ is the official and prevailing annual interest rate in Nigeria from CBN (2013), which in this case is thirty percent (30%) of the total borrowed capital, and it is the same across all the regions in Nigeria.

D. For the regional variable cost incurred to cultivate one ha of each crop produced:

$$VC_{C,B,R} = \sum \left(RRR_{C,LAN,R} * RC_{LAN,R} + RRR_{C,LAB,R} * RC_{LAB,R} + SC_{C,B,R} + RRR_{C,FERT,R} * RC_{FERT,R} + RRR_{C,PEST,R} * RC_{PEST,R} + CC_{C,B,R} + RRR_{C,TRAC,R} * RC_{TRAC,R}\right);\ RRR_{C,B,R}, RC_{B,R}, \neq 0 - - - - - - - - - - - - - - (13)$$

where

$RRR_{C,B,R}$, $RC_{B,R}$, $SC_{C,B,R,}$and $CC_{C,B,R}$ are as already defined, while $VC_{C,B,R}$ is the total variable cost (in US$) incurred to cultivate a hectare of each of the crops considered in the models in each region.

$$TVC_{C,B,R} = \sum_{i=r1}^{r6} VC_i ----------------------------(14)$$

where

$TVC_{C,B,R}$ is the total variable cost required/incurred to grow a ha of each crop considered in the models in all the regions.

E. For the regional domestic sales revenue generated from crops produced in 1 ha:

$$RDREV_{C,R} = \sum \left(Y_{C,R} * DP_{C,R}\right);\ Y_{C,R}, DP_{C,R}, \neq 0 -------------(15)$$

where

$Y_{C,R}$ and $DP_{C,R}$ are as already defined and $RDREV_{C,R}$ is the total regional domestic sales revenue realizable from the crops produced in 1 ha of land.

F. For the regional production variables and equations (model constraints):

There are some differences in the definition and implementation of the model variables and equations between Model 1 and 2. Differences in the regional resource endowments and model constraints based on the conditions considered and implemented in each model are the major reasons for the differences. Thus, two equations are used to describe the production constraints implemented for each variable in each region[10].

i) For regional land allocation constraint (land use balance):

$$\sum_{i=r1}^{r6} Land_{C,i,T} \leq \sum_{i=r1}^{r6} BR_{LANi} -----------------------(16)$$

where

$Land_{C,i,T}$ is the hectare of land required to grow each crop considered in the Base Model (Model 1) in each region according to the seasonal cropping calendar (T). BR_{LANi} is already defined as the base year regional land endowment, i.e., the annual average hectares of land cultivated and harvested in each region between 2008 and 2010. The cropping season (T) is defined in 12 calendar months from January to

[10] It is important to remark that all variables in the model are first declared using a descriptive text input approach before being referenced in the model equations. For brevity, this step is omitted here but implemented in the actual GAMS statements written for the models and can be obtained from the author on request.

December with recognition of the specific periods of the year when certain farm operations: land preparation/planting activities such as clearing, stumping, ploughing, ridging and planting; fertilizer application/weeding; and harvesting; are performed. The cultivated land variable ($XL_{C,i}$) is defined and implemented as the hectares of land allocated for the production of each crop in each region.

$$\sum_{i=r1}^{r6} Land_{C,i,T} \leq \sum_{i=r1}^{r6} RE_{LAN,i} -----------------------(17)$$

where

$Land_{C,i,T}$ is the hectare of land required to grow each crop considered in Model 2 in each region according to the seasonal cropping calendar (T). $RE_{LAN,i}$ is already defined as the regional land endowment - the maximum hectares of arable land in each region available for production activities in the Ethanol-Food Production Model (Model 2).

ii) For the regional labour allocation constraint (labour use balance):

$$\sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,LAB,T} \leq \sum_{i=r1}^{r6} \left(RE_{FLAB,i,T} + RE_{HLAB,i,T}\right) ------- (18)$$

where

$RE_{FLAB,i,T}$ and $RE_{HLAB,i,T}$ are the regional seasonal family labour and hired labour supply variables, respectively; in Model 2. However, family labour supply is limited to the available family labour supply per month, while the hired labour is unrestricted. $XL_{C,i}$ is as defined above while $RRR_{C,i,LAB,T}$ is defined as the regional per ha labour requirement of each crop per month. The monthly available regional family labour in the ethanol and food production model (Model 2) is equal to the earlier estimated crop farming regional family labour as at July 2013; while that of the Base Model (Model 1) is equal to the crop farming regional family labour utilized at the base year.

$$\sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,LAB,T} \leq \sum_{i=r1}^{r6} \left(BR_{FLAB,i,T} + BR_{HLAB,i,T}\right) ------- (19)$$

where

$BR_{FLAB,i,T}$ and $BR_{HLAB,i,T}$ are the regional seasonal family labour and hired labour supply variables, respectively; for Model 1. $XL_{C,i}$ and $RRR_{C,i,LAB,T}$ are as defined above.

iii) For the regional seed allocation constraint (seed use balance):

$$\sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,SEED} \leq \sum_{i=r1}^{r6} RE_{SEED,i} \text{--------------} (20)$$

where

$XL_{C,i}$ and $RRR_{C,i,SEED}$ are as defined above. As noted earlier, $RE_{SEED,i}$ is the unconstrained seed supply variable in Model 2, representing the total quantity of seed supplied for the production of each crop in each region in the Ethanol-Food Production Model (Model 2).

$$\sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,SEED} \leq \sum_{i=r1}^{r6} BR_{SEED,i} \text{----------------} (21)$$

where

$XL_{C,i}$ and $RRR_{C,i,SEED}$ are as defined above. $BR_{SEED,i}$ is the unconstrained seed supply variable in Model 1, representing the total quantity of seed supplied for the production of each crop in each region in the Food Production Model (Model 1). In essence, the seed, fertilizer and pesticide use balance equations ensure that the quantity of each of these resources required for the crop production activities are supplied[11].

iv) For the regional fertilizer allocation constraint (fertilizer use balance):

$$\sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,FERT} \leq \sum_{i=r1}^{r6} RE_{FERT,i} \text{--------------} (22)$$

where

$XL_{C,i}$ and $RRR_{C,i,FERT}$ are as defined above. $RE_{FERT,i}$ is the unrestricted fertilizer supply variable in Model 2, denoting the total quantity of fertilizer supplied for crop production in each region in the Ethanol-Food Production Model (Model 2).

$$\sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,FERT} \leq \sum_{i=r1}^{r6} BR_{FERT,i} \text{----------------} (23)$$

where

$XL_{C,i}$ and $RRR_{C,i,FERT}$ are as defined above. $BR_{FERT,i}$ is the unrestricted fertilizer supply variable in Model 1, denoting the total quantity of fertilizer supplied for crop production in each region in the Food Production Model.

[11] Recall that the seed, fertilizer, pesticide, cash and hired labour supply variables are unrestricted, since their supply is perfectly elastic even in the short-run unlike the land, family labour and tractor supply variables.

v) For the regional pesticide allocation constraint (pesticide use balance):

$$\sum_{i=r1}^{r6} XL_i * \sum_{i=r1}^{r6} RRR_{C,i,PEST} \leq \sum_{i=r1}^{r6} RE_{PEST,i} ---------------- (24)$$

where

$XL_{C,i}$ and $RRR_{C,i,PEST}$ are as defined above. $RE_{PEST,i}$ is the unconstrained pesticide supply variable in Model 2, representing the total quantity of fertilizer supplied for crop production in each region the ethanol and food production model.

$$\sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,PEST} \leq \sum_{i=r1}^{r6} BR_{PEST,i} ----------------- (25)$$

where

$XL_{C,i}$ and $RRR_{C,i,PEST}$ are as defined above. $BR_{PEST,i}$ is the unconstrained pesticide supply variable in Model 1, representing the total quantity of fertilizer supplied for crop production in each region the Food Production Model.

vi) For the regional tractor allocation constraint (tractor use balance):

$$\sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,TRAC} \leq \sum_{i=r1}^{r6} RE_{TRACT,i} -------------- (26)$$

where

$XL_{C,i}$ and $RRR_{C,i,TRAC}$ are as defined above. $RE_{TRACT,i}$ is the regional seasonal tractor labour supply variable for Model 2, constrained with the earlier estimated annual (and by extension monthly) available stock of tractor service. It is important to note that the monthly available tractor service is the same for both models; but it is only implemented as a policy scenario in the Ethanol-Food Production Model to study: 1) the possibility of replacing some of the traditional un-mechanised (manual) labour employed during the land preparation operations with tractor; and 2) the impact of such decision to the potential gross margin, assuming all other parameters are held constant.

vii) For the regional cash requirement constraint (cash use balance):

$$\sum_{i=r1}^{r6} RE_{VARIABLECOST,i} \leq \sum_{i=r1}^{r6} RE_{CASH,i} --------------- (27)$$

and

$$\sum_{i=r1}^{r6} BR_{VARIABLECOST,i} \leq \sum_{i=r1}^{r6} BR_{CASH,i} -----------------(28)$$

where

$BR_{CASH,i}$ and $RE_{CASH,i}$ are the unconstrained cash supply variables in Models 1 and 2, respectively. They represent the total cash used to perform all farm operations prior to harvesting and selling of farm produce in the Food Production Model and Ethanol-Food Production Model, respectively. In other words, they represent the total cost of labour, seed, fertilizer, pesticide and tractor supplied for crop production activities in Models 1 and 2.

G. For Optimal Variable Cost of Production:

i) Accounting Cost for Land Rent (in US$)

$$RACLAN_{C,i} = \sum_{i=r1}^{r6} \left(XL_{C,i} * RC_{LAN,i}\right) ------------------ (29)$$

where

$RACLAN_{C,i}$ is the regional optimum land rent, while $XL_{C,i}$ is as defined already. $RC_{LAN,i}$ is the per ha land rent in each region (implemented as zero in the Base Model).

ii) For Accounting Cost for Labour (in US$)

$$RACLAB_{i} = \sum_{i=r1}^{r6} \left(RE_{FLAB,i} * RC_{FLAB,i} + RE_{HLAB,i} * RC_{HLAB,i}\right) ------- (30)$$

where

$RACLAB_{i}$ is the regional optimum cost of hiring labour, while $RE_{FLAB,i}$ and/or $BR_{FLAB,i}$ are as already defined above. $RC_{FLAB,i}$ and $RC_{HLAB,i}$ are the family and hired labour unit cost, with the family labour (US$3.5) being US$1 lesser than the observed unit cost of hired labour (US$4.5).

iii) For Accounting Cost for Seed (in US$)

$$RACSEED_{C,i} = \sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,SEED} * \sum_{i=1}^{6} SC_{i} -----------(31)$$

where

$RACSEED_{C,i}$ is the regional optimum seed cost, while $XL_{C,i}$, $RRR_{C,i,SEED}$ and SC_{i} are as already defined above.

iv) For Accounting Cost for Fertilizer (in US$)

$$RACFERT_{C,i} = \sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,FERT} * \sum_{i=r1}^{r6} RC_{FERT,i} ---------- (32)$$

where

$RACFERT_{C,i}$ is the regional optimum cost of purchasing fertilizer, while $XL_{C,i,}$ $RRR_{C,i,FERT}$ and $RC_{FERT,i}$ are as already defined above.

v) For Accounting Cost for Pesticide (in US$)

$$RACPEST_{C,i} = \sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,PEST} * \sum_{i=r1}^{r6} RC_{PEST,i} ----------- (33)$$

where

$RACPEST_{C,i}$ is the regional optimum cost of purchasing pesticide, while $XL_{C,i}$, $RRR_{C,i,PEST}$ and $RC_{PEST,i}$ are as already defined above.

vi) For Accounting Cost for Hiring Tractor (in US$)

$$TRAC_{C,i} = \sum_{i=r1}^{r6} XL_{C,i} * \sum_{i=r1}^{r6} RRR_{C,i,TRAC,T} * \sum_{i=r1}^{r6} RC_{TRAC,i} ----------- (34)$$

where

$TRAC_{C,i}$ is the regional optimum cost of hiring tractor, while $XL_{C,i,}$ $RRR_{C,i,TRAC,T}$ and $RC_{TRAC,i}$ are as already defined above.

vii) For Accounting Cost for Cost of Cash Capital (in US$)

$$RACCASH_{C,i} = \sum_{i=r1}^{r6} RE_{CASHi} * RC_{CASH,i} ------------------ (35)$$

where

$RACCASH_{C,i}$ is the regional optimum cost of cash capital required to cultivate all crops considered in the model, while $XL_{C,i}$ and $RC_{CASH,i}$ are as already defined above.

viii) Grand Total Regional Variable/Operational Cost of Production (GTRVC in US$)

$$GTRVC_{C,i} = \sum_{i=r1}^{r6} \big(RACLAN_{C,i} + RACLAB_{C,i} + RACSEED_{C,i} + RACFERT_{C,i} + RACPEST_{C,i} + TRAC_{C,i} + RACCASH_{C,i}\big) -- (36)$$

where

$\text{REVC}_{E,i}$ denotes the regional total ethanol variable cost of production from grains and residues, while other parameters are as previously defined.

ix) For National/Regional Optimum Crop Production Accounting (in MT):

$$NCPAC_{C,R} = \sum (XL_{C,R} * Y_{C,R}); \; Y_{C,R} \neq 0 ------------------(37)$$

where

$Y_{C,R}$ and $XL_{C,R}$ are as already defined and $NCPAC_{C,R}$ is the regional crop production variable, representing the optimum regional domestically produced crops.

x) For National/Regional Optimum Feedstock Production Accounting:

$$RegFDST_{E,R} \leq \sum (XL_{E,R} * Y_{E,R}); \; Y_{E,R} \neq 0 ----------------- (38)$$

where

$Y_{E,R}$ and $XL_{E,R}$ are as already defined and $RegFDST_{E,R}$ is the energy feedstock demand variable, denoting the potential regional quantity of each energy crop (feedstock) demanded (sold) for ethanol production in each region. The regional feedstock equation is implemented with less than or equal to constraint (≤) in order to allow the model the flexibility of choosing the best feedstock(s) for ethanol production in each region based on each feedstock crop-to-ethanol conversion coefficients (yield), energy crop demand and supply specifications in the region as well as crop production inputs' demand and supply conditions in each region. The feedstock supply equation is only relevant to and is implemented in the Ethanol-Food Production Model (Model 2) and not in the Base Model (Model 1). The cost of the feedstock produced/supplied and utilized for ethanol production is implicitly included in the model as part of the total cost of crop production at the objective function; hence, it was not included in the ethanol production cost.

xi) For National/Regional Optimum Residue Production Accounting

$$NRESPAC_{E,R} = \sum (XL_{E,R} * RES_{E,R}) \; RES_{E,R,} \neq 0 -------------(39)$$

where

$XL_{E,R}$ and $RES_{E,R}$ are as already defined; while $NRESPAC_{E,R}$ is the optimum national/regional residues generated from the domestically produced energy crops. It is important to note that equations (38 – 39) are only present in Model 2 where ethanol production from energy crop/residues is considered.

xii) Inter-Regional Crop Trade Equations (regflows):

$REGFLOWS_{C,i^*,i}$ and $REGFLOWS_{C,i,i^*}$ are the inter-regional crop import and export variables - representing the sum of crops imported from region i* to i and exported from region i to i*, respectively. In the two models, they are implemented such that only the cost of net-crop import from region i* to i (after deducting the quantity of crops exported from region i to i*) enters the objective function with a negative sign as recommended and applied in Hazell and Norton (1986, ch.8, p.181); thus making it possible for the model to account for the quantity traded as well as the direction of trade among the regions. The net-crop import cost – $REGFLOWSC_{C,i^*,i}$ is implemented by multiplying the net-imported quantity of crops by their respective inter-regional transportation cost.

xiii) National/Regional Total Crop Demand Equation (RegDem):

$$RegDem_{C,i} = \sum_{i=r1}^{r6} RegCons_{C,i} + \sum_{i=r1}^{r6} RCEX_{C,i} + \sum_{i=r1}^{r6} REGFLOWS_{C,i,i^*} + \sum_{i=r1}^{r6} RegFDST_{E,i} \text{---------------------} (40)$$

where

$RegCons_{C,i}$ is the regional crop consumption demand variable (equivalent to reference crop consumption demand (DCD) estimated earlier). It is the sum of all other internal domestic crop utility demands such as crop demand for food, feed, seed, raw materials and stock. $RCEX_{C,i}$ is the regional export demand variable for each of the crops, $REGFLOWS_{C,i,i^*}$ and $RegFDST_{E,i}$ are as already defined and $RegDem_{C,i}$ is total crop demand in each region.

xiv) National/Regional Total Crop Supply Equation (RegSup):

$$RegSup_{C,i} = \sum_{i=r1}^{r6} NCPAC_{C,i} + \sum_{i=r1}^{r6} RCIM_{C,i} + \sum_{i=r1}^{r6} REGFLOWS_{C,i^*,i} \text{-----} (41)$$

where

$NCPAC_{C,i}$ is the regional optimal crop output; $RCIM_{C,i}$ is the regional import supply variable for each of the crops. $REGFLOWS_{C,i^*,i}$ is as already defined while $RegSup_{C,i}$ is total crop supply in each region. All units are in metric tonnes. For a market driven economy, the materials balance equation below must hold.

xv) National Crop (Material) Balance Equation (MatBal)

$$\text{MatBal}_{C,i} = \sum_{i=r1}^{r6} NCPAC_{C,i} + \sum_{i=r1}^{r6} IMD_{C,i} + \sum_{i=r1}^{r6} REGFLOWS_{C,i^*,i} \geq \sum_{i=r1}^{r6} RegCons_{C,i} + \sum_{i=r1}^{r6} RegFDST_{E,i} + \sum_{i=r1}^{r6} EXD_{C,i} + \sum_{i=r1}^{r6} REGFLOWS_{C,i,i^*} ----(42)$$

where

$\text{MatBal}_{C,i}$ represents the crop material (demand-supply) balance and other parameters are as already defined.

xvi) National Crop Consumption Equation (RegCons)

$$\text{RegCons}_{C,i} = \sum_{i=r1}^{r6} NCPAC_{C,i} + \sum_{i=r1}^{r6} RCIM_{C,i} + \sum_{i=r1}^{r6} REGFLOWS_{C,i^*,i} - \sum_{i=r1}^{r6} RegFDST_{E,i} - \sum_{i=r1}^{r6} RCEX_{C,i} - \sum_{i=r1}^{r6} REGFLOWS_{C,i,i^*} --- (43)$$

where

$\text{RegCons}_{C,i}$ represents the regional crop consumption and other parameters are as already defined.

H. For Ethanol Production Accounting:

i) National/Regional Ethanol Production From Grain only (REPGAC):

$$\text{REPGAC}_{E,i} = \sum_{i=r1}^{r6} \text{RegFDST}_{E,i} * \sum_{i=r1}^{r6} EPF_{E,GCEi} ---------------(44)$$

where

$\text{REPGAC}_{E,i}$ represents the regional total volume of ethanol produced from the energy crop grains while other parameters are as already defined.

ii) National/Regional Ethanol Production from Energy Crop Residues (REPRAC):

$$\text{REPRAC}_{E,i} = \sum_{i=r1}^{r6} NRESPAC_{E,i} * \sum_{i=r1}^{r6} EPF_{E,i,RCE} -------------- (45)$$

where

$\text{REPRAC}_{E,i}$ represents the national/regional total volume of ethanol produced from the energy crop residues while other parameters are as defined already.

iii) Regional Ethanol Variable Cost of Production from Grains (REVCGAC):

$$\text{REVCGAC}_{E,i} = \sum_{i=r1}^{r6} \left(\text{REPGAC}_{E,i} * EPF_{E,i.VCG}\right) ---------------(46)$$

where

All parameters are as previously defined. Here $\text{REPGAC}_{E,i}$ multiplied by $EPF_{E,i,VCG}$ is equal to the variable (processing) cost of producing ethanol without the feedstock (grain) cost, since the cost of the feedstock produced and supplied for ethanol production has already been implicitly included in the model as the modelled feedstock demand in the objective function.

iv) Regional Ethanol Variable Cost of Production from Residues (REVCRAC):

$$\text{REVCRAC}_{E,i} = \sum_{i=r1}^{r6} \left(\text{REPRAC}_{E,i} * EPF_{E,i,VCR}\right) ---------------(47)$$

where

All parameters are as previously defined. Similarly, $\text{REPRAC}_{E,i}$ multiplied by $EPF_{E,i,VCR}$ is equal to the variable cost of producing ethanol without the feedstock (residue) cost. We assumed the cost (price) of the residues supplied to be equal to zero since residues are not currently traded in Nigeria. However, this would be subject to sensitivity analysis in order to test the impact of residues' cost on ethanol production gross margin if the model suggests that cellulosic ethanol has significant potential in the ethanol production mix in Nigeria.

v) National/Regional Total Ethanol Variable Cost of Production (Grain + Residues):

$$\text{REVC}_{E,i} = \sum_{i=r1}^{r6} \left(\text{REVCGAC}_{E,i} + \text{REVCRAC}_{E,i}\right) ---------------(48)$$

where

$\text{REVC}_{E,i}$ denotes the regional total ethanol variable cost of production from grains and residues, while other parameters are as previously defined.

vi) National/Regional Ethanol Revenue from Grains (REREVGAC):

$$\text{REREVGAC}_{E,i} = \sum_{i=r1}^{r6} \left(\text{REPGAC}_{E,i} * EPF_{E,i,EREV}\right) ------------(49)$$

where

$\text{REREVGAC}_{E,i}$ is the regional revenue generated from ethanol produced from grains, other parameters remain as already defined.

vii) National/Regional Ethanol Revenue from Residues (REREVRAC):

$$\text{REREVRAC}_{E,i} = \sum_{i=r1}^{r6} \left(\text{REPRAC}_{E,i} * EPF_{E,i,EREV} \right) ------------ (50)$$

where

$\text{REREVRAC}_{E,i}$ is the regional revenue generated from ethanol produced from residues, other parameters are as already defined.

viii) National/Regional Total Ethanol Revenue from Grains and Residues (REREV):

$$\text{REREV}_{E,i} = \sum_{i=r1}^{r6} \left(\text{REREVGAC}_{E,i} + \text{REREVRAC}_{E,i} \right) ------------ (51)$$

where

$\text{REREV}_{E,i}$ is the total regional revenue generated from ethanol produced from grains and residues, other parameters are as already defined.

ix) National/Regional Ethanol Gross Margin (REGM):

$$\text{REGM}_{E,i} = \sum_{i=r1}^{r6} \left(\text{REREV}_{E,i} - \text{REVC}_{E,i} \right) ----------------- (52)$$

where

$\text{REGM}_{E,i}$ is the regional gross margin from ethanol produced from grains and residues, other parameters are as already defined.

x) National/Regional Gasoline-Ethanol Blending (REB):

$$\text{REB}_{E,i} = \sum_{i=r1}^{r6} \left(\text{REPGAC}_{E,i} + \text{REPRAC}_{E,i} \right) * ETB ------------- (53)$$

where

$\text{REB}_{E,i}$ represents the total volume of gasoline (in litres) substituted with the ethanol produced from the energy crops (grains and residues) in each region, while other parameters are as already defined.

xi) National/Regional CO_2 Saving Impact (RCO2S):

$$\text{RCO2S}_{E,i} = \sum_{i=r1}^{r6} \text{REB}_{E,i} * CO2SF ------------------(54)$$

where

$\text{RCO2S}_{E,i}$ represents the quantity of CO_2 emission (MT) saved as a result of the gasoline substituted with the ethanol produced from the energy crops in each region, while other parameters are as already defined.

xii) National/Regional Refined Petroleum Products Import Saving Impact:

$$\text{RRPPIMS}_{E,i} = \sum_{i=r1}^{r6} \text{REB}_{E,i} * RRPPIMRS ----------------(55)$$

where

$\text{RRPPIMS}_{E,i}$ represents the amount of money (in US$) saved as a result of the quantity of gasoline (RPP) substituted with the ethanol produced in each region, while other parameters are as already defined.

I. National/Regional Ethanol Demand Constraint (REDC):

$$\sum_{i=r1}^{r6} \text{REPGAC}_{E,i} + \sum_{i=r1}^{r6} \text{REPRAC}_{E,i} + \sum_{i=r1}^{r6} \text{RETHANOLIMPORT}_{i} - \sum_{i=r1}^{r6} \text{RETHANOLEXPORT}_{i} \geq DED(i) ----------- (56)$$

where

DED_i represents the estimated total national ethanol demand from both the energy crop grains and residues (5.14 billion litres as reported by Ohimain (2010)), disaggregated into regional ethanol demands using the percentage regional arable land data. From the Nigerian land use data, the SE has the least share of the total available arable land in Nigeria and consequently the least ethanol demand (3.2%), while the NE has the highest share (30.8%). In a descending order of magnitude, the arable land and ethanol demand share of other regions are 24.5%, 23.3%, 9.3% and 8.4% for NC, NW, SS and SW, respectively. The regional population data would also be relevant in estimating the regional ethanol demand; however, we preferred the percentage regional arable land data since the feedstock required for the production of ethanol would require land (as the most important production factor) to grow. Also each region has the possibility of importing ethanol if their production is lower than their corresponding ethanol demand. RETHANOLIMPORT_i and RETHANOLEXPORT_i are the regional ethanol import and export variables. The cost of importing and exporting ethanol enter the objective function as a cost (with negative sign) and as a revenue (with positive), respectively. To implement the ethanol import and export costs, ethanol minimum selling price (EMSP) of US$.57 as advanced by Humbird et al. (2011, p.iv) is utilized. For the import, the EMSP is increased by 20% to account for the importation cost (CIF); and reduced by 20% for export in order to adjust for the exporting cost (FOB). Hence, the real cost of importing one litre of ethanol from the world market is US$0.68, denoted by EMSPIM while that of export is US$0.46, represented by EMSPEX. Other parameters are as already defined.

J. National/Regional Crop Export Revenue:

$$\text{REXREV}_{C,i} = \sum_{i=r1}^{r6} \left(RCEX_{C,i} * EXP_{C,i} \right) ------------------ (57)$$

where

$\text{REXREV}_{C,i}$ is the regional export revenue generated from the sale of locally produced crops, other parameter are as already defined.

K. National/Regional Crop Import Expenses

$$\text{RIMC}_{C,i} = \sum_{i=r1}^{r6} \left(RCIM_{C,i} * IMP_{C,i} \right) ------------------- (58)$$

where

$\text{RIMC}_{C,i}$ is the regional import cost of food crops, other parameter are as already defined.

L. National/Regional Slope/Gradient of the Demand Curve (Beta) for the Crops:

$$\text{BETA}_{C,i} = DP_{C,i} \div DCD_{C,i} \div PED_{C,i};\ DP_{C,i}, DCD_{C,i}, PED_{C,i} \neq 0 ------ (59)$$

where

$\text{BETA}_{C,i}$ is the national/regional slope (gradient) of the linear demand curve for the entire crops considered in the models, other parameters are as already defined. $\text{BETA}_{C,i}$ is alternatively defined as the change in price over the change in quantity demanded of such goods (crops) and/or services.

M. National/Regional Crops Demand Curve Intercept (Alpha):

$$\text{ALPHA}_{C,i} = DP_{C,i} - BETA_{C,i} * DCD_{C,i};\ DP_{C,i}, \neq 0 ------------(60)$$

where

$\text{ALPHA}_{C,i}$ is the national/regional intercept of the linear demand curve for the entire crops considered in the models, other parameters are as already defined.

N. Regional Crop Marketing (Transportation) Variable (RegCropTrans):

$$RegCropTrans_{C,i} = \text{NCPAC}_{C,i}; ------------------(61)$$

where

$\text{NCPAC}_{C,i}$ are the quantities of crops produced in each region as defined earlier; and $RegCropTrans_{C,i}$ are the quantities of crops transported from the point of production (regional level) to the marketing or processing centres (national level).

O. National Crop Marketing (Transportation) Cost (NatMktCost):

$NatMktCost_{C,i}$ is the cost of marketing (transportation) 1 MT of each crop from each region to the national/regional market centres. It is represented by values in row 'NIG' in Table RegTransC(C,R) and unit is in US$ per MT. Note that equations (59) to (61) are implemented as Parameters in GAMS.

P. National/Regional Consumer-Producer Surplus (Objective Function) (CPS):

$$\begin{aligned}\text{CPS}_{C,i} = &\sum_{i=r1}^{r6}\left(\text{ALPHA}_{C,i} * \text{RegCons}_{C,i}\right) + \sum_{i=r1}^{r6}\left(0.5 * \text{BETA}_{C,i} * \text{RegCons}_{C,i}{}^{2}\right)\\ &- \sum_{i=r1}^{r6}\left(REGFLOWS_{C,i^*,i} * REGFLOWSC_{C,i^*,i}\right)\\ &+ \sum_{i=r1}^{r6}\left(\text{REXREV}_{C,i} - \text{RIMC}_{C,i}\right) + \sum_{i=r1}^{r6}\text{REGM}_{E,i}\\ &- \sum_{i=r1}^{r6}(\text{RETHANOLIMPORT}_{i} * \text{EMSPIM})\\ &+ \sum_{i=r1}^{r6}(\text{RETHANOLEXPORT}_{i} * \text{EMSPEX})\\ &- \sum_{i=r1}^{r6}\left(NatMktCost_{C,i} * RegCropTrans_{C,i}\right) - \sum_{i=r1}^{r6} GTRV_{C,i} \quad (62)\end{aligned}$$

where

$\mathrm{CPS}_{C,i}$ is the national/regional consumer-producer surplus under competitive market equilibrium system in the integrated model (Models 1 and 2), other parameter are as already defined. Ethanol production component of the model is deactivated and the ethanol gross margin, ethanol importing and exporting costs removed from the objective function when the objective is to evaluate only crop production.

As a last remark on the model structure, the estimated base year domestic crop demand (DCD) is implemented as upper bound for the regional consumption variable to ensure that the modelled regional consumption is not greater than the reference (base year) domestic crop demand in the calibration and the first simulation (ethanol production) runs, since static comparison of the Base Model and Ethanol-Food Production Model results are required.

Chapter 4. The Model Results

The major objective of this research is to develop and apply a sectoral Energy-Food Model (EFM) for the production of biofuel feedstocks and staple food crops in six different regions of Nigeria, in order to assess how biofuel production can contribute to energy and food securities in Nigeria. The specific research objectives are to: 1) analyse the supply capacity and economic viability of the feedstock and food suppliers (the farmers in Nigeria) to the conceived ethanol policy, given the available production resources; 2) estimate the bioethanol production potential in Nigeria; 3) identify the regional potential 'best' feedstock; 4) estimate the potential foreign exchange savings from RPP import based on the ethanol produced; 5) assess the impacts of the potential feedstock and bioethanol demands and supplies on the national energy and food securities; and 6) proffer some policy recommendations based on the EFM results. Results presented in this chapter address all the specific objectives except the last one which is addressed in Chapter 6. In addition, scenarios and sensitivity analyses of the baseline results are presented in Chapter 5. The discussion of the results in this chapter is organised in this order: calibration run (Model 1) results are presented in Section 4.1, while the first simulation run (initial Energy-Food Model – Baseline (S0)) results are presented in Section 4.2.

4.1 Calibration Run (Model 1) Results

In calibrating[12] (and/or validating) mathematical programming models, different approaches have been proposed and applied in different studies. Hazell and Norton (1986, ch.11, p.270) recommend six tests: a) the capacity test[13] – proposed first by Kutcher (1972, 1983), involves inclusion of a selling (demand or consumption) constraint in the model which requires the model to sell or consume at least the observed base year output for each product. Hence, the test entails checking if the quantity sold (demanded or consumed) in the model is at least equal to the base year domestic crop demand/consumption; b) the marginal cost test – also proposed by Kutcher (1972, 1983), requires comparing product price (i.e., shadow prices on the demand-supply balance) with marginal cost for all outputs, especially where marginal

[12] Although model calibration and validation are sometimes used interchangeably, a distinction exists between the two. Model calibration or verification means checking if the model's construction is consistent with applied data and logic whereas model validation entails checking if the model's behaviour conforms to the observed world. HARVEY, D. R. 1990. Agricultural Modelling for Policy Development. *In:* JONES, J. G. W. & STREET, P. R. (eds.) *System Theory Applied to Agriculture and The Food Chain.* Crown House, Linton Road, Barking Essex 1G11 8JU, England: Elsevier Science Plublishers Ltd.

[13] This is a basic requirement, in that the current (base) year output needs to be within the model's feasible set for the model to be at all consistent with the system being modelled.

cost includes the opportunity costs of fixed resources; c) the land rent test – first applied by Bassoco et al. (1973, p.412), entails comparing the shadow price on the land use constraint in the model solution with the actual annual land rent; d) the input use level test – involves comparing the model's input use levels with the actual input use levels; e) production tests – the most commonly used test also involves comparing the model production output for each product with the base year level. However, as noted by Hazell and Norton, there is usually considerable variation between the model's production outputs and the historic base year levels with no consensus on the statistic to be used for measuring the goodness of fit of model's outputs with the historic data. Nevertheless, simple measures such as Percentage Absolute Deviation (PAD) (also known as Mean Absolute Percentage Deviation – MAPD) have been applied in most cases. Price test – the last of the proposed six tests is similar to the production test, and involves comparing the model's generated product prices (shadow prices at the supply-demand balance) with the actual product prices. Nevertheless, it should also be noted that there are usually more deviations between the model's product prices and the actual (real life) prices due to the fact that most of the applied price elasticities of demand are less than one (unity) in absolute value (Hazell and Norton, 1986, ch.11, pp. 270 - 272). However, it is most-likely that this note is relevant to only LP models and not NLP models since Howitt (1995a) and more recently Heckelei and Britz (2005) show that this limitation is overcome using PMP calibration approach adopted in this study. Similarly, McCarl and Spreen (1997, ch.18, pp.1-7) proposed the two broad validation approaches:

1) validation by construct which consists of ensuring that: a) the appropriate procedures were followed, b) the trial results suggest that the model is behaving consistently, c) constraints were used (or imposed) which restrict the model to realistic solutions; and

2) validation by results which involves comparing the model results with the real life situation. Validation by result is further divided into two, namely: validation by parameter outcome set which requires model's data to contain values for both input parameters and output measurement; and validation experiments. Validation experiments on the other hand include: a) the feasibility (primal and dual) tests, b) quantity experiment, c) price experiment, d) prediction experiment, e) change experiment, f) tracking experiment, and g) partial tests (details can found from McCarl and Spreen); which cumulatively are somewhat synonymous to the validation tests proposed earlier by Hazell and Norton. Furthermore, Howitt (1995a) states that

observed behaviours of producers (farmers) and/or their behavioural reactions are formally the basis for calibrating models in an acceptable way that is consistent to, and with, microeconomic theory. In general, the essence of model calibration and validation is to ensure the integrity of the model results, their adoption and real life applications or extension. Calibration is also necessary to guarantee that the model results are a close approximation of current data. Hence, the calibration of the Base model (Model 1 or NEFM1) is pursued. To do this, comparisons of the model results with the past results, trends or available 'observed' data are employed, particularly with respect to the above proposed six tests, utilizing MAPD as a measurement tool where applicable.

In the calibration run, the model is implemented to reproduce the reference domestic crop consumption demand (DCD) and where necessary the reference export (EXD) demand and import (IMD) supply. The EXD and IMD are implemented as the upper bounds of the export and import variables using less than or equal to constraint (=l=) in order to provide the model with the flexibility to either export up to the base year export demand or less where it is necessary (profitable) to do so. The import supply constraint allows the model to substitute the base year import supply with domestically produced crops where it is feasible and profitable to do so or replicate it through importation. In other words, the base year export demand and import supply representing export and import quota system was implemented in the calibration run using the less than or equal to constraint. In the same vein, the domestic (regional) crop consumption demand variable (RegCons) is defined and implemented as equal to the domestic crop production (DCP) plus imports (IMD) minus exports (EXD). The base year domestic consumption demand (DCD) is set as the upper bound of the RegCons variable (i.e., as the maximum amount of crops that can be demanded (sold to the domestic market) and/or consumed).

Prior to the discussion of the calibration run result (model verification), it is necessary to highlight some important data reconciliations made in the model calibration process. First, the base year crop export data show that Nigeria exported potato, plantain and wheat without a corresponding domestic production (output and cultivated land) data for these crops in the national crop production survey from the Nigerian Bureau of Statistics (NBS, 2010b). Therefore to account for the production output and area cultivated/harvested data for these crops (since exported crops have to be produced domestically within the structure of this model) and to avoid using infeasible lower quantity of land as the land resource endowment (right hand side - RHS) for the Base Model, a three-year average production and cultivated land data for these crops were obtained from FAOSTAT (precisely the Nigerian Crop Production and Food Balance Sheet (2007-2009) data), within the same accounting period as the base year. These FAO production and cultivated land data were added to the base year production output and cultivated land data from NBS and the result is used as the base year land resource endowment in the Base Model. Second, the three-year average total labour employed for crop production in the base year (2008) was disaggregated into family labour and hired labour, with family labour consisting of the farm holders plus their family members who were involved in crop production as reported in the NBS's farm survey data, in order to give the model the possibility of hiring more labour in the Base Model so as to realise the cultivation of those crops which were not originally reported in the NBS crop production data. Consequently, the family labour employed for crop production at the base year was implemented as the upper bound of the family labour variable in the calibration run while the hired labour variable was unconstrained but attracted the observed hired labour cost of US$4.5. Similarly, the family labour received a reservation wage lower than the hired labour by US$1, as recommended by Hazell and Norton (1986, pp. 202, 205). This is because institutional knowledge and literature support the opinion that the opportunity cost of family labour in the rural areas of developing countries, where there are limited off-farm jobs, is less than the cost of hired labour but certainly greater than zero (Hazell and Norton, 1986, p.205). Lastly, the base year domestic consumption demand data (DCD) were scaled (divided) by one thousand before using it to estimate the demand intercept and slope so as to bring the non-linear variable gradient close to one in absolute value (McCarl, 1998, ch.10, p.17). Consequently, the right hand side values (the resource endowments – land and family labour) as well as other model bounds (upper limit values such as base year export and import values) were also scaled (divided) by the same factor to ensure consistency, making all variable output levels to be in thousands instead of single unit values.

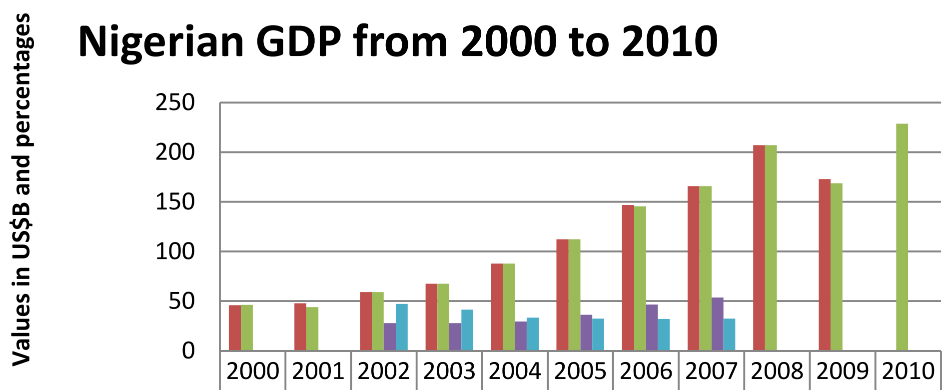
The calibration run results replicate the existing input data in terms of resource use levels, production levels, as well as the demand and supply levels (including exports and imports, though the reference import supply was largely substituted with local supply (production) and the model's exports were slightly lower than the base year export demand for some crops where it is rather more profitable to export less). Thus the results indicate that the model is consistent given the available and specified data in the model. Further, it shows that fixed resources (land and family labour) are used up to their base year upper limit values at some periods of the farming season and consequently their shadow prices were revealed as shown and discussed in their respective sections (land and labour use) below. To demonstrate that the developed and applied NLP model replicates the base year data and as such serves as a benchmark against which simulation/scenario runs can be evaluated, the calibration run results are presented below.

4.1.1 Model 1 Gross Margin

A total gross margin (GM) of US$43.93 billion is achieved in the calibration run with the base year domestic consumption demand replicated. However, relaxing the import quota in the calibration run by changing the import variable constraint from less than or equal (=l=) to greater than or equal to (=g=) in order to assess if the import restriction has been implemented appropriately with the (=l=) constraint and to examine the potential impact of trade liberalization (border opening) in the calibration run yields a very marginally smaller gross margin of US$43.57 billion (a US$351 million (less than 0.1%) decrease from the initial calibration run GM). Further, in comparison with the results obtained when import quota was implemented with (=l=) constraint in the calibration run (hereafter called the 'optimised' calibration run), implementation of the import quota with (=g=) constraint led to a replication of the base year import supply levels. Consequently, the increase in import supply reduced the domestic supply (production) levels as expected, resulting in lower shadow prices of land in all the regions. To justify the implementation of the export quota constraint with (=l=) in the models, Hazell and Norton observe that exports are typically implemented as facing either perfectly elastic demands or demands that are elastic up to the importing country import quota (1986, p 261) in sector models; and further show that export quota is implemented using less than or equal to constraint quota (1986, p.153). In addition, implementation of the export quota in the 'optimised' calibration run with less than or equal to constraint ensured that only crops with positive contribution to the objective function are exported up to their base year export levels; thus revealing crops in which the regions have comparative export advantage on. The resultant export level conforms closely to the base year export level, thereby confirming the assumed perfectly elastic nature of exports in sector models. It was therefore concluded that the import and export quotas were properly implemented in the 'optimised' calibration run using less than or equal to constraint. For brevity, only the results from the 'optimised' calibration run are presented below.

The total gross margin from the entire crop production enterprise (US$43.93 billion) is the gross return to fixed factors employed in the cultivation and sale of the crops captured in the model. Data from World Bank and IMF (Figure 4.1) reveal the national GDP and the agricultural share to the national GDP from 2000 to 2010. Comparing the potential GM from the crop farming subsector (US$44B) with the agricultural value as at 2007 (US$54B), for example, shows that the potential GM is about 82% of the total agricultural value at this period. Hence, the potential GM is consistent with the available data, bearing in mind that the model's base year is 2008; and also given the fact that the other agricultural sub-sectors (livestock, aquaculture and horticulture) are not included in the model. Further, the GM suggests that the model is structurally consistent and reasonably replicates the existing production environment in the Nigerian agricultural (crop farming) sector. Resource allocation and output levels support this assertion as demonstrated below.

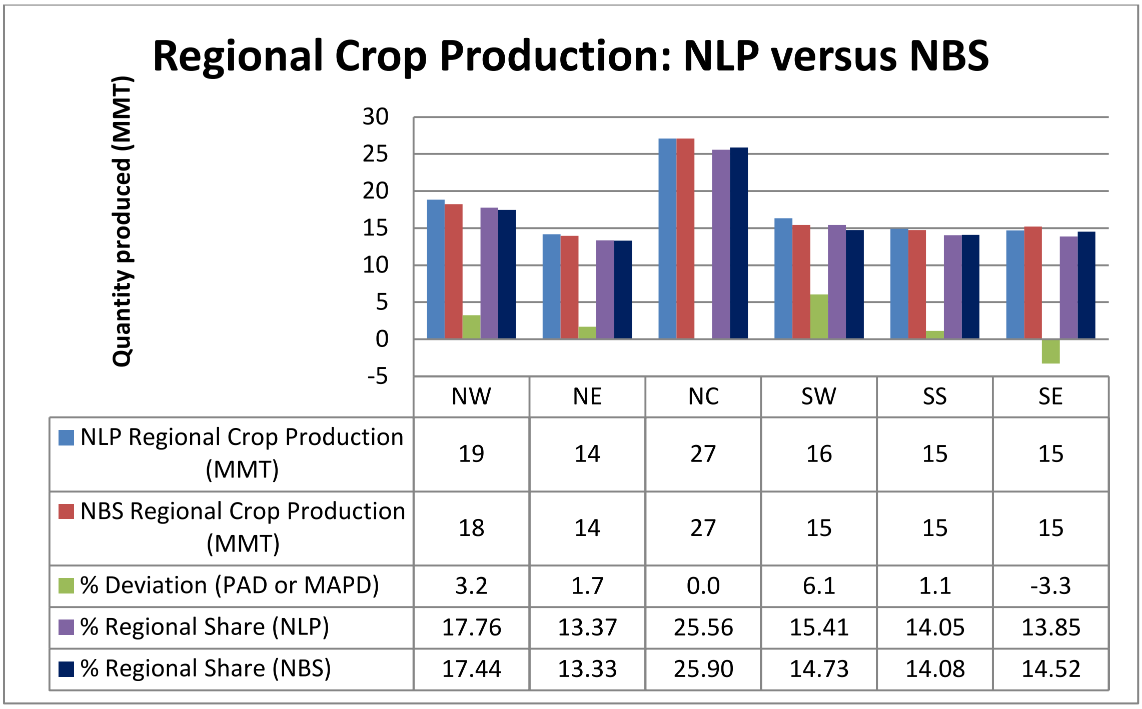
Figure 4.1, Nigerian GDP from 2000 to 2010, adapted from World Bank Country Profile and IMF World Economic Outlook databases assessed from: http://data.worldbank.org/country/nigeria?display=default and http://www.imf.org/external/pubs/ft/weo/2013/02/weodata/index.aspx



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
World Bank GDP (US$B) at Current Prices	46	48	59	68	88	112	147	166	207	173	
IMF GDP (US$B) at Current Prices	46	44	59	68	88	112	145	166	207	169	229
WB Agric. Value (US$B) at current prices			28	28	29	36	47	54			
% Agric. Contribution to GDP			47	41	33	32	32	32			

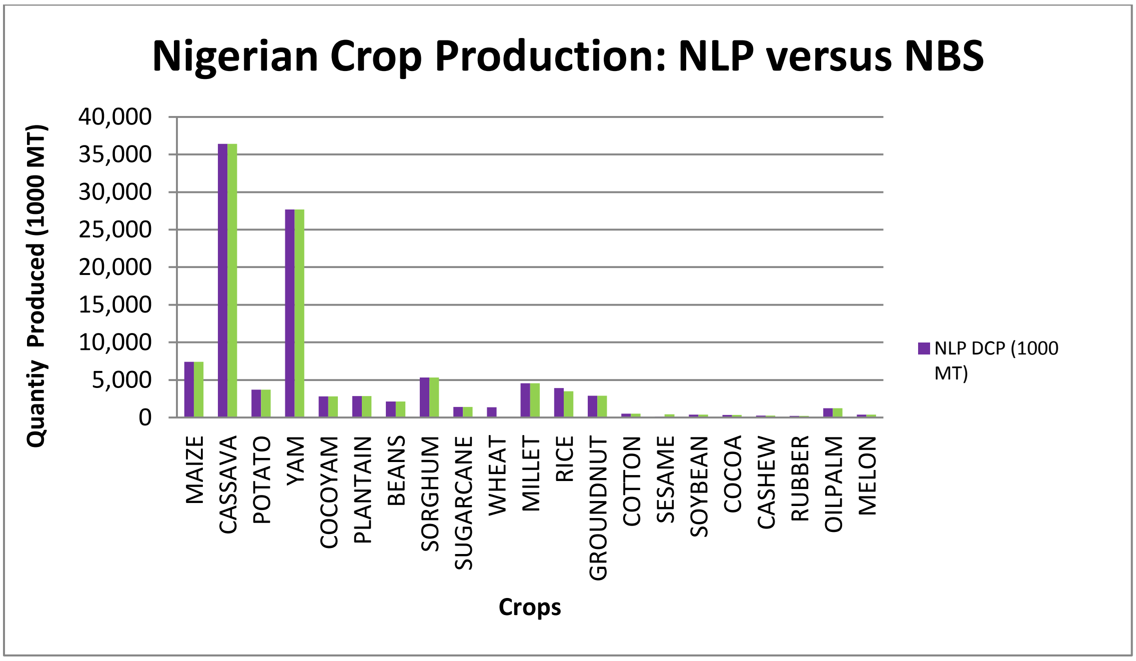
4.1.2 Regional Crop Production Level

Figure 4.2a, Nigerian Crop Production by Region.



	NW	NE	NC	SW	SS	SE
NLP Regional Crop Production (MMT)	19	14	27	16	15	15
NBS Regional Crop Production (MMT)	18	14	27	15	15	15
% Deviation (PAD or MAPD)	3.2	1.7	0.0	6.1	1.1	-3.3
% Regional Share (NLP)	17.76	13.37	25.56	15.41	14.05	13.85
% Regional Share (NBS)	17.44	13.33	25.90	14.73	14.08	14.52

Figure 4.2b, Nigerian Crop Production by Crop.



Figures 4.2a and 4.2b show that the crop production pattern and output from the NLP Base Model (optimised calibration run) reproduce the base year (NBS) crop production data both in terms of regional output and individual crop basis (cropping pattern). In fact, they show that more crops were produced in the optimised calibration

run in most of the regions, except in SE where the implemented inter-regional trade variable slightly reduced the region's production levels below that of the base year as illustrated in Table 4.2c below. In essence, the inter-regional trade variable functions in a way such that crops which cannot be feasibly and/or profitably produced within each region can be imported from other regions. In particular, Figure 4.2a shows that the mean absolute percentage deviation of the model's production output from the base year output is within the 'acceptable deviation range' for all the regions. Mean Absolute Percentage Deviation (MAPD) or simply Percentage Absolute Deviation (PAD) is a measure or criterion used to evaluate the precision and consistency of mathematical models and have been applied in several previous studies (see Hazell and Norton, 1986, pp. 271-272, Bauer and Kasnakoglu, 1990). Hazell and Norton suggest that MAPD values below 15 indicates the consistency and goodness of fit of the applied model to the observed data while values from 15 upwards might require a review before the model is used, especially if the deviation is a major one (i.e. occurs in most of the products and/or regions). To be more precise, Hazell and Norton (1986, pp. 271 - 272) propose these specific evaluation criteria as acceptable and/or unacceptable PAD range: ≤ 5% - Exceptional, ≤ 10% - Good, ≥ 15% - may require improvement. In general, Figures 4.2a and 4.2b show that the optimised calibration run satisfies the capacity and production verification tests since the model is able to replicate the base year production levels with all the deviations being within the 'exceptional' deviation range.

The individual crop production levels from the calibration run are shown in Table 4.1a. From Table 4.1a, columns with zero values imply that those crops were not produced in the calibration run, i.e., not part of the prescribed cropping plan from the base model's solution even though they were historically produced from those regions. On the other hand, columns with 'N/A' in Table 4.1a imply that those crops were not produced in those regions either in the regional historic production data or the model's production output.

In terms of crop production costs, Table 4.1b shows the total cost of purchased inputs utilized in the production of one metric tonne of each crop in each region, i.e., the producers' cash outlay; while Table 4.1c indicates the associated marketing cost of each crop. The implemented marketing cost (Table 4.1c) is the cost of transporting or transferring each crop from the regional production points (farm-gate) to the marketing or processing centres or to the national level. The two add up to the total input cost of producing and marketing each crop in each region. Similarly, the opportunity cost of fixed resources (land, family labour and management) employed in the production of each crop in each region or simply the corresponding gross margins (gross profits) achieved from the production of one metric tonne of each crop in each region is shown in Table 4.1d. The total input cost (purchased input and marketing costs) plus the opportunity cost of fixed resources is equal to the marginal cost (MC) of producing one metric tonne of each crop in each region.

The per MT input cost (IC) in Table 4.1b reveals the regional competitive production advantage and consequently the profitability of each crop in each region since it indicates the resource use efficiency of each region in producing the same quantity of crop. For instance, it reveals that NW has competitive advantage in maize production over other regions- having the least per MT input cost (and consequently the highest opportunity cost of utilized fixed resources) for maize production but most disadvantaged in cassava production. In contrast, SW has competitive production advantage in cassava over other regions but disadvantaged in soybean production. Similarly, Table 4.1b indicates that it is more expensive (and consequently less profitable) to grow yam in the NW region than in the SW. Hence, investors interested in cassava and maize production will find it more profitable to invest in the SW and NW for cassava and maize production enterprises, respectively; assuming all production resources are available at the required level in the two regions, since marginal cost (MC) is equal to the explicit costs of purchased inputs plus opportunity costs of fixed resources employed in the production of each crop (Hazell and Norton, 1986, p. 167). The concept of marginal cost (MC) being equal to the explicit costs of purchased inputs plus the opportunity costs of fixed resources used in the production process is well-established as one of the two important Kuhn-Tucker's optimality requirements for mathematical programming models.

The opportunity costs of fixed resources utilized in the production of these crops indicate the increment in the objective function value that would arise if one additional unit of the fixed resources were to be further utilized for the production and supply of the corresponding crops in each region. In other words, they represent the resource opportunity costs of one additional metric tonne of each crop. Equally, the opportunity costs indicate the corresponding gross margins (gross profits) achieved from the production of one metric tonne of each crop in each region. The columns with negative opportunity costs indicate crops which are not produced from those regions. The negative opportunity costs of fixed resources can be interpreted as the amounts of money farmers have lost for utilizing one unit of their fixed resources to produce those crops (in cases where production actually took place); or would have lost if they had utilized one unit of their fixed resources to produce these crops (in cases where production did not take place, since those crops are not consumed or demanded in these regions and/or may not even survive in those regions due to unfavourable climatic and soil conditions). In the former situation for instance, the result implies that producers in the NW and NE lost US$7.14 and US$0.18, respectively, for utilizing one unit of their fixed resource to produce beans. However, it is comparatively cheaper and better to produce beans locally from these regions than to import to meet regional demand. Hence, it was produced in the model. On the latter, the result indicates that drought-loving crops such as sorghum, wheat, millet, soybean and cotton were not produced in the SS and SE from the model and historically from the input production data. Similarly, sesame was not produced from the SW, SS and SE. Further, it implies that cocoa and rubber were not produced in the NW and NE and NW, respectively. Hence, their fixed resource opportunity costs are negative. On the other hand, columns with zero opportunity costs (if any) would imply that the cost of producing and marketing such crops are just equal to their market values (prices); hence, the farmers are only breaking even without making any profit.

The marginal cost of producing and marketing one MT of each crop is equal to the domestic market price of that crop at the national level since marginal cost must be equal to marginal revenue in a competitive market system under profit maximization. For instance, the marginal cost of producing and marketing one MT of maize in the NW is equal to US$117 (i.e., 14.95 + 10.95 + 91.10) and this is exactly equal to the revealed shadow price (equilibrium price) of maize in that region on the supply-demand balance equation (market equilibrium) in Table 4.2a[14]. This result implies that the regional market price of each crop is equal its input cost in Table 4.1b plus the opportunity cost of fixed resources utilized in its production (Table 4.1d), excluding the marketing/transportation cost (Table 4.1c). Equivalently, the products' prices at the regional level are the same as the crops' farmgate prices while the corresponding products' prices in Table 4.2a are equal to their retail (or city wholesale) prices. Therefore the difference between the national and regional market price of each crop is its marketing cost. Hence, the revealed product market prices at regional and national levels conform to the established knowledge about the relationships among regional marketing cost, regional and national commodity prices in sector model (Hazell and Norton, 1986, p.179).

---

[14] See Appendix 24 for an alternative empirical method of estimating and/or verifying the model generated shadow prices at the commodity balance constraint (product prices).

Table 4.1a, Domestic Crop Production (Domestic Supply) Levels (1000 MT)

Crops	**NW (1000 MT)**	**NE (1000 MT)**	**NC (1000 MT)**	**SW (1000 MT)**	**SS (1000 MT)**	**SE (1000 MT)**
MAIZE	2,852	1,526	1,397	708	472	468
CASSAVA	2,214	2,551	9,489	7,328	7,712	7,097
POTATO	1,254	1,104	1,339	12	11	10
YAM	1,921	2,240	8,873	4,774	4,459	5,415
COCOYAM	7	14	237	1,133	580	868
PLANTAIN	176	202	750	1,141	610	0
BEANS	809	789	452	0	82	0
SORGHUM	2,621	1,681	983	25	N/A	N/A
SUGARCANE	1,135	110	89	21	47	3
WHEAT	479	259	262	351	N/A	N/A
MILLET	2,371	1,786	409	3	N/A	N/A
RICE	1,209	859	1,199	160	148	347
GROUNDNUT	975	859	1,042	17	8	0
COTTON	363	145	23	0.5	N/A	N/A
SESAME	N/A	34	89	N/A	N/A	N/A
SOYBEAN	170	25	196	6	N/A	N/A
COCOA	N/A	N/A	46	115	75	133
CASHEW	42	0	119	0	112	0
RUBBER	0	0	0.00	48	174	4
OILPALM	0	0	118	364	413	348
MELON	243	0	0	138	0	0

Table 4.1b, Input Cost per MT of Crop (US$/MT)

Crops	**NWIC (US$/MT)**	**NEIC (US$/MT)**	**NCIC (US$/MT)**	**SWIC (US$/MT)**	**SSIC (US$/MT)**	**SEIC (US$/MT)**
MAIZE	14.95	51.64	39.02	31.07	31.30	36.14
CASSAVA	20.60	19.99	15.37	12.67	17.68	17.94
POTATO	117.35	123.49	114.47	110.70	112.41	124.15
YAM	38.63	60.43	43.75	36.29	46.55	37.53
COCOYAM	30.84	58.71	23.56	24.66	42.25	25.47
PLANTAIN	183.87	187.27	182.55	180.43	181.00	206.70
BEANS	118.19	111.23	59.22	88.21	54.70	67.84
SORGHUM	64.55	84.52	70.48	88.82	N/A	N/A
SUGARCANE	5.96	15.71	15.62	10.72	18.29	9.43
WHEAT	57.18	71.07	51.43	43.02	N/A	N/A
MILLET	76.22	72.57	65.95	38.99	N/A	N/A
RICE	35.07	68.51	36.82	42.49	12.74	40.30
GROUNDNUT	99.09	81.75	39.63	59.39	84.56	138.92
COTTON	61.21	74.35	62.11	65.29	N/A	N/A
SESAME	249.22	222.95	216.38	N/A	N/A	N/A
SOYBEAN	64.89	53.15	49.20	76.32	N/A	N/A
COCOA	N/A	340.99	308.15	349.75	336.62	323.48
CASHEW	49.49	134.60	58.94	134.36	70.60	135.73
RUBBER	N/A	N/A	166.45	79.47	115.85	132.50
OILPALM	146.33	172.60	120.53	95.97	107.49	149.08
MELON	29.86	56.13	62.70	64.89	97.73	91.16

Table 4.1c, Regional Marketing (Transportation) Cost per MT of Crop (US$/MT)

Crops	**NWTC (US$/MT)**	**NETC (US$/MT)**	**NCTC (US$/MT)**	**SWTC (US$/MT)**	**SSTC (US$/MT)**	**SETC (US$/MT)**
All Crops	10.95	10.95	10.95	8.76	8.76	8.76

Note that the marketing costs are assumed to be same for all crops in all the regions.

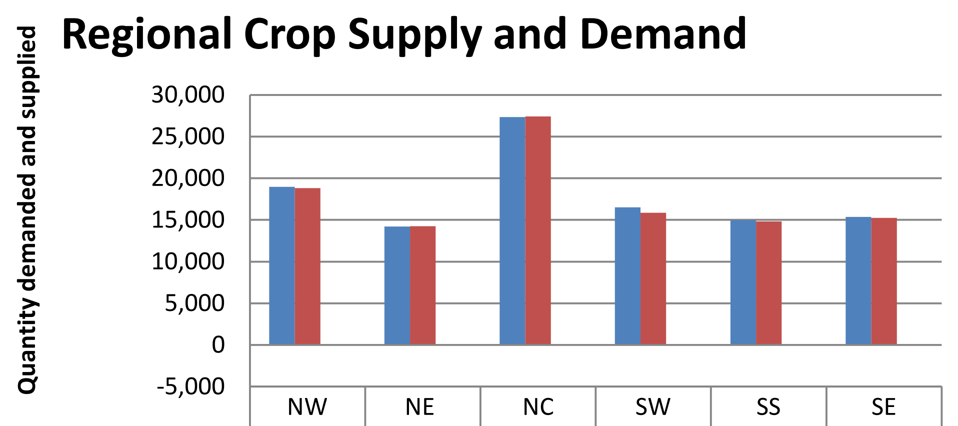
Table 4.1d, Opportunity Cost of Fixed Resources per MT of Crop (US$/MT)

Crops	**NWOC ($)**	**NEOC ($)**	**NCOC ($)**	**SWOC ($)**	**SSOC ($)**	**SEOC ($)**
MAIZE	91.10	54.41	67.03	77.17	76.94	72.10
CASSAVA	53.15	53.76	58.38	63.27	58.26	58.00
POTATO	144.50	138.36	147.38	153.34	151.63	139.89
YAM	80.32	58.52	75.20	84.85	74.59	83.61
COCOYAM	69.51	41.64	76.79	77.88	60.29	77.07
PLANTAIN	125.68	122.28	127.00	131.31	130.74	105.04
BEANS	-7.14	-0.18	51.83	25.70	58.54	45.40
SORGHUM	42.80	22.83	36.87	20.72	-130.42	-123.85
SUGARCANE	98.89	89.14	89.23	96.32	88.75	97.61
WHEAT	124.37	110.48	130.12	140.72	-84.62	-78.05
MILLET	24.13	27.78	34.40	63.55	-80.59	-74.02
RICE	85.98	52.54	84.23	80.75	110.50	82.94
GROUNDNUT	15.46	32.80	74.92	57.35	32.18	31.08
COTTON	326.34	313.20	325.44	324.45	-106.89	-100.32
SESAME	11.43	37.70	44.27	-266.74	-279.88	-273.31
SOYBEAN	131.06	142.80	146.75	121.82	-71.95	-58.81
COCOA	-378.21	334.56	367.40	327.99	341.12	354.26
CASHEW	192.76	166.49	183.31	141.00	173.84	160.70
RUBBER	-140.78	-114.51	258.66	298.07	261.69	245.04
OILPALM	522.62	496.35	548.42	575.17	563.65	522.06
MELON	149.19	122.92	116.35	116.35	83.51	90.08

4.1.3 Regional Crop Demand and Supply Levels

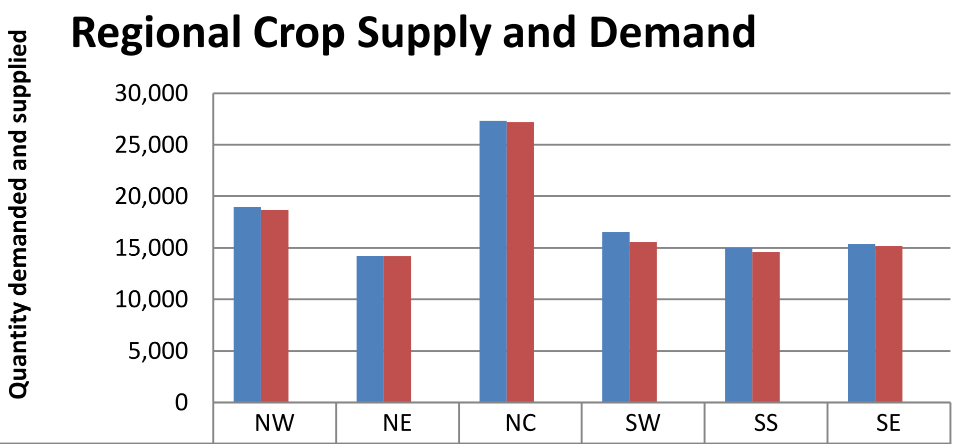
As expected, Figure 4.3a shows that the base year total crop demand (regional consumption demand plus export demand) is satisfied by the model's total crop supply (regional production plus inter-regional import plus external import). In addition, Table 4.2c shows that reference total crop demand is satisfied through domestic supply and not through imports as all the externally supplied crops in the reference crop demand were grown and supplied domestically due to the implied marginal revenue contribution to the total gross margin for growing those crops domestically. Table 4.2c also indicates that the total crop supply from the calibration run is relatively greater than the base-year total crop demand; thus signifying further that the production test is validated by the model's production level. The insignificant negative percentage deviations in the NE and NC indicate that the total crop supply from the model is lower than the base year total crop demand by these percentages; and this is due to the unprofitable export levels of some crops which were not attained (satisfied) in the calibration run in order to avoid loss. Figure 4.3b shows that the model is able to simulate a competitive market system, despite the incorporation of some market imperfections (regional transportation inadequacies and its inherent costs) in the model as earlier observed by Hazell and Norton (1986, p.178). To be more precise, Figure 4.3b shows that the modelled total crop demand is satisfied by total crop supply from the Base Model; i.e. that demand and supply are at equilibrium in the Base Model since the total quantity supplied is slightly greater than the total quantity demanded. As a result, the associated shadow prices at the equilibrium point were revealed as shown in Table 4.2a. Kuhn-Tucker's second optimality condition for simulating a market equilibrium system indicates that the model's shadow prices on the commodity balances are equal to the corresponding commodity prices (Hazell and Norton, 1986, p.167). In other words, the shadow prices on the commodity balance constraint from the model solution (Table 4.2a) are the corresponding domestic market prices of the crops modelled in the Base Model. Further, these shadow prices are equal to the sum of the marginal cost of producing and marketing each crop, thus satisfying Kuhn-Tucker's first optimality condition. Equally, these shadow prices can be interpreted as the marginal revenues from the corresponding crops, implying how much the objective function value would be increased by if an extra 1 MT of the corresponding crop were to be demanded (sold). For instance, the objective function value (GM) would increase by US$117 if one extra MT of maize were to be produced and sold from any of the regions, i.e., if the current domestic demand for maize in Table 4.2b were to be increased by one metric tonne. In Table 4.2a, columns with 'N/A' imply that those crops were not demanded in those regions (i.e., they are not part of the regional historic and by extension the model's consumption data). From the foregoing analysis, the duality tests (Kuhn-Tucker's conditions) are therefore satisfied by the revealed MC and MR from the Base Model. Further, the product prices generated from the model compare closely with the actual commodity real market prices. For example, the model generated prices for all crops are exactly the same with the actual real market prices of these products from the input data- NBS farm survey. Therefore the model-generated product prices satisfy the price verification test.

Figure 4.3a, NLP Domestic Crop Supply versus NBS Total Crop Demand by Region



	NW	NE	NC	SW	SS	SE
NLP Total Crop Supply (1000 MT)	18,958	14,224	27,328	16,530	14,974	15,374
NBS Total Crop Demand (1000 MT)	18,819	14,254	27,428	15,853	14,805	15,246
% Deviation (MAPD)	0.7	-0.2	-0.4	4.3	1.1	0.8

Figure 4.3b, NLP Total Crop Supply versus NLP Total Crop Demand by Region



	NW	NE	NC	SW	SS	SE
NLP TCropSup (1000 MT)	18,958	14,224	27,328	16,530	14,974	15,374
NLP TCropDem (1000 MT)	18,682	14,200	27,184	15,556	14,589	15,205
% Deviation (MAPD)	1.5	0.2	0.5	6.3	2.6	1.1

Table 4.2a, Regional Shadow Prices at the Crop Demand-Supply Balance (US$/MT)

Crops	**NWSP ($)**	**NESP ($)**	**NCSP ($)**	**SWSP ($)**	**SSSP ($)**	**SESP ($)**
MAIZE	117.00	117.00	117.00	117.00	117.00	117.00
CASSAVA	84.70	84.70	84.70	84.70	84.70	84.70
POTATO	272.80	272.80	272.80	272.80	272.80	272.80
YAM	129.90	129.90	129.90	129.90	129.90	129.90
COCOYAM	111.30	111.30	111.30	111.30	111.30	111.30
PLANTAIN	320.50	320.50	320.50	320.50	320.50	320.50
BEANS	122.00	122.00	122.00	122.00	122.00	122.00
SORGHUM	118.30	118.30	118.30	118.30	N/A	N/A
SUGARCANE	115.80	115.80	115.80	115.80	115.80	115.80
WHEAT	192.50	192.50	192.50	192.50	N/A	N/A
MILLET	111.30	111.30	111.30	111.30	N/A	N/A
RICE	132.00	132.00	132.00	132.00	132.00	132.00
GROUNDNUT	125.50	125.50	125.50	125.50	125.50	125.50
COTTON	398.50	398.50	398.50	398.50	N/A	N/A
SESAME	271.60	271.60	271.60	N/A	N/A	N/A
SOYBEAN	206.90	206.90	206.90	206.90	N/A	N/A
COCOA	N/A	686.50	686.50	686.50	686.50	686.50
CASHEW	253.20	253.20	253.20	253.20	253.20	253.20
RUBBER	N/A	N/A	386.30	386.30	386.30	386.30
OILPALM	679.90	679.90	679.90	679.90	679.90	679.90
MELON	190.00	190.00	190.00	190.00	190.00	190.00

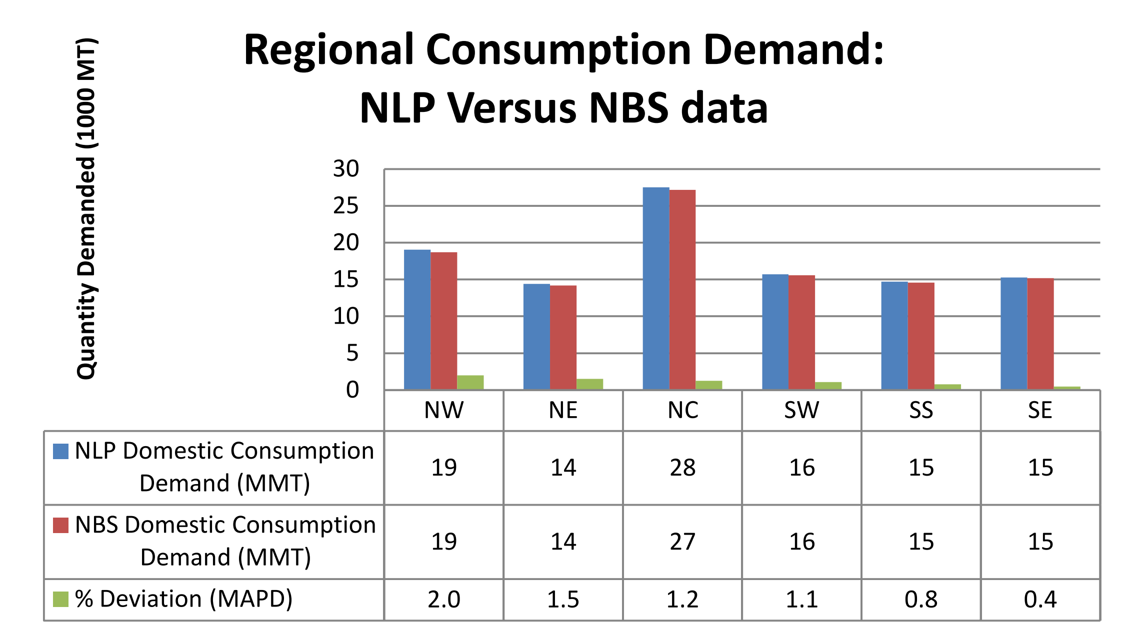
Table 4.2b, Regional Crop Demand (Domestic Consumption Demand) Levels (1000 MT)

Crops	**NW (1000 MT)**	**NE (1000 MT)**	**NC (1000 MT)**	**SW (1000 MT)**	**SS (1000 MT)**	**SE (1000 MT)**
MAIZE	2,852	1,526	1,397	708	472	468
CASSAVA	2,214	2,551	9,489	7,328	7,712	7,097
POTATO	1,254	1,104	1,339	12	11	10
YAM	1,921	2,240	8,873	4,774	4,459	5,415
COCOYAM	7	14	237	1,133	580	868
PLANTAIN	176	202	750	580	610	561
BEANS	872	789	452	15	1	3
SORGHUM	2,621	1,681	983	25	N/A	N/A
SUGARCANE	1,135	110	89	21	47	3
WHEAT	479	259	262	351	N/A	N/A
MILLET	2,371	1,786	409	3	N/A	N/A
RICE	1,208	859	1,199	160	148	347
GROUNDNUT	975	859	1,042	9	8	8
COTTON	362	145	23	0.5	N/A	N/A
SESAME	43	18	63	N/A	N/A	N/A
SOYBEAN	169	25	196	6	N/A	N/A
COCOA	N/A	1	1	1	1	1
CASHEW	15	1	47	12	9	23
RUBBER	N/A	N/A	3	20	70	3
OILPALM	5	7	118	352	413	348
MELON	2	23	213	46	49	49

Table 4.2c, NLP Total Crop Supply by Sources versus Base year Total Crop Demand

Parameters	NW	NE	NC	SW	SS	SE
NLP Domestic Supply (Production) (1000 MT)	18,840	14,185	27,112	16,345	14,902	14,693
NLP Inter-Regional Supply (1000 MT)	118	39	216	185	72	681
NLP Import Supply (1000 MT)	0	0	0	0	0	0
NLP Total Crop Supply (1000 MT)	**18,958**	**14,224**	**27,328**	**16,530**	**14,974**	**15,374**
NBS Total Crop Demand: Domestic Consumption + Exports (1000 MT)	**18,819**	**14,254**	**27,428**	**15,853**	**14,805**	**15,246**
% Increase in NLP Total Supply Over NBS Total Demand	0.74	-0.21	-0.37	4.27	1.15	0.84

Figure 4.3c, NLP versus NBS Domestic Consumption Demand by Region



4.1.5 Inter-Regional Crop Trade

Table 4.3a shows the quantity of each crop supplied (internally imported) from one region: an area of surplus and/or region with the greatest production comparative advantage to other regions (areas of scarcity and/or regions with less production comparative advantage); while Table 4.3b shows the inter-regional and intra-regional transportation costs. As mentioned earlier, the intra-regional transportation cost refers to the cost of transferring one metric tonne of each crop from one region's farmgate to the marketing and/or processing centres and/or to the national level. In Table 4.3b, Nig represents the marketing/processing centre at the national level. From Table 4.3a, beans are supplied from the SS to the NW and SE. The net-effect of inter-regional trade in the sector model is significant in re-distributing commodities from areas of surplus to areas of scarcity, thereby reducing pressure on the demand of production resources, especially land in the regions with the less production comparative advantage. For instance, the shadow price for land in all the regions increased significantly (e.g., 92%, 81% and 73% in the SS, SW and NE, respectively;) when the Base Model was implemented without inter-regional trade compared to when inter-regional trade was implemented, suggesting that its implementation improves the models' ability to reflect the real world situation. However, implementing inter-regional trade in the sector model significantly expands the size of the model to a large size that is somewhat difficult to manage. Hence, Hazell and Norton (1986, p.187) suggested leaving it out in a model with large number of regions and/or products. Nevertheless, the successful implementation and management of it counts as an achievement of this study.

Table 4.3a, Inter-Regional Trade Flows (Inter-Regional Import Supply Levels) (MT)

Crops	**From:**	**To: NW**	**To: NE**	**To: NC**	**To: SW**	**To: SS**	**To: SE**
PLANTAIN	SW	0	0	0	0	0	561,274
BEANS	SS	63,041	0	0	14,597	0	3,370
GROUNDNUT	SW	0	0	0	0	0	7,595
SESAME	NE	16,611	0	0	0	0	0
SESAME	NC	25,953	0	0	0	0	0
COCOA	NC	0	6,487	0	35,866	0	0
COCOA	SE	0	0	0	105,120	23,630	0
CASHEW	NW	0	2,990	0	0	0	0
CASHEW	SS	0	0	0	29,249	0	59,274
RUBBER	SW	0	0	3,559	0	0	0
OILPALM	NW	0	6,899	0	0	0	0
OILPALM	SW	12,111	0	0	0	0	0
MELON	NW	0	22,513	212,530	0	6,176	0
MELON	SW	0	0	0	0	42,674	49,497

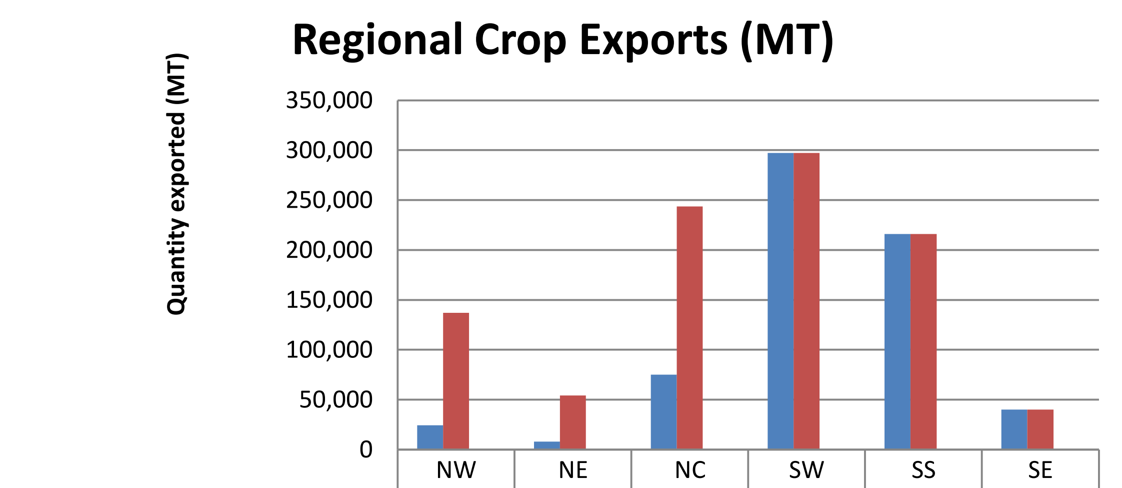
Table 4.3b, Inter-Regional Crop Transportation Cost (US$ per MT)

	NW	NE	NC	SW	SS	SE	NIG
NW	0.00	26.27	32.84	52.55	65.68	59.11	10.95
NE	26.27	0.00	32.84	45.98	59.11	52.55	10.95
NC	32.84	26.27	0.00	39.41	52.55	45.98	10.95
SW	52.55	45.98	39.41	0.00	32.84	26.27	8.76
SS	65.68	59.11	52.55	32.84	0.00	13.14	8.76
SE	59.11	52.55	45.98	26.27	13.14	0.00	8.76
NIG	10.95	10.95	10.95	8.76	8.76	8.76	0.00

4.1.6 Import and Export Levels

As remarked earlier, the base year export demand (EXD) and import supply (IMD) were implemented as the upper bounds of the model's export and import variables using less than or equal to constraint (=l=) in order to provide the model with the flexibility to either export up to the base year export demand or less where necessary. In particular, the upper bound import supply constraint allows the model to substitute the base year import supply with domestically produced crops where it is feasible and more profitable to do so; and/or replicate the base year import supply via importation. As a result, Figures 4.4a and 4.4b show that the calibration run replicated the base year export demand up to the level where it is feasible and profitable to do so. This implies that crops whose export would reduce the GM as indicated by their reduced cost values (Table 4.4a) were either not exported at all or not up to their base year export levels in the calibration. For instance, the export reduced costs in Table 4.4a suggest that exporting 1 MT of sesame seed from NW, NE and NC would reduce the objective function value (achievable GM) by US$42.89, US$16.62 and US$10.05, respectively. Equally, the negative reduced cost values imply that the cost of producing sesame in these regions would have to be reduced (or the export price of sesame increased) by these amounts before it would be profitable to export sesame from these regions. Similar interpretation applies to the reduced costs of other crops. The reduced cost of crops that were exported in the calibration run is zero and their export shadow prices are as shown in Table 4.4b. Empty columns in Table 4.4b imply that such crops were not exported from those regions. The positive export shadow prices imply that the achievable GM would increase by the corresponding shadow price values if the export demand of such crops were to be increased by one metric tonne. Alternatively, negative shadow prices would imply that the export of additional unit of such crops would reduce the GM by the shadow price amounts. Importantly, these shadow prices highlight the regional export competitive advantage and the crops in which the regions have those advantages. For example, NW has the greatest competitive advantage to export maize among other regions while the SW has the most favourable export advantage on cassava and yam. This result is consistent with the actual situation in Nigeria, where grains are majorly exported from the northern part of Nigeria (especially the far-north which is the NW and/or NE) to other parts/regions of Nigeria and to the neighbouring countries like The Republic of Niger; and the tubers from the southern part and/or middle-belt (NC). In contrast, the shadow prices of crops that were neither exported at all nor exported up to their upper limit values (base year export demands) are zero. For instance, none of the regions has the advantage to export sesame; hence, its shadow price is zero in all the regions where it is produced. This same explanation can be given to other crops with zero shadow prices. On the regional export share, Figure 4.4a shows that the highest volume of export would come from SW, followed by SS and SE while NE would export the least volume. On crop share basis, cocoa seed have the most significant share, followed by natural rubber, among other crops (see Figure 4.4b). In terms of imports, the result indicates that base year import supply was completely substituted with domestic supply (locally produced crops) and as such there was no crop import in the calibration run solution. Consequently, the associated import reduced costs are displayed in Tables 4.4c. The import reduced costs imply that the potential gross margin would be reduced by the corresponding reduced cost values if one metric tonne of the crops are imported. Consistently, relaxing the import variable constraint by changing the less than or equal to constraint (=l=) to greater than or equal to (=g=) constraint while leaving the export constraint as (=l=) reproduced both the base year import and export levels (Figure 4.4c and 4.4d), and thus confirms the consistency of the model structure in replicating the historic data and simulating the existing crop production environment in Nigeria. This assertion is further supported by the resource allocation results below.

Figure 4.4a, NLP Crop Exports versus Reference Crop Export by Region



	NW	NE	NC	SW	SS	SE
NLP Total Exports (MT)	24,421	7,927	75,181	297,116	216,088	40,189
Total Reference Exports (MT)	137,155	54,202	243,723	297,116	216,088	40,189
% regional export share	3.69	1.20	11.38	44.95	32.69	6.08

Table 4.4a, Regional Reduced Costs of the Crop Export Variables from Model 1

Crops	NWRC ($)	NERC ($)	NCRC ($)	SWRC ($)	SSRC ($)	SERC ($)
COCOYAM		19.38				
BEANS	-31.54	-24.58		1.30		
SORGHUM		-0.83	13.21	-2.94	N/A	N/A
MILLET	1.87	5.52			N/A	N/A
GROUNDNUT	-9.64	7.70			7.08	5.98
SESAME	-42.89	-16.62	-10.05	N/A	N/A	N/A

Figure 4.4b, NLP Crop Exports versus Reference Crop Export by Crop

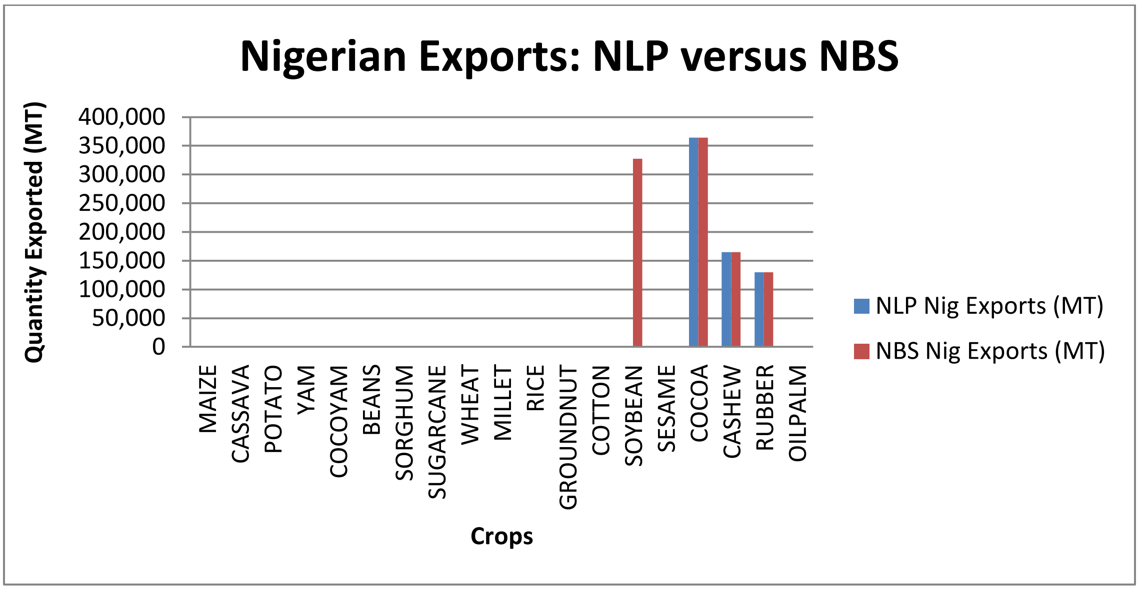
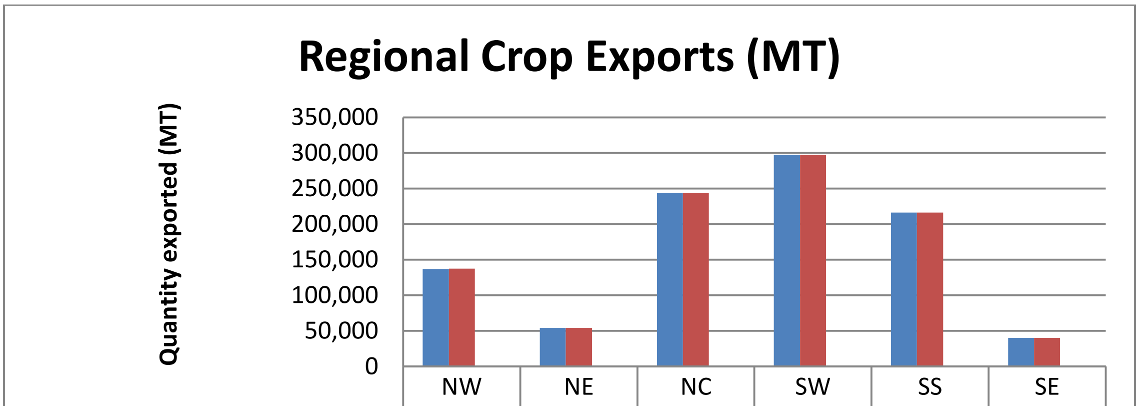
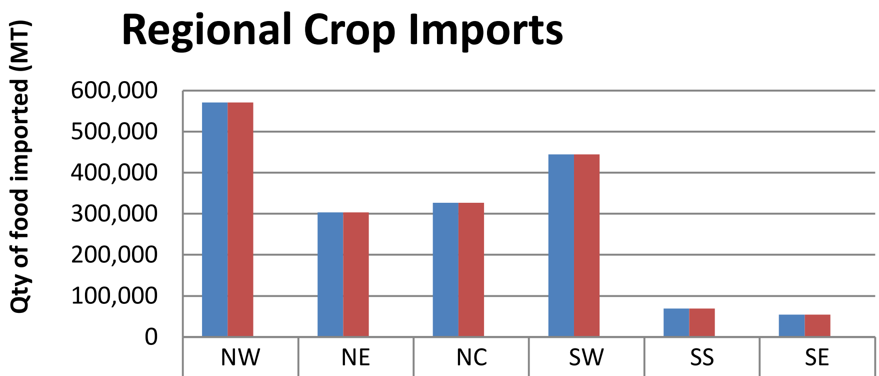


Figure 4.4c, NLP Crop Exports versus Reference Crop Export by Region



	NW	NE	NC	SW	SS	SE
NLP Total Exports (MT)	137,135	54,202	243,723	297,116	216,088	40,189
Total Reference Exports (MT)	137,155	54,202	243,723	297,116	216,088	40,189
% regional export share	13.87	5.48	24.66	30.06	21.86	4.07

Figure 4.4d, NLP Crop Imports versus Reference Crop Import by Region



	NW	NE	NC	SW	SS	SE
NLP Total Imports (MT)	570,831	303,352	326,953	444,203	69,490	54,170
Total Reference Imports (MT)	570,831	303,352	326,953	444,203	69,490	54,170
% regional import share	32	17	18	25	4	3

Table 4.4b, Regional Export Shadow Prices from the Base Model (Model 1)

Crops	NWSP ($)	NESP ($)	NCSP ($)	SWSP ($)	SSSP ($)	SESP ($)
MAIZE	67.70	31.01	43.63	53.77	53.54	48.70
CASSAVA	36.21	36.82	41.44	46.33	41.32	41.06
POTATO	89.94	83.80	92.82	98.78	97.07	85.33
YAM	54.34	32.54	49.22	58.87	48.61	57.63
COCOYAM	47.25		54.53	55.62	38.03	54.81
PLANTAIN	61.58	58.18	62.90	67.21	66.64	40.94
BEANS			27.43		34.14	21.00
SORGHUM	19.14				N/A	N/A
SUGARCANE	75.73	65.98	66.07	73.16	65.59	74.45
WHEAT	85.87	71.98	91.62	102.22	N/A	N/A
MILLET			12.14	41.29	N/A	N/A
RICE	59.58	26.14	57.83	54.35	84.10	56.54
GROUNDNUT			49.82	32.25		
COTTON	246.64	233.50	245.74	244.75	N/A	N/A
SOYBEAN	89.68	101.42	105.37	80.44	N/A	N/A
COCOA	N/A	197.26	230.10	190.69	203.82	216.96
CASHEW	142.12	115.85	132.67	90.36	123.20	110.06
RUBBER	N/A	N/A	181.40	220.81	184.43	167.78
OILPALM	386.64	360.37	412.44	439.19	427.67	386.08
MELON	111.19	84.92	78.35	78.35	45.51	52.08

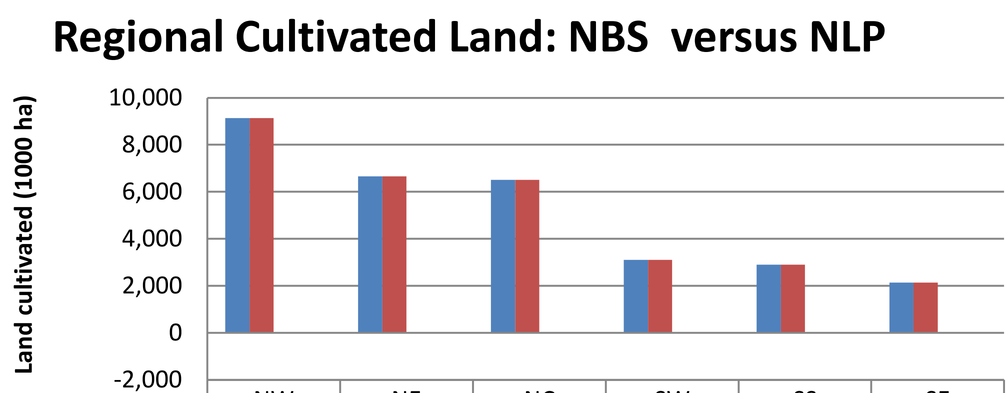
Table 4.4c, Regional Reduced Costs of the Crop Import Variables from the Base Model (Model 1)

Crops	NWRC ($)	NERC ($)	NCRC ($)	SWRC ($)	SSRC ($)	SERC ($)
MAIZE	-129.74	-93.05	-105.67	-115.81	-115.58	-110.74
CASSAVA	-80.29	-80.90	-85.52	-90.41	-85.40	-85.14
POTATO	-231.82	-225.68	-234.70	-240.66	-238.95	-227.21
YAM	-121.90	-100.10	-116.78	-126.43	-116.17	-125.19
COCOYAM	-105.09	-77.22	-112.37	-113.46	-95.87	-112.65
PLANTAIN	-228.18	-224.78	-229.50	-233.81	-233.24	-207.54
BEANS	-31.90	-38.86	-90.87	-64.74	-97.58	-84.44
SORGHUM	-80.62	-60.65	-74.69	-58.54	N/A	N/A
SUGARCANE	-135.97	-126.22	-126.31	-133.40	-125.83	-134.69
WHEAT	-185.91	-172.02	-191.66	-202.26	N/A	N/A
MILLET	-59.71	-63.36	-69.98	-99.13	N/A	N/A
RICE	-128.22	-94.78	-126.47	-122.99	-152.74	-125.18
GROUNDNUT	-55.68	-73.02	-115.14	-97.57	-72.40	-71.30
COTTON	-453.92	-440.78	-453.02	-452.03	N/A	N/A
SESAME	-98.39	-124.66	-131.23	N/A	N/A	N/A
SOYBEAN	-197.16	-208.90	-212.85	-187.92	N/A	N/A
COCOA	N/A	-554.30	-587.14	-547.73	-560.86	-574.00
CASHEW	-273.76	-247.49	-264.31	-222.00	-254.84	-241.70
RUBBER	N/A	N/A	-382.24	-421.65	-385.27	-368.62
OILPALM	-740.20	-713.93	-766.00	-792.75	-781.23	-739.64
MELON	-209.99	-183.72	-177.15	-177.15	-144.31	-150.88

4.1.7 Resource Allocation: Land Use Level

As expected, Figure 4.5 shows that the land use result from the Base Model calibrates exactly with the base-year cultivated land data, with the mean absolute percentage deviation (MAPD) in all the regions being equal to zero. Thus the prescribed regional cultivated land use result suggests that the model is consistent with the base data. Figure 4.5 further shows that the northern part (NW, NE and NC) cultivated more land than the southern part (SW, SS and SE), accounting for 73% of the total cultivated arable land while the southern part accounts for 27%. On the regional basis, NW has the highest share (30%), followed by the NC (22%) while the SE cultivated the least hectares of land (7%). This result corresponds with the observed (NBS) cultivated land data. It also indicates that the land use constraints for all the regions are binding (i.e., the available land endowment (RHS) in these regions are completely utilized) since there is no slack (unused) land. As a result, the corresponding shadow prices (Lagrange multipliers or dual values) of land in all the regions were revealed as shown in Table 4.5. The shadow price of the land in each region is the opportunity cost of using 1 ha of land for crop farming in those regions (potential land rent), given that the actual cropped area at the base year was implemented as the maximum available land for crop production in the calibration run. This implies that it will still be profitable and advisable for farmers in each region to pay land rents up to their respective regional land use shadow prices in order to cultivate one additional hectare of land for one year. As such, they represent the maximum rents that farmers in these regions would be willing to pay in order to cultivate extra 1 ha of land beyond their initial cultivated hectares of land. Comparatively, the shadow price of land in the SE is slightly lower than the actual land rent (US$131) in one of the five states in the region (Abia State) based on the available land rent information from Abia State Agricultural Development Programme (ADP) in 2014. This difference could be due to demands for other land uses in the state and/or region such as construction of new houses, roads and other infrastructures which are not accounted for in the model, bearing in mind that the region has the least land mass in Nigeria. Note that the actual land rent information from Abia State (in the SE region) is the only available one during this study. Efforts to obtain land rent information from other regions were not successful. It is also important to remark that results from this base model are potentially useful implications of the calibration run for other studies.

Figure 4.5, NLP versus NBS (Observed) Cultivated Land data by Region



	NW	NE	NC	SW	SS	SE
NLP Land (1000 ha)	9,132	6,663	6,515	3,099	2,896	2,133
NBS Land (1000 ha)	9,132	6,663	6,515	3,099	2,896	2,133
% Deviation (MAPD)	0.0	0.0	0.0	0.0	0.0	0.0
Reg. % share	30.0	21.9	21.4	10.2	9.5	7.0

Table 4.5, Regional Land Shadow Prices from the Base Model (Model 1)

Crops	**NW**	**NE**	**NC**	**SW**	**SS**	**SE**
Regional Land rents or Land Shadow Prices (US$/ha)	70	95	64	52	53	86

4.1.8 Resource Allocation: Labour Employment Level

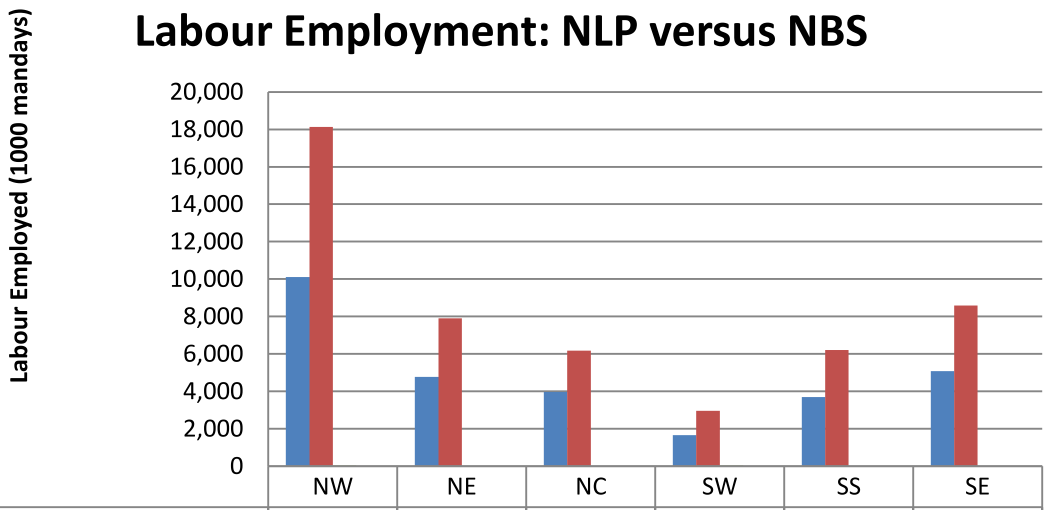
Prior to the discussion of the labour allocation result, it is necessary to describe and/or explain how labour demand and supply were specified and implemented in Models 1 and 2.

The per hectare monthly labour requirement (demand) of each crop was estimated from the available per hectare annual labour requirement of each crop in each region in order to specify and implement labour demand and supply according to the seasonal cropping calendar. Seasonal (monthly) labour specification is important in order to avoid over and/or under-estimation of labour required at certain periods of the year (during the cropping season) when labour is essential to perform certain farm operations which need to be completed within certain time interval when rainfall and temperature supply are conducive to ensure optimum crop yield. It is also necessary to ensure uniform planting, growth, ripening and harvesting of crops (Hazell and Norton, 1986, p. 42). The per hectare annual labour requirement of each crop was initially estimated by dividing the total number of labourers employed in each region for the base-year crop production with the total harvested hectares of land in that region[15]. The per hectare monthly labour requirement of each crop in each region is approximated by dividing the per hectare annual labour requirement of each crop in each region by 12 (the number of months per year). On the supply side (family labour endowment or RHS), the number of family labour supplied per annum is also divided by 12 to in order ensure consistency and to also derive the available number of family labours per month. As a result, the total regional labour supply from the model is significantly different from that of the base year (see Figure 4.6a), with the Base Model being more efficient in labour allocation – using less labour and avoiding excess labour employment at some periods of the year when they are not really needed in the farm; thereby revealing the potential seasonal opportunities for regional off-farm labour employments and the associated revenues. The model's seasonal labour allocation results (Figures 4.7a to 4.7f) indicate the seasons when extra labour will be needed and hired to augment the family labour supply. Note that only Figure 4.7a is presented here to illustrate and explain the model's seasonal labour allocation result, the rest (Figures 4.7b to 4.7f) are in Appendix 3 for brevity. From Figure 4.7a, the model's family labour employment is

[15] This approach is a necessary alternative to obtaining the unique individual crop labour requirements from surveys or interviews as it is extremely difficult to conduct such interviews in six different regions (consisting of 36 states) for 22 crops being modelled in this study within the period of this study. In addition, such exercise has a huge economic cost implication. Also the mixed cropping system that is commonly practiced in most part of Nigeria as well as lack of proper farm record keeping among peasant farmers complicates the challenge of obtaining a reliable annual or monthly crop labour requirement.

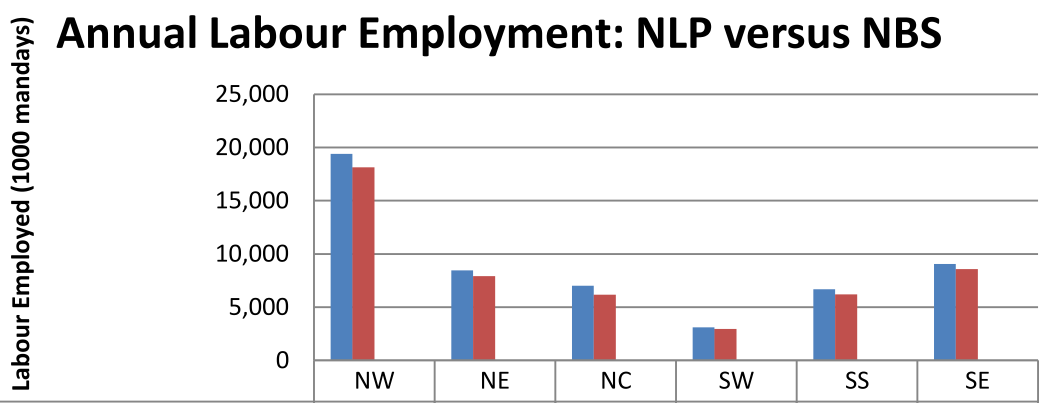
equal to the base year family labour employment in the northwest region only during the peak labour demand seasons and lower at other periods. The peak labour demand season corresponds to the regional land preparation and planting seasons of the cropping calendar (Appendix 4). Additional labour is required and hired during the land preparation and planting season when the available family labour supply for each month is completely utilized (see Figures 4.7b) and the corresponding shadow prices for the hired and family labours employed during this season are respectively shown in Tables 4.6a and 4.6b. The shadow prices indicate the maximum amount that can be paid in order to engage additional unit of labour for one day. The shadow price of hired labour is, of course, exactly equal to the actual hired labour wage implemented in the model; while the shadow price of family labour is lower than the implemented reservation wage (US$3.5) but higher than zero, thus supporting the existing argument about the family labour wage being greater than zero but less than hired labour wage. Empty shadow price columns within the cropping season imply that the monthly available family labour is not completely utilized in those periods; hence, additional labour employment was neither required nor hired. For example, the available family labour in the NW is completely used up and additional labour hired between May and October which is the season when land preparation and planting operations are performed for most of the crops in the region. Similarly, the SW only employs additional labour between July and August when it has exhausted the family labour available to it. From the cropping calendar, this period also coincides with the land preparation and planting season for most of the crops in the southwest region. From the labour employment results (Figure 4.7a and Tables 4.6a and 4.6b), it follows that some family labours are not engaged in the farming activities during other periods and/or seasons of the year (e.g. during weeding/fertilizer application and harvesting operations); hence, they can engage in other off-farm jobs, if any. To estimate the number of family labour that could engage in off-farm employment during the off-peak cropping season and the potential off-farm income accruable from their engagement, the number of family labour employed each month is subtracted from the monthly available family labour and the result is multiplied by the hired labour wage (US$4.5). The estimated family labour available for the potential off-farm employment and the accruable off-farm income are shown in Figures 4.8a and 4.8b, respectively. To justify the labour use results obtained from the monthly labour demand and supply specification (Figure 4.6a), the initial model's result with per hectare annual labour specification and implementation (Figure 4.6b) is presented. It indicates that the Base Model's labour employment data exceeds that of the base-year; thus confirming the over-estimation drawback of per ha annual labour specification as observed by Hazell and Norton (1986, p. 44) and the sense of the monthly labour allocation result (Figure 4.6a).

Figure 4.6a, NLP (seasonality) versus NBS (Observed) Total Labour Employment Level



	NW	NE	NC	SW	SS	SE
NLP Total Labour (1000 mandays)	10,114	4,771	3,961	1,655	3,691	5,082
NBS Total Labour (1000 mandays)	18,128	7,909	6,169	2,957	6,212	8,586
% Deviation (MAPD)	44.2	39.7	35.8	44.0	40.6	40.8
Reg. % share	34.5	16.3	13.5	5.7	12.6	17.4

Figure 4.6b, NLP (non-seasonality) versus NBS Total Labour Employment Level



	NW	NE	NC	SW	SS	SE
NLP Total Labour (1000 mandays)	19,404	8,470	7,019	3,098	6,674	9,049
NBS Total Employed Labour (1000 mandays)	18,128	7,909	6,169	2,957	6,212	8,586
% Deviation (MAPD)	7.0	7.1	13.8	4.8	7.4	5.4
Reg. % share	36.1	15.8	13.1	5.8	12.4	16.8

Figure 4.7a, NLP versus NBS Family Labour Employment for NW

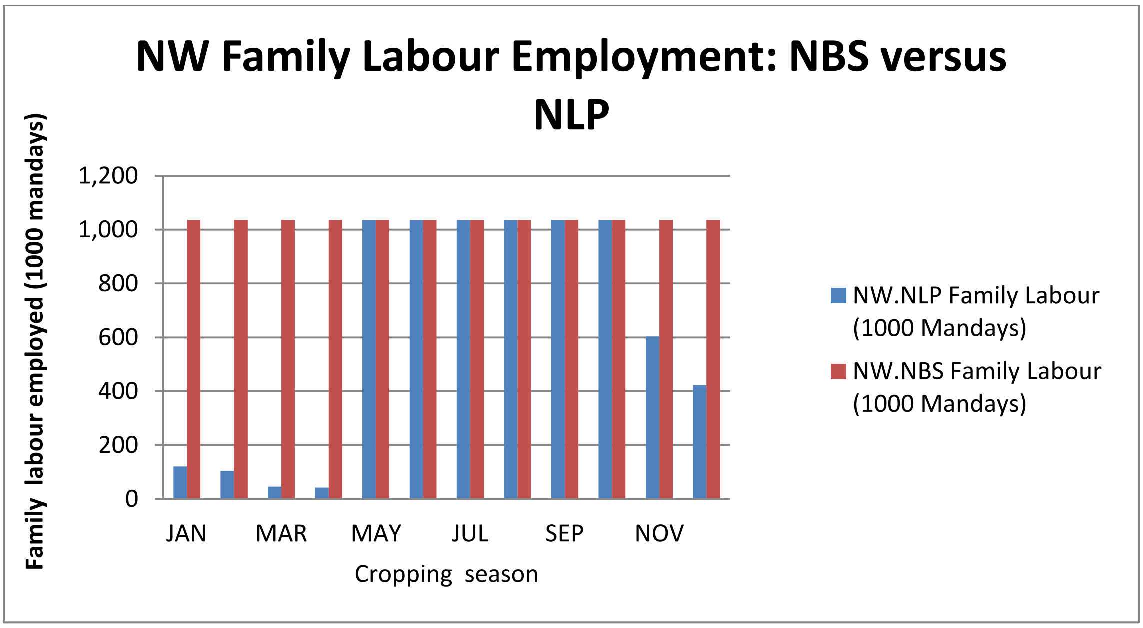


Figure 4.7b, NLP Regional Hired Labour Employment Level

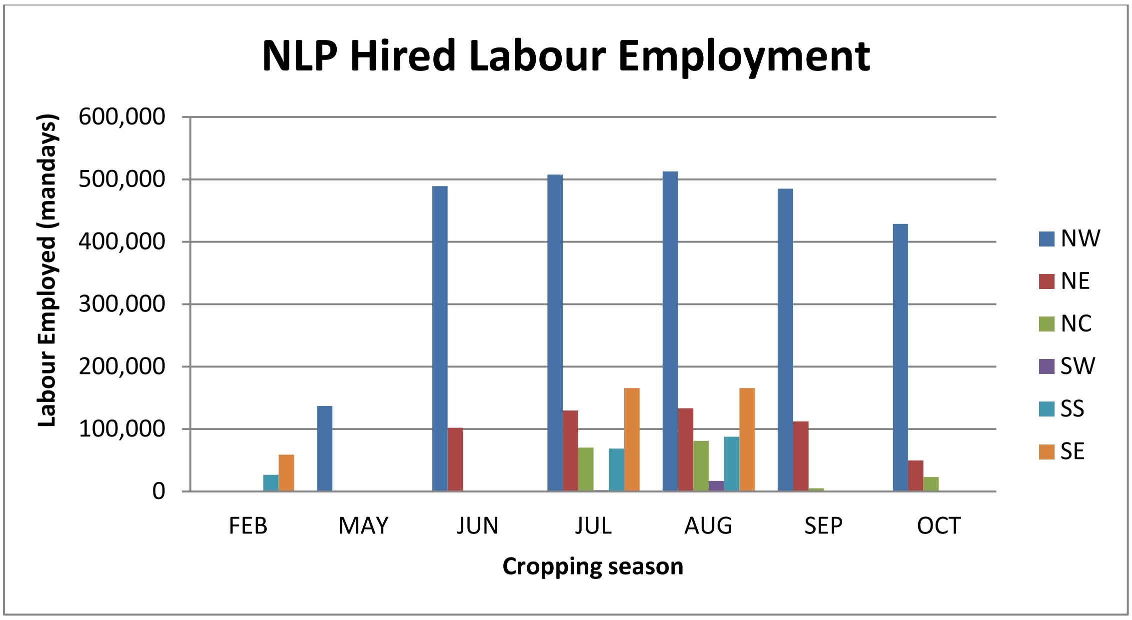


Table 4.6a, Shadow Prices for the Regional Hired Labour Employment in the Base Model

Crops	**NWSP ($)**	**NESP ($)**	**NCSP ($)**	**SWSP ($)**	**SSSP ($)**	**SESP ($)**
JAN						
FEB					4.5	4.5
MAR						
APR						
MAY	4.5					
JUN	4.5	4.5				
JUL	4.5	4.5	4.5	4.5	4.5	4.5
AUG	4.5	4.5	4.5	4.5	4.5	4.5
SEP	4.5	4.5	4.5			
OCT	4.5	4.5	4.5			
NOV						
DEC						

Table 4.6b, Shadow Prices for the Regional Family Labour Employment in the Base Model

Crops	**NWSP ($)**	**NESP ($)**	**NCSP ($)**	**SWSP ($)**	**SSSP ($)**	**SESP ($)**
JAN						
FEB					1.3	1.3
MAR						
APR						
MAY	1.3					
JUN	1.3	1.3				
JUL	1.3	1.3	1.3	1.3	1.3	1.3
AUG	1.3	1.3	1.3	1.3	1.3	1.3
SEP	1.3	1.3	1.3			
OCT	1.3	1.3	1.3			
NOV						
DEC						

Figure 4.8a, Regional Potential Family Labour Off-farm Employment

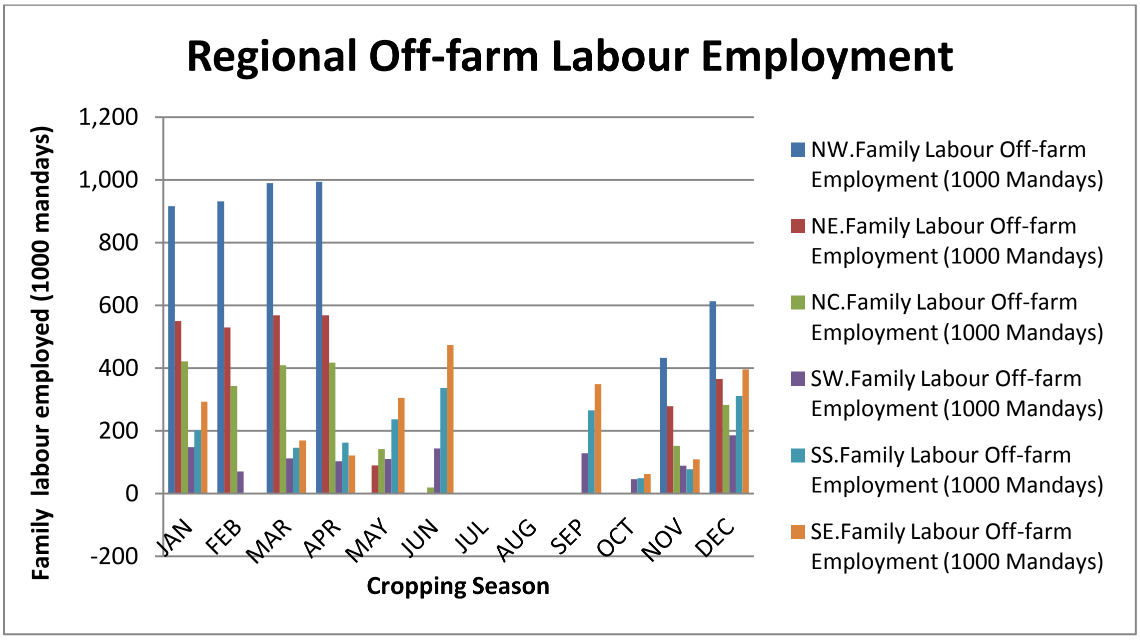
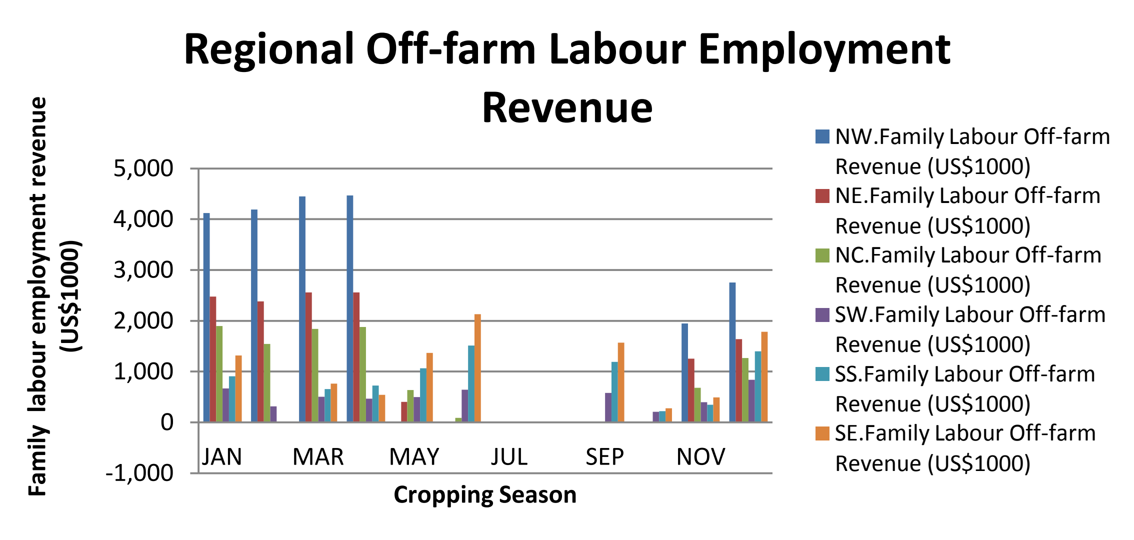


Figure 4.8b, Regional Potential Family Labour Off-farm Employment Revenue



From Figures 4.8a and 4.8b, NW which engages more family labour in cropping farming than any other region also has the highest off-farm employment opportunities and off-farm employment revenue potential for its farming family. Following NW in a descending order of magnitude are NE, SE and NC. The potential regional off-farm employment revenues are not included in the potential gross margin reported earlier, due to the uncertainty in the availability of off-farm jobs in rural areas where farming activities are performed. Hence, the achievable GM would increase on the availability of off-farm jobs in the rural areas and this could be created if the ethanol industry comes on stream.

Further results and discussions on the Base model input resource allocation (e.g., seed, fertilizer, pesticide and cash for funding farm operations) are found in Appendix 5.

4.1.9 Calibration Run Summary

In summary, the above results indicate that the NLP Base Model is consistent in structure and in the representation of the base year data on crop production (technology/techniques), based on the specified and implemented model data. Therefore, the calibration run can serve as the benchmark against which simulation runs can be evaluated. In addition, the calibration model results also provide potentially useful information on the rental value of crop land and the cash, seed, fertiliser and chemical requirements associated with each crop in each region, which are not available in current data. The results also provide information on the extent of under-employment and crop labour constraints by region, which again are not presently available otherwise.

4.2 Ethanol-Food Production Run (Model 2) Results

Having established that the Base Model complies with the reference domestic crop demand and supply conditions in addition to replicating the historic crop production levels and input resource use levels; we now proceed to apply and extend it to evaluate the ethanol production potential in Nigeria. Prior to this, it is essential to briefly explain the major differences between the Food Production Model (Model 1 or Base Model) and the Energy (Ethanol)-Food Production Model (Model 2). Structurally, the major differences between the two models are: 1) the inclusion of feedstock demand and supply variables and equations; 2) the addition of ethanol demand and supply parameters, including the feedstock-to-ethanol conversion estimates from published previous studies; 3) the use of all available regional arable land as the maximum hectare of land that can be used for the production ethanol feedstocks and food crops in each region; and 4) the implementation of the estimated current available family labour for crop farming as the maximum available family labour that can be used for the production ethanol feedstocks and food crops in each region in Model 2; in order to test if Nigeria has the potential to produce sufficient feedstock and food crops required to meet the domestic ethanol demand and the total crop demand (domestic consumption and export demands) without reducing domestic food supply or increasing the domestic commodity prices. In particular, we model the quantity of ethanol that could be produced from each region using the local energy (starch and sugar) crops after satisfying the domestic demands for those crops, identifying which feedstock (energy crop) that could be used for ethanol production in each region based on the derived feedstock viability from the model. We also examine the impact of producing ethanol from the local feedstocks (staple energy food crops) on their local food prices; land availability for the production of other non-energy crops; CO_2 emission; gross margin from ethanol production; food import substitution; refined petroleum product (RPP) import substitution; and the foreign exchange savings that will result from food and energy (RPP) import substitutions. Each of these evaluation (impact) factors is presented below.

4.2.1 Gross Margin from the Energy-Food Model

The achievable total gross margin (GM) from the Energy-Food Production Model (Model 2) (excluding ethanol co-products' revenues) is US$45.71 billion- a 4% increase from the Base Model's GM (US$43.93B). The increase in GM is mainly due to the sale of the ethanol produced from the extra energy crops demanded and supplied (produced) in the model as the domestic consumption and export demands from the model's solution remain the same with that of the base year as shown below. Ethanol co-products' revenue refers to the revenue from the sale of by/co-products produced jointly with bioethanol. This includes revenue from the sale of Distillers' Dried Grains with Soluble (DDGS), recovered CO_2 and carbon credits earned for implementing a clean development mechanism (CDM) project. Details of the Energy-Food Production Model results are discussed below in order to highlight the potential resource use and other impacts of the potential biofuel policy in Nigeria.

4.2.2 Regional Crop Production from the Energy-Food Model

Regional crop production levels from the Energy-Food Production Model are shown in Appendix 6. As expected, the major changes affect the energy crops selected as feedstocks for ethanol production in each region. On a national level, the percentage change in crop production from the Base Model is shown in Figure 4.9. From the figure, the major increase in production is from cassava and sesame. Cassava is selected as the best feedstock for ethanol production in all the regions. Hence, its production level relative to that of the base model increased by 78%. On a regional level, the production increments are 301%, 345%, and 75% in the NW, NE and NC, respectively. Similarly, in the SW, SS and SE, cassava production increased by 33%, 34% and 13%, respectively. The increase in the production of sesame (266%) was mainly used to satisfy the base year domestic consumption and export demands as well as in substituting base year external import supply with domestic supply. On a cumulative regional level, the NE will have the highest increase in crop production (63%) because this region has the greatest supply of currently un-cropped land, followed by NW (35%) and NC (27%). In the south, the greatest increase will be in the SS (17%), followed by the SW (12%) and the SE with the least increase (10%).

Selection of cassava as the best feedstock for ethanol production in Nigeria is in contrast with the choice of sugarcane in Brazil and corn in the United States. Reasons for the differences could stem from various factors which include per ha yield of sugarcane in Nigeria (25 MT/ha on the maximum) (NBS, 2010b) which is lower than that of Brazil (75 MT/ha) (Macedo et al., 2008), the differences in unit cost of feedstock production as well as production technology/techniques and management practices. However, China, Thailand, Philippines and Indonesia also produce ethanol from cassava (Qiu et al., 2010, Rañola Jr et al., 2009, Yoosin and Sorapipatana, 2007). From a management practice and practical view point (based on the researcher's experience), cassava is the easiest and most-adaptive crop to grow in Nigeria, as it can grow in a humid or dry climate, in a fertile or less fertile soil, with zero or moderate tillage as well as with moderate (minimum) or zero weeding as corroborated by others (Yoosin and Sorapipatana, 2007, Rañola Jr et al., 2009). This is probably why Nigeria is the highest cassava producer and exporter in the world as recognised by FAO (FAOSTAT, 2014b). Therefore, the guarantee of sustainable supply of cassava to the ethanol industry by the local farmers, which is very important in developing and sustaining a vibrant and competitive ethanol industry, might be relatively easier to achieve with cassava compared to other feedstocks.

Figure 4.9, National Percentage Change in Crop Production from the Base Model.

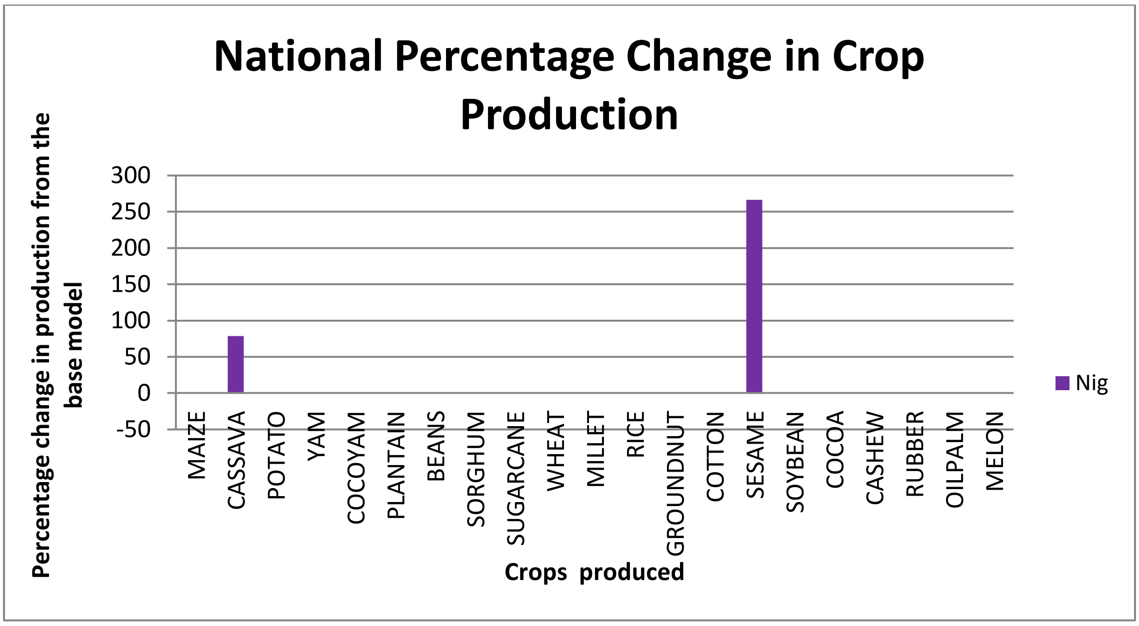


Table 4.6a indicates the input cost of producing one metric tonne of each crop produced in the Energy-Food Production Model. Comparative analysis of the unit cost of producing each crop under the Energy-Food and the Food Production Models shows a substantial decrease in the unit cost of producing each crop (both energy and non-energy crops) in all the regions (see Table 4.6b). Table 4.6b shows the percentage change (decrease) in the unit input cost of production between the Energy-Food Production Model and the Base Model. For example, it indicates that cost of producing maize in the NW, SW and SE decreased by 85%, 84% and 86%, respectively in the Energy-Food Production Model compared to the unit cost of producing maize in those regions from the Base Model. The reduction in the unit cost of production is because the shadow price of land (land rent) in all the regions is zero in the Energy-Food Production

Model, since the availability of land is increased to include un-cropped land. Hence, the unit cost of production is lower in the Energy-Food Production Model where the shadow price of land is zero compared to the Base Model where the shadow price of land is significantly greater than zero. Hence, the production of ethanol feedstocks and their conversion into ethanol does not have any negative effect (or impact) on the production cost of the crops, providing sufficient idle land is available. Consequently, the corresponding opportunity costs of producing one metric tonne of each crop in each region in the Energy-Food Production Model (Table 4.6c) is greater than that of the Base Model (Table 4.1d) in every region. For example, the opportunity cost of maize production in the NW, SW and SE from the Energy-Food Production Model is greater than that of the Base Model by 14%, 34% and 43%, respectively. As in the Base Model, the opportunity costs indicate the corresponding gross profits made from the production of one metric tonne of each crop in each region. The columns with 'N/A' imply that those crops are not produced from those regions both from the model and the historic production data. In addition, Table 4.6a shows that NW still has the best comparative advantage for maize production compared to other regions. Similarly, the SW and SE have the greatest comparative advantage in cassava and yam production, respectively. In contrast, SE is the most disadvantaged region for beans production while NW is most disadvantaged region in cassava production.

As in the Base Model, the marginal cost (MC) of producing one metric tonne of each crop is equal to the explicit input costs of producing those crops (Table 4.6a) plus the opportunity costs of producing them (their gross margins) (Table 4.6c) plus their marketing costs (which is the same as that of the Base Model in Table 4.1c). For instance, the MC of producing maize in the NW is equal to US$117, estimated from the input cost of producing maize in that region (US$2.22) plus its opportunity cost (US$103.83) plus the marketing cost (US$10.95). Consistently, this is the same as the revealed shadow price of maize at the commodity balance (equilibrium) constraint shown in Appendix 9. Therefore a necessary part of Kuhn-Tucker requirements (marginal cost being equal to input cost plus opportunity cost of fixed resources utilized as well as the product price) is satisfied by the results from the Energy-Food Production Model.

Table 4.6a, Regional Unit Cost of Crop Production (US$/MT) for the Ethanol-Food Production Model

Crops	NWIC (US$/MT)	NEIC (US$/MT)	NCIC (US$/MT)	SWIC (US$/MT)	SSIC (US$/MT)	SEIC (US$/MT)
MAIZE	2.22	4.13	5.44	5.08	5.92	5.20
CASSAVA	14.71	12.85	11.23	9.73	13.53	12.02
POTATO	95.93	94.39	94.92	94.81	96.12	97.66
YAM	32.77	48.50	37.57	32.00	40.96	30.77
COCOYAM	19.50	32.20	15.25	17.07	29.25	15.00
PLANTAIN	172.38	171.67	172.07	171.91	172.26	172.65
BEANS	19.53	9.98	8.89	15.01	11.01	41.78
SORGHUM	10.24	7.14	10.17	14.56	N/A	N/A
SUGARCANE	3.19	6.98	8.57	6.40	10.98	4.63
WHEAT	10.16	7.19	8.53	8.14	N/A	N/A
MILLET	11.96	6.02	9.38	6.30	N/A	N/A
RICE	5.89	6.30	5.63	7.37	2.60	6.47
GROUNDNUT	16.68	7.40	5.99	9.89	16.23	20.27
COTTON	11.88	8.26	10.96	12.79	N/A	N/A
SESAME	56.03	32.60	48.15	N/A	N/A	N/A
SOYBEAN	13.39	6.72	9.74	17.26	N/A	N/A
COCOA	N/A	86.72	88.11	113.49	113.51	81.61
CASHEW	9.69	15.63	10.87	28.28	16.51	25.27
RUBBER	N/A	N/A	36.22	19.73	30.85	26.31
OILPALM	66.23	61.17	34.30	30.99	36.10	37.45
MELON	5.02	10.31	11.10	10.75	43.59	39.06

Table 4.6b, Percentage Change in Input Cost per MT of Crop from the Base Model.

Crops	NWIC (%)	NEIC (%)	NCIC (%)	SWIC (%)	SSIC (%)	SEIC (%)
MAIZE	-85.18	-92.01	-86.06	-83.65	-81.08	-85.60
CASSAVA	-28.58	-35.73	-26.97	-23.18	-23.46	-33.00
POTATO	-18.26	-23.56	-17.08	-14.36	-14.50	-21.34
YAM	-15.16	-19.74	-14.12	-11.82	-12.02	-18.02
COCOYAM	-36.76	-45.16	-35.26	-30.80	-30.77	-41.09
PLANTAIN	-6.25	-8.33	-5.74	-4.72	-4.83	-16.47
BEANS	-83.48	-91.03	-84.99	-82.99	-79.87	-38.41
SORGHUM	-84.13	-91.55	-85.57	-83.60	N/A	N/A
SUGARCANE	-46.49	-55.60	-45.11	-40.27	-39.97	-50.89
WHEAT	-82.22	-89.88	-83.42	-81.09	N/A	N/A
MILLET	-84.31	-91.71	-85.78	-83.85	N/A	N/A
RICE	-83.22	-90.80	-84.70	-82.64	-79.57	-83.95
GROUNDNUT	-83.17	-90.95	-84.89	-83.35	-80.81	-85.41
COTTON	-80.59	-88.89	-82.35	-80.41	N/A	N/A
SESAME	-77.52	-85.38	-77.75	N/A	N/A	N/A
SOYBEAN	-79.37	-87.36	-80.21	-77.39	N/A	N/A
COCOA	N/A	-74.57	-71.41	-67.55	-66.28	-74.77
CASHEW	-80.42	-88.39	-81.55	-78.95	-76.61	-81.39
RUBBER	N/A	N/A	-78.24	-75.18	-73.37	-80.14
OILPALM	-54.74	-64.56	-71.54	-67.70	-66.42	-74.88
MELON	-83.19	-81.62	-82.29	-83.44	-55.40	-57.15

Table 4.6c, Regional Opportunity Cost of Crop Production (GM from Crop Production) (US$/MT)

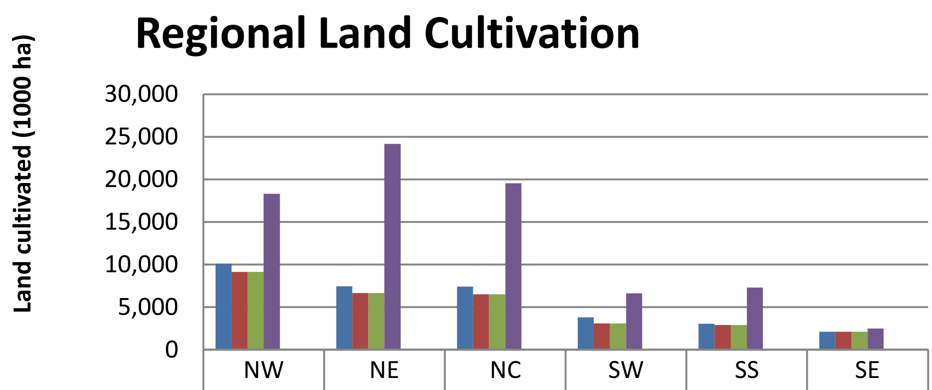
Crops	NWOC (US$/MT)	NEOC (US$/MT)	NCOC (US$/MT)	SWOC (US$/MT)	SSOC (US$/MT)	SEOC (US$/MT)
MAIZE	103.83	101.92	100.61	103.16	102.32	103.04
CASSAVA	59.04	60.90	62.52	66.21	62.41	63.92
POTATO	165.92	167.46	166.93	169.23	167.92	166.38
YAM	86.18	70.45	81.38	89.14	80.18	90.37
COCOYAM	80.85	68.15	85.10	85.47	73.29	87.54
PLANTAIN	137.17	137.88	137.48	139.83	139.48	139.09
BEANS	91.52	101.07	102.16	98.23	102.23	71.46
SORGHUM	97.11	100.21	97.18	94.98	N/A	N/A
SUGARCANE	101.66	97.87	96.28	100.64	96.06	102.41
WHEAT	171.39	174.36	173.02	175.60	N/A	N/A
MILLET	88.39	94.33	90.97	96.24	N/A	N/A
RICE	115.16	114.75	115.42	115.87	120.64	116.77
GROUNDNUT	97.87	107.15	108.56	106.85	100.51	96.47
COTTON	375.67	379.29	376.59	376.95	N/A	N/A
SESAME	204.62	228.05	212.50	N/A	N/A	N/A
SOYBEAN	182.56	189.23	186.21	180.88	N/A	N/A
COCOA	N/A	588.83	587.44	564.25	564.23	596.13
CASHEW	232.56	226.62	231.38	216.16	227.93	219.18
RUBBER	N/A	N/A	339.13	357.81	346.69	351.23
OILPALM	602.72	607.78	634.65	640.15	635.04	633.69
MELON	174.03	168.74	167.95	170.49	137.65	142.18

4.2.3 Optimal Land Use for the Energy-Food Production Model

The optimal land use for the ethanol production is depicted in Figure 4.10. Importantly, it shows that ethanol production will impact on land use across the regions, resulting in more land allocated to energy crops, as expected. On the regional basis, the highest increment (the greatest overall land use change impact) will be in the SW (22%), followed by NC (14%) and NE (12%), in a descending order. The SE will have the least increase (0.2%) in land allocated for the growing of energy crops due to its feedstock and ethanol demand – having the least ethanol demand among other regions and consequently the least feedstock demand. The regional ethanol demand distribution is consistent with the regional refined petroleum product (RPP) distribution (consumption) data from NNPCSTAT (2012) between 2009 and 2012 (Appendix 7), which shows that the SE region received (and consumed) the least RPP among other regions. As shown in Figure 4.10, the available uncultivated arable land in each region would not be exhausted if ethanol production policy is implemented to meet the current ethanol demand in Nigeria. Substantial uncultivated hectares of land will still be available in all the regions, except in the SE where almost all available arable land is already used. The available total arable land in each region excludes areas covered by in-land waters, forest and built-up areas, but includes the area currently being cultivated. Therefore the land use impact of the contemplated bioethanol programme will be relatively insignificant since some uncultivated arable lands are still available in each region even after meeting the domestic food consumption demand, export demand and the ethanol feedstock demand as shown earlier. This result therefore corroborates the findings of previous studies (de la Torre Ugarte, 2006, Hazell, 2006, von Braun, 2008), indicating that ethanol production will lead to cultivation of more land, on one hand, but most importantly conforms to the research findings that the land use change impact of bioethanol is more severe and significant in areas where available arable land is limited as reported in several previous studies (Qiu et al., 2010, Mitchell, 2010, Timilsina et al., 2012, Zilberman et al., 2013).

In the Nigerian case, the land use impact should rather be viewed as a positive impact instead of negative since the ‘unprofitable’ hectares of fertile arable land currently lying fallow will be put into productive use through ‘moderate’ ethanol production, i.e., in meeting the current ethanol demand. An ‘aggressive’ bioethanol programme such that all available arable lands will be dedicated for the production of energy crops may not be advisable since it might displace some food/cash crops. Further, ethanol production may not lead to the displacement of food crops from arable lands since all the cash and food crops currently cultivated in Nigeria were considered in the model without any being displaced in the optimal solution result.

Figure 4.10, Regional Optimal Land Use for the Energy-Food Production Model

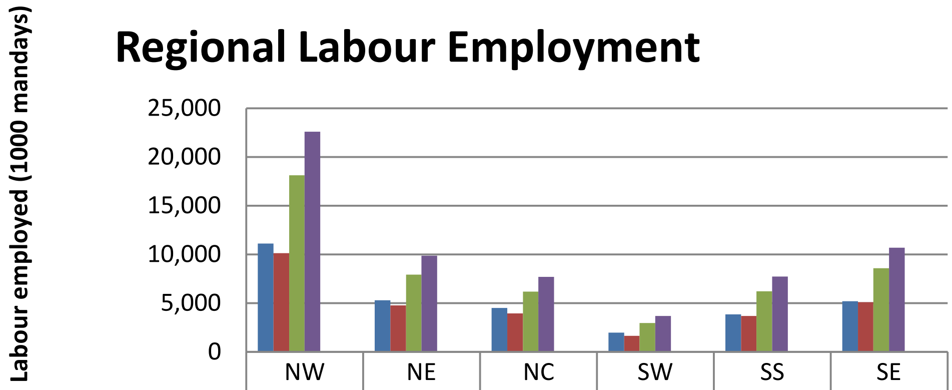


	NW	NE	NC	SW	SS	SE
S0 land (1000 ha)	10,126	7,455	7,428	3,793	3,044	2,137
NLP Baseyr Land (1000 ha)	9,132	6,663	6,515	3,099	2,896	2,133
NBS Baseyr Land (1000 ha)	9,132	6,663	6,515	3,099	2,896	2,133
Available Land (1000 ha)	18,300	24,166	19,533	6,623	7,292	2,498
% Increase in Land Use with respect to the NLP Baseyr	10.9	11.9	14.0	22.4	5.1	0.2
% Regional share	29.8	21.9	21.9	11.2	9.0	6.3

4.2.4 Optimal Labour Employment for the Ethanol-Food Model

The labour displayed in Figure 4.11a refers to only the number of labour employed for the production of the ethanol feedstock and the base year catch and cash crops required to satisfy the domestic consumption and export demands. The number and cost of labour employed in the ethanol refinery to process the feedstocks into ethanol were already factored into the per litre variable cost of producing ethanol given in the reference literature (Shapouri and Gallagher, 2005). Similar to the land use impact, Figure 4.11a shows that the production of bioethanol will require additional labour to cultivate and/or produce the ethanol feedstocks. Employment creation (increase in agricultural (crop farming) labour force) is a positive and desirable outcome of the bioethanol production project since it will help reduce the unemployment rate in Nigeria. It could by extension help to improve the security challenge in the nation as it is more likely that engaged-people will be less prone to destructive activities than unemployed ones. It will further impact positively on the Nigerian gross domestic product (GDP) and gross national income (GNI) thereby growing Nigerian economy further and bettering the living standard of the citizens.

Figure 4.11a, Regional Optimal Labour Employment for the Ethanol-Food Production Model



	NW	NE	NC	SW	SS	SE
S0 labour (1000 mandays)	11,114	5,300	4,492	1,987	3,831	5,198
NLP Baseyr labour (1000 mandays)	10,114	4,771	3,961	1,655	3,691	5,082
NBS Baseyr Labour (1000 mandays)	18,128	7,909	6,169	2,957	6,212	8,586
Available labour (1000 mandays)	22,595	9,858	7,689	3,686	7,743	10,701
% Increase in Labour Use with respect to the NLP Baseyr	10	11	13	20	4	2
% Regional Share	34.8	16.6	14.1	6.2	12.0	16.3

In terms of seasonal labour demand and supply and the opportunity for family labour off-farm employment, Figure 4.11b shows that the available family labour will be completely utilized and additional labour required and hired (Figure 4.11d) in the NW during the land preparation and planting season for most crops in the region, i.e. from May to October as in the Base Model. The associated shadow prices for hired and family labour employed (Tables 4.7a and 4.7b) are exactly the same in magnitude as that of the base model (Tables 4.5a and 4.5b). Notably, Tables 4.7a and 4.7b and Figure 4.11c indicate that the SE will not require nor hire additional labour throughout the cropping season since the available family labour will not be completely used up in any of the cropping seasons from January to December.

Additional information about the quantity of other resources (fertilizer, pesticide and cash) utilized in the Ethanol-Food Production Model is presented in Appendix 8.

Figure 4.11b, NW Family Labour Employment for the Ethanol-Food Production Model

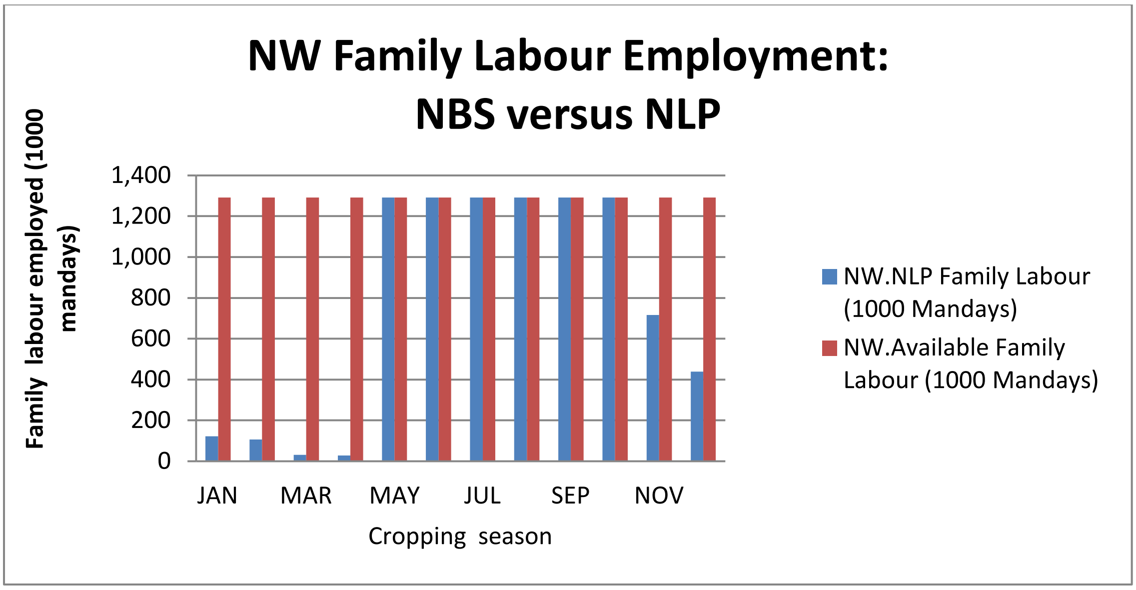
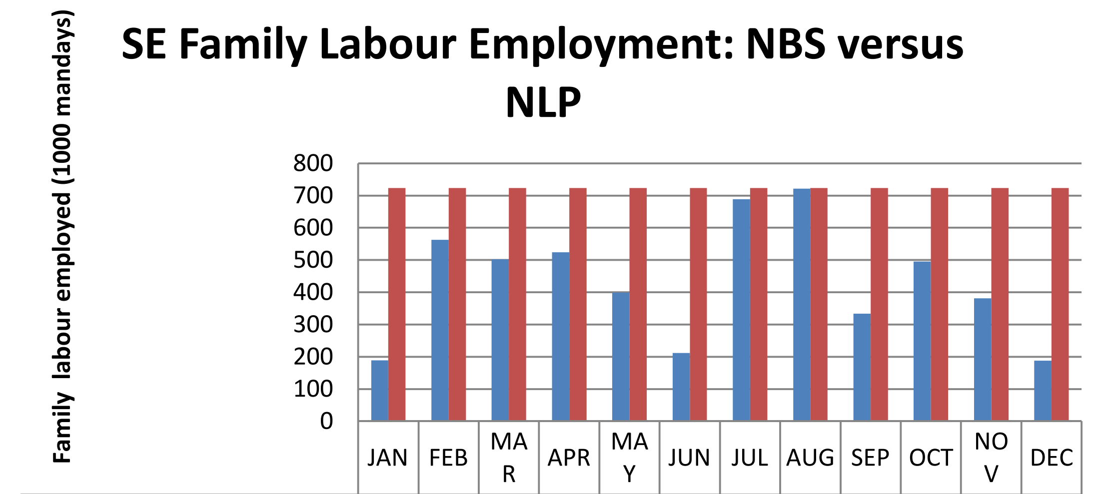


Figure 4.11c, SE Family Labour Employment for the Ethanol-Food Production Model



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SE.NLP Family Labour (1000 Mandays)	189	562	502	524	400	212	689	721	333	495	381	188
SE.Available Family Labour (1000 Mandays)	724	724	724	724	724	724	724	724	724	724	724	724

Figure 4.11d, Regional Hired Labour Employment for the Ethanol-Food Production Model

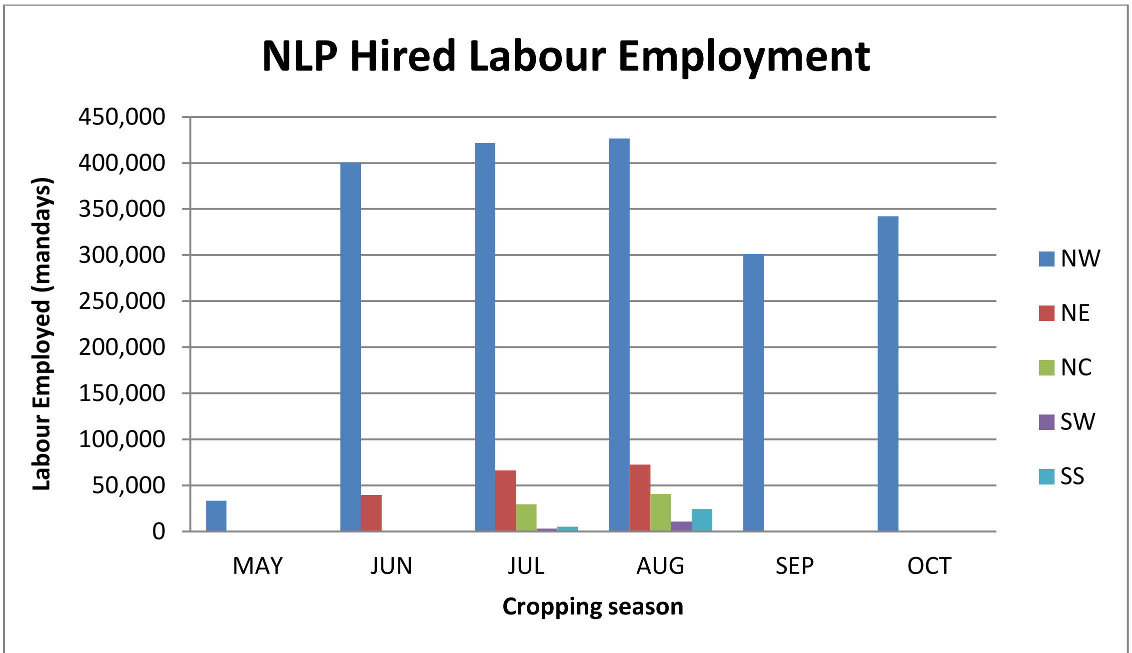


Table 4.7a, Shadow Prices for the Hired Labour Employment from the Ethanol-Food Model

Crops	**NWSP ($)**	**NESP ($)**	**NCSP ($)**	**SWSP ($)**	**SSSP ($)**	**SESP ($)**
JAN						
FEB						
MAR						
APR						
MAY	4.5					
JUN	4.5	4.5				
JUL	4.5	4.5	4.5	4.5	4.5	
AUG	4.5	4.5	4.5	4.5	4.5	
SEP	4.5					
OCT	4.5					
NOV						
DEC						

Table 4.7b, Shadow Prices for the Family Labour Employment from the Ethanol-Food Model

Crops	**NWSP ($)**	**NESP ($)**	**NCSP ($)**	**SWSP ($)**	**SSSP ($)**	**SESP ($)**
JAN						
FEB						
MAR						
APR						
MAY	1.3					
JUN	1.3	1.3				
JUL	1.3	1.3	1.3	1.3	1.3	
AUG	1.3	1.3	1.3	1.3	1.3	
SEP	1.3					
OCT	1.3					
NOV						
DEC						

Consequent to the seasonal labour employment, the family labour off-farm employment and the inherent potential family labour off-farm employment revenue are as depicted in Figures 4.11e and 4.11f. From the figures, NW has the highest family labour off-farm employment and off-farm revenue opportunity, followed by NE and SE, in a decreasing order.

Figure 4.11e, Regional Potential Family Labour Off-farm Employment from the Ethanol-Food Model

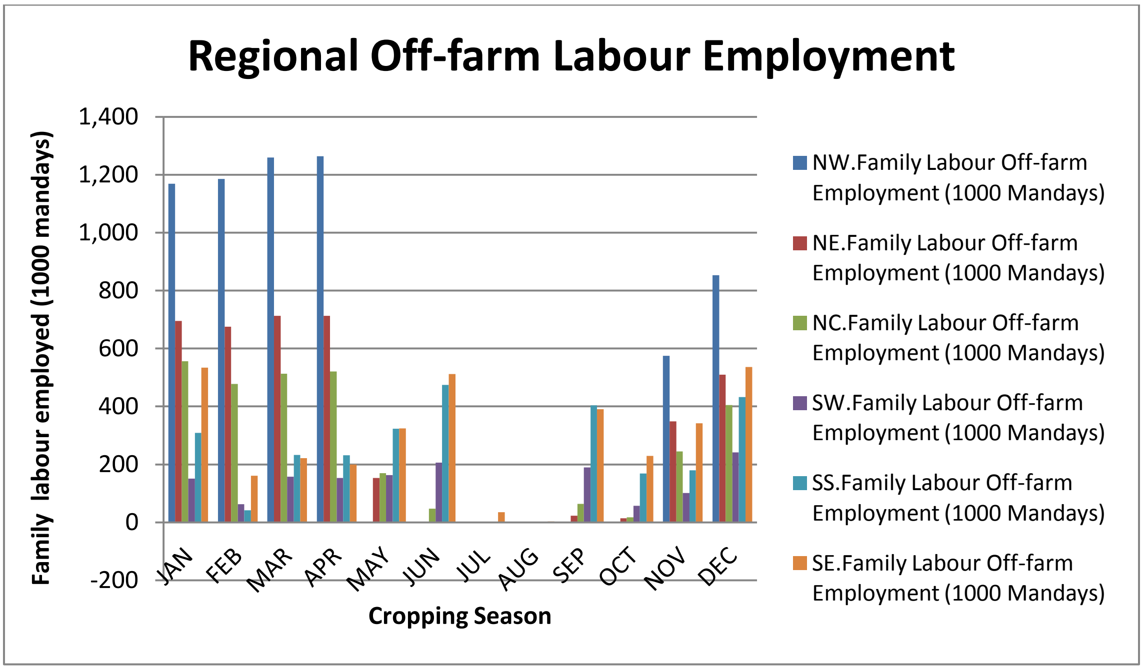
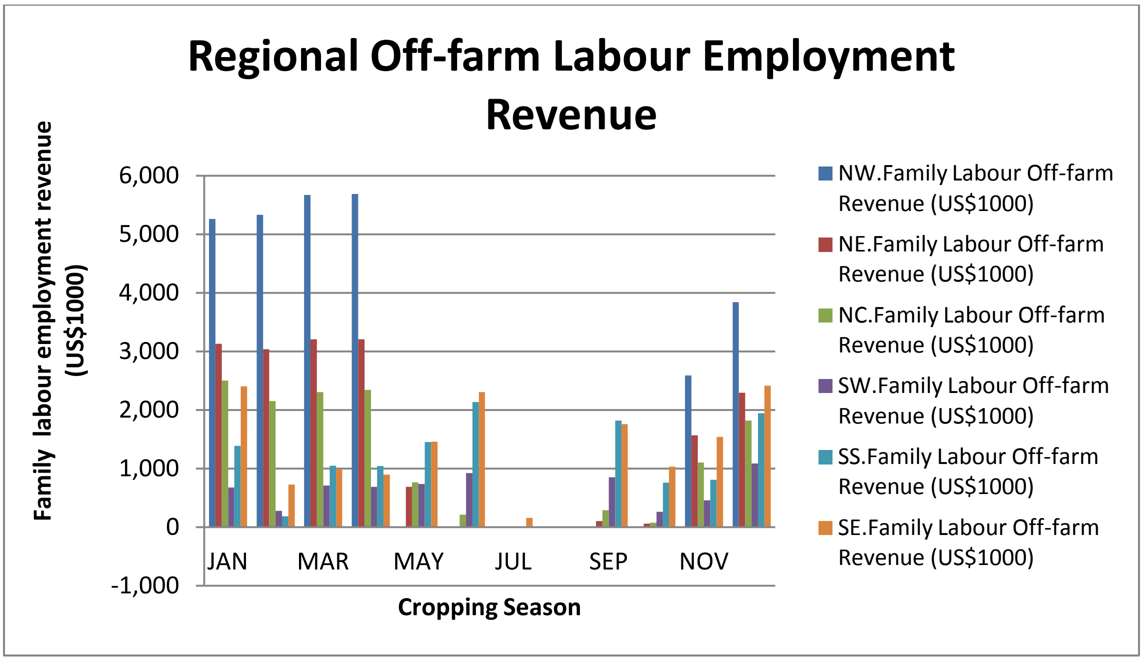


Figure 4.11f, Regional Potential Family Labour Off-farm Employment Revenue from Model 2.



4.2.5 Crop Demand-Supply Balance for the Energy-Food Model

Importantly, Figures 4.12a and 4.12b show that the total crop demand (domestic consumption, exports and feedstock demands) is satisfied by total crop supply in the Ethanol-Food Production Model. As expected, Figure 4.12b shows that cassava demand and supply (the second bar in the figure, after maize) increased significantly more than other crops due to its demand for ethanol production. The corresponding shadow prices at the model's demand-supply balance for each crop are in Appendix 9. As in the base model, columns with 'N/A' in Appendix 9 imply that those crops were not demanded in those regions. Remarkably, a comparison of the shadow prices at the commodity balance constraints for the Base and the Ethanol-Food Production Models (Table 4.2a and Appendix 9) indicates that the domestic market prices of the crops from the two models are exactly the same. Further, the domestic consumption demand from the Ethanol-Food Production Model (Figure 4.12c) is exactly the same as that of the Base Model (Figure 4.3c) both on regional and individual crop basis. In other words, the quantity of crops consumed (or sold to the domestic market) in the Ethanol-Food Production Model is exactly the same with that of the base year since the Base Model's consumption demand is exactly the same as the base year domestic consumption demand.

The commodity price results from the base model and the Ethanol-Food Production Model imply that producing ethanol from the local energy crops (which are also the local staple foods) may not have any significant effect on the energy crop prices and/or the prices of other non-energy crops. This result justifies the recommendation for country specific impact analysis study to be conducted prior to the implementation of bioethanol production programme (Hazell and Pachauri, 2006b, Hazell, 2006, von Braun, 2008). It also corroborates the findings of recent studies (Zilberman et al., 2013, Timilsina et al., 2012) that the production and/or expansion of biofuel production may have very little or no impact on agricultural commodity prices; but rather that the impact is more significant on land use.

The land use impact is in the form of cultivation of new arable land or reallocation of land from food crops to fuel crops, which increases the demand for land and consequently its rent and food prices where availability of arable land is highly constrained. Hence, the impact on land use and food prices will be much reduced where there is a substantial supply of uncultivated arable land as in Nigeria, as suggested by the product price result of this study. Therefore this study answers the research question of 'what impact will the production of ethanol from the local staple food crops makes on the food market prices'? Further, it has also shown through the domestic consumption demands (Figures 4.12c and 4.3c) that the availability food in the domestic market need not be affected by the introduction of the biofuel programme. Hence, impact on food security might be minimal.

Figure 4.12a, Total Crop Supply versus Total Crop Demand by Region from the Energy-Food Model

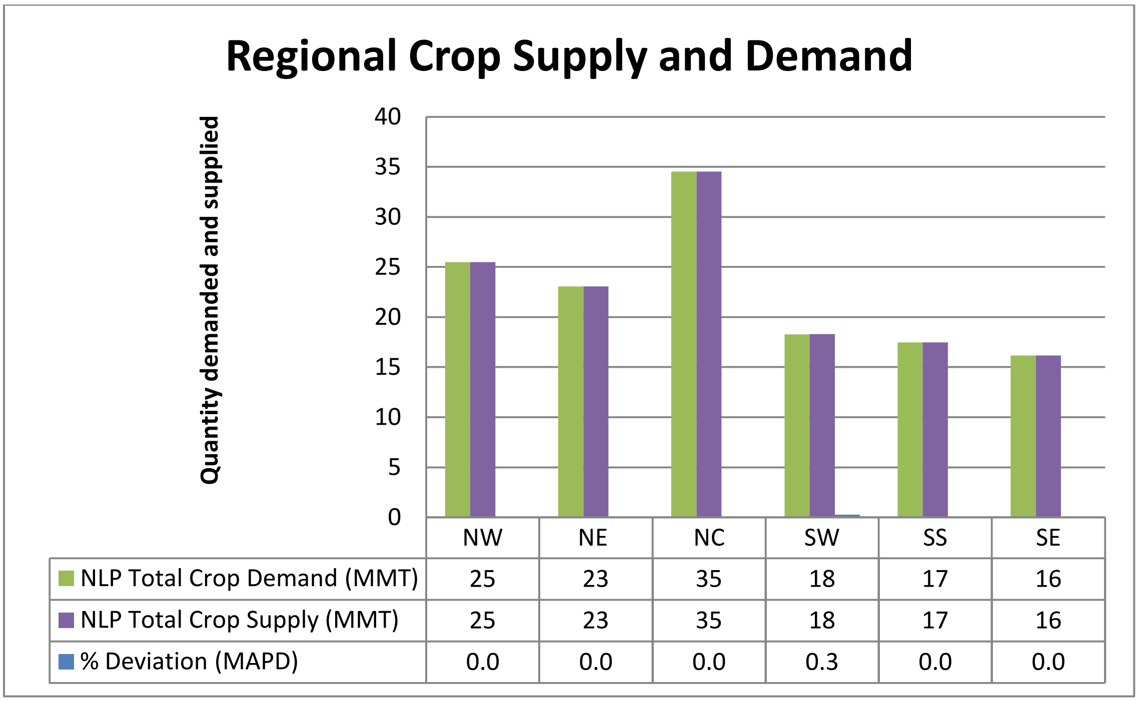


Figure 4.12b, Total Crop Supply versus Total Crop Demand by Crop from the Energy-Food Model

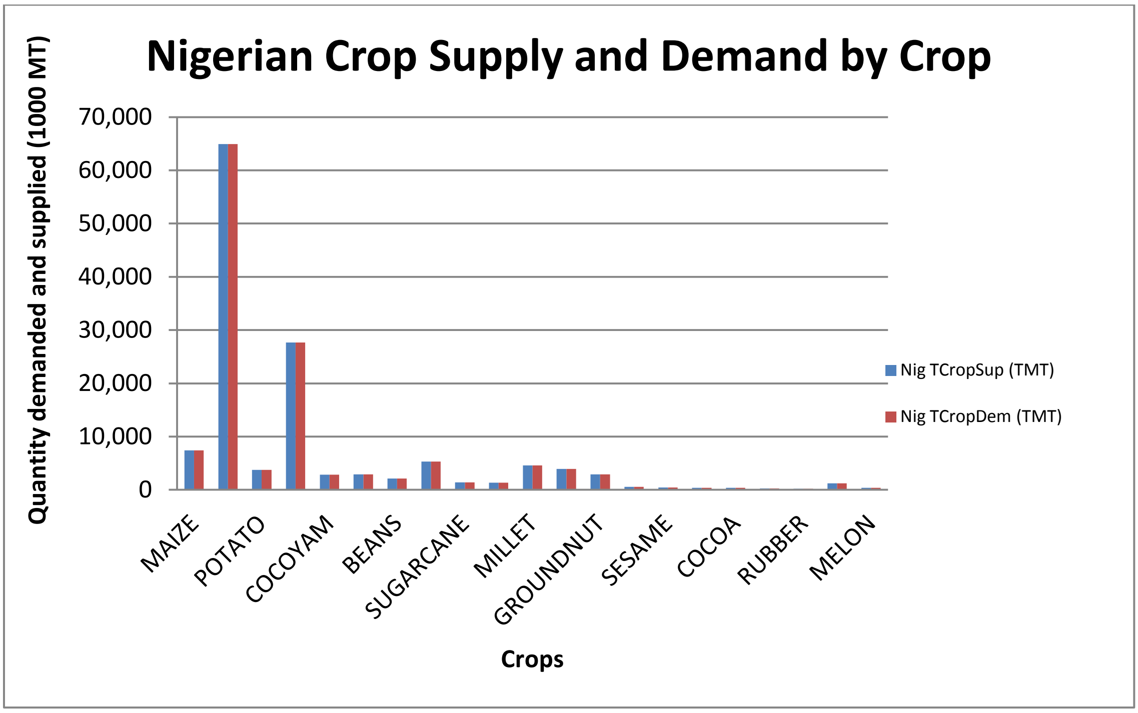
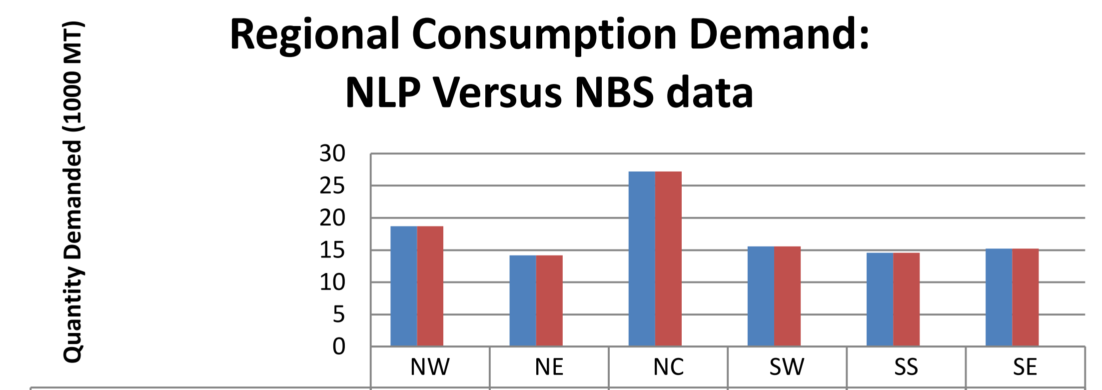


Figure 4.12c, NLP versus NBS Domestic Consumption Demand from Energy-Food Model



	NW	NE	NC	SW	SS	SE
NLP Domestic Consumption Demand (MMT)	19	14	27	16	15	15
NBS Domestic Consumption Demand (MMT)	19	14	27	16	15	15
% Deviation (MAPD)	0.0	0.0	0.0	0.0	0.0	0.0

4.2.6 Inter-Regional Crop Trade from the Energy-Food Model

The inter-regional trade result from the Ethanol-Food Production Model showed a significant reduction in the trade flows among the regions due to the availability of the limiting production resource (land), thus giving the regions the possibility of producing what they consume, export and/or use for ethanol production. The result shows that only the SS region will import forty eight thousand, eight hundred and fifty metric tonnes (48,850 MT) of melon seed from the SW in order to augment their total regional supply (which is only domestic production in this case since external supply/import is zero) and satisfy their total regional demand (domestic consumption plus feedstock plus export).

4.2.7 Imports and Exports for the Energy-Food Model

As in the optimized Base Model, where the base year export demand and import supply are respectively implemented as the upper bounds of the export and import variables using less than or equal to constraint (=l=), the prescribed import levels are equal to zero signifying import supply substitution with domestic supply (production). Therefore, as in the Base Model, the reference total crop demand is satisfied through domestic supply and not through import as all the externally supplied crops in the reference crop demand were instead grown and supplied domestically due to the implied marginal revenue contribution to the total gross margin for growing those crops domestically. In contrast, the crops that were not exported in the Base Model (Table

4.4a) are now exported in the Ethanol-Food Production Model due to the availability of additional key production resources (land and labour), thereby making the export levels in the latter model to be exactly equal to the base year levels (see Figure 4.13). The corresponding import reduced costs and export shadow prices are reported in Appendices 10a and 10b, respectively. Tables 8a and 8b highlight the respective percentage change in import reduced costs and export shadow prices from the Base Model. Columns with 'UNDF' in Table 4.8b imply that the percentage change calculation is mathematically undefined for the associated crops. This is because those crops were not exported in the Base Model; hence, their export shadow prices were zero (see Table 4.4a). Also columns with 'N/A' means that those crops were neither exported/imported in the base year nor in the two models in those regions. From Table 8a, the import reduced costs for the crops increased significantly from that of the Base Model due to the reduction in domestic cost of production (owing to the zero land rents) in the Ethanol-Food Production Model. Hence, it is cheaper to import in the Base Model where domestic cost of production is generally higher than in the Ethanol-Food Production Model where it is lower. Similarly, the export shadow prices in the Ethanol-Food Production Model increased substantially from that of the Base Model due to the same reason. This is because the reduction in domestic cost of production led to an increase in the opportunity cost of producing and selling 1 MT of each crop in the domestic market (Table 4.6c) as earlier discussed in Section 4.2.2; while profit maximization constraint requires the export price of a commodity and the accruing gross margin from its export to be at least equal to what is obtainable from the domestic market in order for that commodity to be exported. Hence, the commodity export shadow prices in the Ethanol-Food Production Model would increase in order to grantee, on the minimum, equal accruing gross margins from the domestic market sales since exporting below domestic market prices (i.e. below prices that would grantee equal accruing gross margins with the domestic market sales) would result to losses which no rational economic agent would like to incur.

Figure 4.13, NLP versus NBS Export Demands from the Energy-Food Model

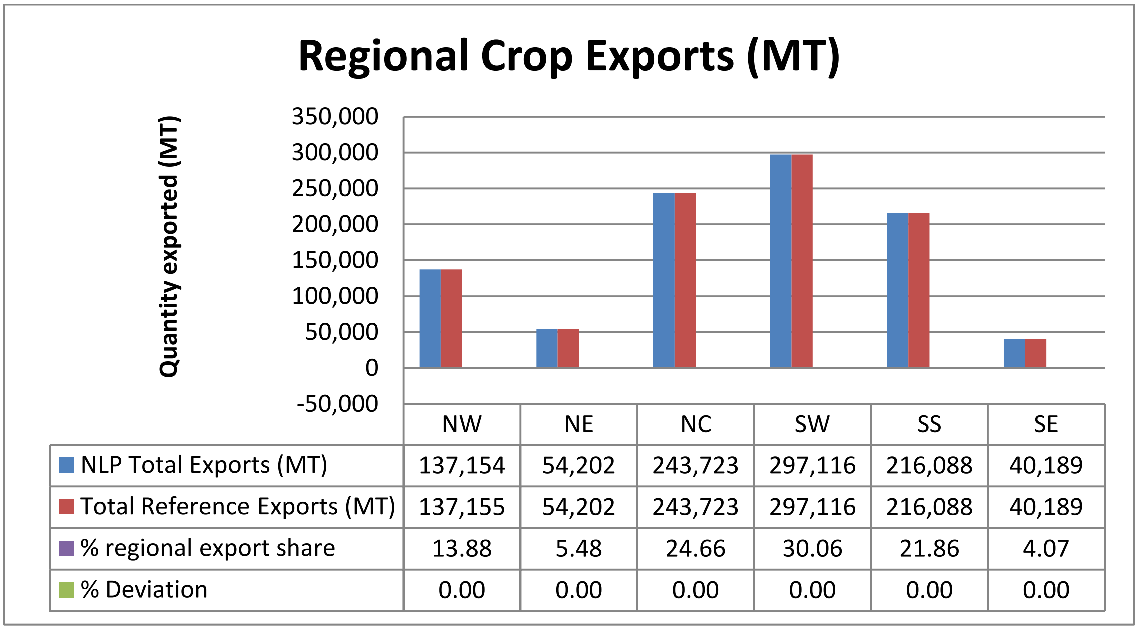


Table 4.8a, Percentage Change in Regional Import Reduced Costs from the Base Model

Crops	**NW**	**NE**	**NC**	**SW**	**SS**	**SE**
MAIZE	9.8	51.1	31.8	22.4	22.0	27.9
CASSAVA	7.3	8.8	4.8	3.3	4.9	7.0
POTATO	9.2	12.9	8.3	6.6	6.8	11.7
YAM	4.8	11.9	5.3	3.4	4.8	5.4
COCOYAM	10.8	34.3	7.4	6.7	13.6	9.3
PLANTAIN	5.0	6.9	4.6	3.6	3.7	16.4
BEANS	309.3	260.6	55.4	112.0	44.8	30.9
SORGHUM	67.4	127.6	80.7	126.9	N/A	N/A
SUGARCANE	2.0	6.9	5.6	3.2	5.8	3.6
WHEAT	25.3	37.1	22.4	17.2	N/A	N/A
MILLET	107.6	105.0	80.8	33.0	N/A	N/A
RICE	22.8	65.6	24.7	28.6	6.6	27.0
GROUNDNUT	148.0	101.8	29.2	50.7	94.4	91.7
COTTON	10.9	15.0	11.3	11.6	N/A	N/A
SESAME	196.4	152.7	128.2	N/A	N/A	N/A
SOYBEAN	26.1	22.2	18.5	31.4	N/A	N/A
COCOA	N/A	45.9	37.5	43.1	39.8	42.1
CASHEW	14.5	24.3	18.2	33.9	21.2	24.2
RUBBER	N/A	N/A	21.1	14.2	22.1	28.8
OILPALM	10.8	15.6	11.3	8.2	9.1	15.1
MELON	11.8	24.9	29.1	30.6	37.5	34.5

Table 4.8b, Percentage Change in Regional Export Shadow Prices from the Base Model

Crops	**NW**	**NE**	**NC**	**SW**	**SS**	**SE**
MAIZE	18.8	153.2	77.0	48.3	47.4	63.5
CASSAVA	16.3	19.4	10.0	6.3	10.0	14.4
POTATO	23.8	34.7	21.1	16.1	16.8	31.0
YAM	10.8	36.7	12.6	7.3	11.5	11.7
COCOYAM	24.0	UNDF	15.2	13.6	34.2	19.1
PLANTAIN	18.7	26.8	16.7	12.7	13.1	83.2
BEANS	UNDF	UNDF	183.5	UNDF	128.0	124.1
SORGHUM	283.8	UNDF	UNDF	UNDF	N/A	N/A
SUGARCANE	3.7	13.2	10.7	5.9	11.1	6.4
WHEAT	54.8	88.7	46.8	34.1	N/A	N/A
MILLET	UNDF	UNDF	466.0	79.2	N/A	N/A
RICE	49.0	238.0	53.9	64.6	12.1	59.8
GROUNDNUT	UNDF	UNDF	67.5	153.5	UNDF	UNDF
COTTON	20.0	28.3	20.8	21.5	N/A	N/A
SESAME	UNDF	UNDF	UNDF	N/A	N/A	N/A
SOYBEAN	57.4	45.8	37.4	73.4	N/A	N/A
COCOA	N/A	128.9	95.6	123.9	109.5	111.5
CASHEW	28.0	51.9	36.2	83.2	43.9	53.1
RUBBER	N/A	N/A	44.4	27.1	46.1	63.3
OILPALM	20.7	30.9	20.9	14.8	16.7	28.9
MELON	22.3	54.0	65.9	69.1	119.0	100.0

4.2.8 Regional Ethanol Production from the Energy-Food Model

In general, the results show that ethanol can only be profitably produced from the first generation feedstocks (grains) and not from the second generation feedstocks (cellulosic crop residues) as ethanol production from the cellulosic material of each feedstock would reduce the potential GM by the corresponding reduced cost in Table 4.9e. Specifically, Figure 4.14a shows the total volume of ethanol produced in each region. From Figure 4.14a, the northern part of Nigeria has greater potential for ethanol production than the southern part due to the availability of more landmass and arable land for food and feedstock production. Figure 4.14b indicates that the estimated total ethanol demand in Nigeria (5.14 billion litres) would be met from domestic ethanol supply (production) using cassava as feedstock. Notably, it indicates that ethanol can only be most profitably produced from cassava in Nigeria at the current feedstock and ethanol production technologies and costs as reflected in the model. However, maize, sorghum, millet, wheat (in the NC and SW) and rice appear to be potentially close substitutes in terms of the costs of producing feedstock (Table 4.9a), but are ruled out because of their ethanol conversion characteristics (Table 4.9b). Conversely, potatoes, sugarcane and wheat (in the NW and NE) are shown to be approximately competitive in their conversion characteristics, but are ruled out on the basis of their production costs. For example, the reduced cost of supplying 1 MT of sugarcane for ethanol production in the NW region is - US$3, implying that supplying 1 MT of sugarcane from the NW region to the ethanol industry instead of the food (sugar) industry would reduce the achievable GM by US$3. Similar interpretation can be advanced for other feedstocks with positive or negative reduced cost values[16]. Columns with 'N/A' in Table 4.9a imply that such feedstocks are not produced (supplied) from those regions. On the other hand, Table 4.9b shows that the reduced cost of producing 1 litre of ethanol from maize in the NW is US$0.11, implying that producing 1 litre of ethanol from maize in this region would reduce the achievable GM by US$0.11. Similarly, the reduced cost of producing 1 litre of ethanol from sugarcane in all the regions is zero, suggesting that ethanol would be produced from sugarcane in all the regions without reducing the potential GM; however, the associated feedstock supply reduced costs makes it unprofitable to produce ethanol from sugarcane in any of the regions. As indicated in Table 4.9a, the reduced cost of supplying 1 MT of each energy crop that could be selected as feedstock for ethanol production is zero. In the same vein, the reduced cost of producing 1 litre of ethanol from each potential feedstock is zero. Therefore for a feedstock to be selected as a viable feedstock for ethanol production in any region, that feedstock must have zero reduced cost values in Tables 4.9a and 4.9b; hence, only cassava is selected as a viable feedstock for ethanol production in all the regions. These results are thus consistent with the Kuhn-Tucker or mathematical programming conditions for optimal solution, which requires the reduced costs of basic variables to be equal to zero and that of the non-basic variable to be greater than zero in absolute value (McCarl, 1998, Ch.9, p.22, McCarl and Spreen, 1997, Ch.17, p. 22, Ch.18, p.5). Further, Table 4.9d reveals the opportunity costs of producing one litre of ethanol from any of the feedstocks (factoring the implicit feedstock cost per litre). In other words, it is the per litre GM of processing ethanol from each grain feedstock.

[16] Positive and negative reduced costs only indicate that the corresponding variables are respectively in their lower and upper bounds in the optimal solution. Both suggest how much the potential GM would reduce by if additional unit of that activity/variable is further added into or removed from the optimal solution. In essence, it is the absolute value of the reduced costs that are more important than their signs. For further details, see: DAWSON, B., DICKSON, A., NAUGHTEN, B., NOBLE, K. & FISHER, B. 1996. ABARE MARKAL Workshop. *Asia Least Cost Greenhouse Gas Abatement Strategies (ALGAS) project.* Canberra, Australia: Asian Development Bank (ADB). PSU. 2013. The Pennsylvania State University. Available: https://www.courses.psu.edu/for/for466w_mem14/Ch11/HTML/Sec4/ch11sec4.htm https://www.courses.psu.edu/for/for466w_mem14/Ch11/HTML/Intro/ch11intro.htm [Accessed 30/10/ 2013].

From Table 4.9d, cassava, sugarcane and potatoes have exactly the same opportunity costs per litre of ethanol produced in all the regions. Also the three feedstocks have the highest opportunity costs per litre of ethanol produced among other feedstocks in all the regions. This implies that producing one litre of ethanol from cassava and sugarcane in each region would increase the objective function value by the same amount. Hence, sugarcane could be classified as the second best feedstock for ethanol production in Nigeria. From Table 4.9d, ethanol production from maize adds the least amount to the potential GM. Following maize in a decreasing order of magnitude is rice. Therefore potatoes, followed by wheat, will be the least feedstock to be selected for ethanol production due to their feedstock supply reduced costs.

The estimated aggregate feedstock cost per litre of ethanol produced is US$0.13; implying that the feedstock cost accounts for 54% of the per litre total cost of producing ethanol from cassava feedstock (US$0.24), with the rest being the ethanol processing cost. This result corresponds to the findings of previous studies (Shapouri et al., 2002a, Shapouri and Gallagher, 2005, Wallace et al., 2005), which suggest that feedstock cost accounts for more than half of the total ethanol production cost. It also implies that an average gross margin of US$0.33 is made per litre of ethanol demand and supplied in all the regions, since the implemented per litre ethanol minimum selling price is US$0.57. Consistently, the regional shadow prices on the ethanol demand-supply balance constraint (Table 4.9c) are approximately equal to US$0.33 for each region. Again, these shadow prices represent the gross margin per litre of ethanol demanded and supplied from each region. It also implies the amount by which the objective function value (the enterprise total GM) would increase by if an additional litre of ethanol is demanded and supplied from each region. In summary, the potential viable and 'best' feedstock that can be used for ethanol production in each region has been identified as cassava, followed by sugarcane, among others. However, we need to examine the ethanol production viability (including its co-products), in order to fully assess the potential contribution of ethanol to the Nigerian economy.

Figure 4.14a, Ethanol Production by Region

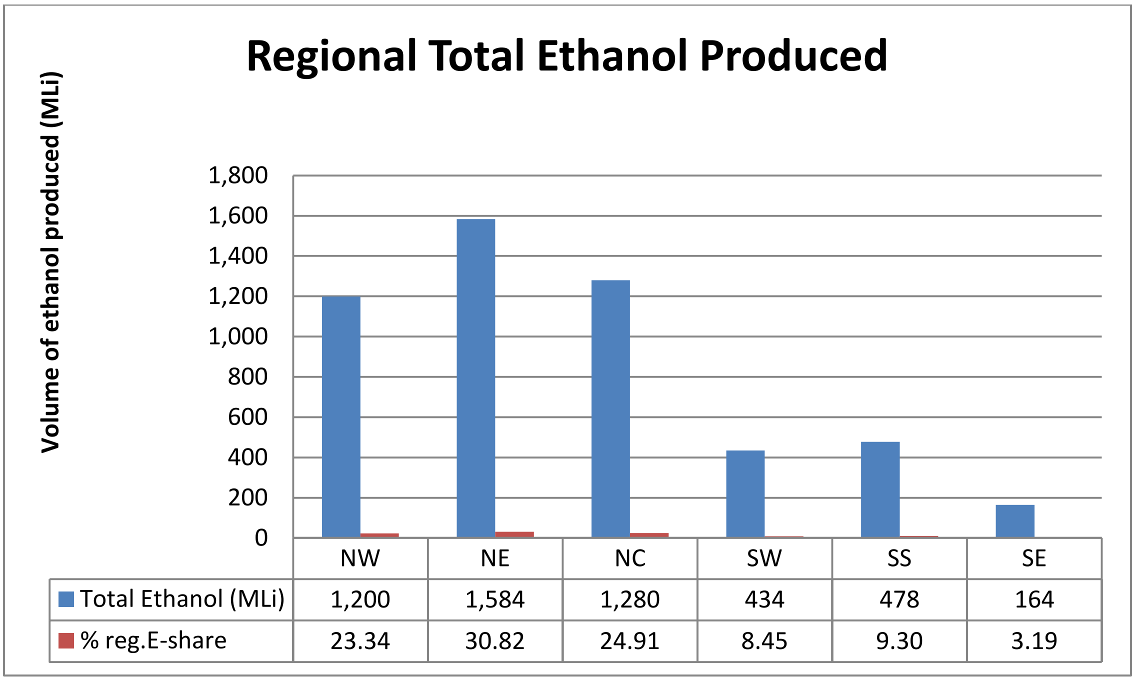


Figure 4.14b, Ethanol Production by Feedstock

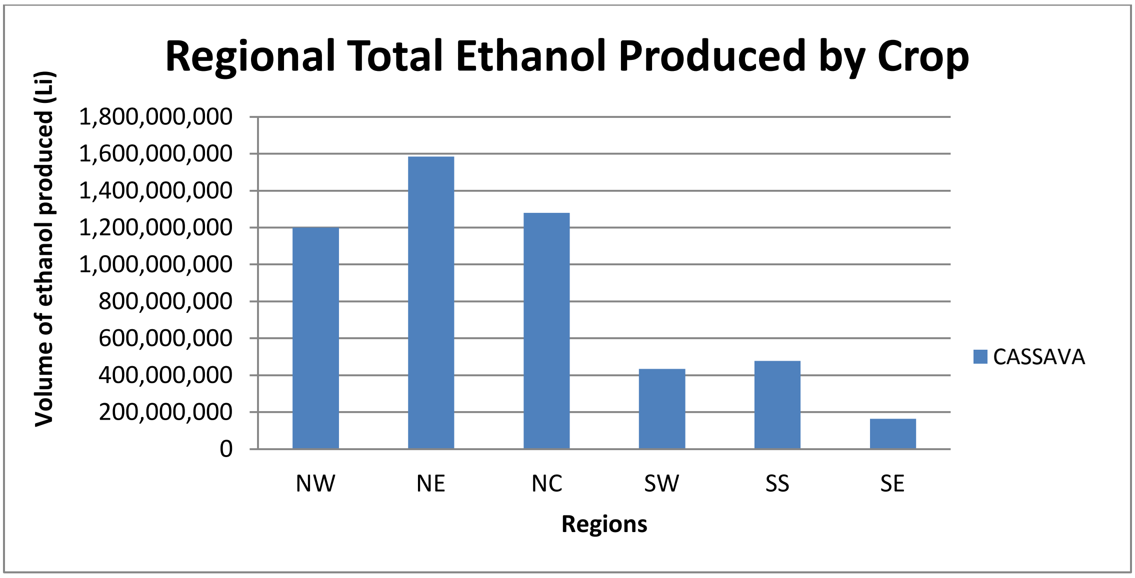


Table 4.9a, Reduced Costs for the Feedstock Supply Variables from the Ethanol-Food Production Model

Crops	**NWRC ($)**	**NERC ($)**	**NCRC ($)**	**SWRC ($)**	**SSRC ($)**	**SERC ($)**
MAIZE	0	0	0	0	0	0
CASSAVA	0	0	0	0	0	0
POTATO	-89.06	-88.81	-90.47	-90.72	-89.39	-91.99
SORGHUM	0	0	0	0	N/A	N/A
SUGARCANE	-2.59	-7.22	-9.55	-6.84	-9.71	-4.04
WHEAT	34.35	33.29	0	0	N/A	N/A
MILLET	0	0	0	0	N/A	N/A
RICE	0	0	0	0	0	0

Table 4.9b, Reduced Costs for the Ethanol Production Variables from the Ethanol-Food Model

Crops	**NWRC ($)**	**NERC ($)**	**NCRC ($)**	**SWRC ($)**	**SSRC ($)**	**SERC ($)**
MAIZE	0.11	0.10	0.08	0.07	0.09	0.08
CASSAVA	0	0	0	0	0	0
POTATO	0	0	0	0	0	0
SORGHUM	0.09	0.09	0.07	0.04	N/A	N/A
SUGARCANE	0	0	0	0	0	0
WHEAT	0	0	0.07	0.06	N/A	N/A
MILLET	0.08	0.09	0.07	0.06	N/A	N/A
RICE	0.10	0.09	0.08	0.07	0.10	0.08

Table 4.9c, Shadow Prices on the Regional Ethanol Demand-Supply Balance in the Ethanol-Food Model

Crops	**NW**	**NE**	**NC**	**SW**	**SS**	**SE**
Shadow Prices/GM (US$/Li)	0.3174	0.3278	0.3368	0.3573	0.3362	0.3446

Table 4.9d, Ethanol Production Shadow Price from Grain Feedstock in the Ethanol-Food Model

Crops	**NWSP ($)**	**NESP ($)**	**NCSP ($)**	**SWSP ($)**	**SSSP ($)**	**SESP ($)**
MAIZE	0.03	0.04	0.04	0.03	0.04	0.03
CASSAVA	0.14	0.13	0.12	0.10	0.12	0.12
POTATO	0.14	0.13	0.12	0.10	0.12	0.12
SORGHUM	0.05	0.05	0.05	0.06	N/A	N/A
SUGARCANE	0.14	0.13	0.12	0.10	0.12	0.12
WHEAT	0.14	0.13	0.05	0.04	N/A	N/A
MILLET	0.06	0.04	0.05	0.04	N/A	N/A
RICE	0.04	0.04	0.04	0.04	0.03	0.04

Table 4.9e, Reduced Costs for the Cellulosic Ethanol Production in the Ethanol-Food Production Model

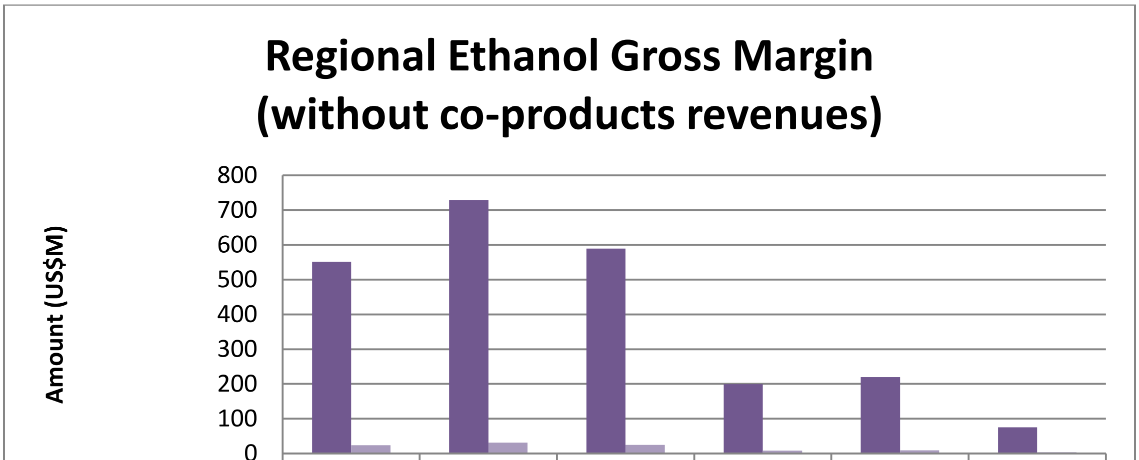
Crops	**NWRC ($)**	**NERC ($)**	**NCRC ($)**	**SWRC ($)**	**SSRC ($)**	**SERC ($)**
MAIZE	-0.55	-0.56	-0.57	-0.59	-0.57	-0.57
CASSAVA	-0.55	-0.56	-0.57	-0.59	-0.57	-0.57
POTATO	-0.55	-0.56	-0.57	-0.59	-0.57	-0.57
SORGHUM	-0.55	-0.56	-0.57	-0.59	N/A	N/A
SUGARCANE	-0.55	-0.56	-0.57	-0.59	-0.57	-0.57
WHEAT	-0.55	-0.56	-0.57	-0.59	N/A	N/A
MILLET	-0.55	-0.56	-0.57	-0.59	N/A	N/A
RICE	-0.55	-0.56	-0.57	-0.59	-0.57	-0.57

4.2.9 Ethanol Production Gross Margin from the Energy-Food Model

Although the potential gross margin from the ethanol production activities are included in the total potential gross margin from the crop and ethanol production enterprises in the Ethanol-Food Production Model, separate analysis of ethanol production gross margin from that of the entire enterprise merits a section in order to illustrate clearly the viability of using the local feedstocks for ethanol production. Such information is helpful in a market driven environment to induce and convince interested parties (government, corporate organisations and/or individuals) that investment in the development of the bioenergy (bioethanol) sector (starting with feedstock production to bioethanol refining), is worthwhile. From the result (Figure 4.15a), a total gross margin of US$2,364M on a national scale would be achieved from ethanol production (excluding the co-products' revenues). As shown in Figure 4.15a, the positive potential gross margin suggests that ethanol production from the local grain feedstocks is viable in Nigeria; implying that the potential total revenue from the sales of the ethanol produced is greater than the total operating (variable, fixed and feedstock) cost incurred in processing the feedstocks into ethanol.

However, the GM shown in Figure 4.15a does not include the revenues from the bioethanol co-products such as distillers' dried grains with soluble (DDGS); carbon credits obtainable from the bioethanol project as a clean development mechanism; sale of organic fertilizer obtained as wastewater from the bio-refinery; and sale of CO_2 captured from the fermentation of starch/sucrose into ethanol. In addition, the total operating cost not does include the investment cost of setting-up the combined starch and lignocellulosic or starch and sugar anhydrous bioethanol refineries, which is estimated at US$8 per litre (Wallace et al., 2005, p. 36). Of course, the total investment cost can be deducted or discounted from the total accruable net-income (gross margin minus annual tax and depreciation) over the project/refinery lifespan in a cash-flow analysis, which is outside the scope of this study. Nonetheless, the total operating cost represents the actual cost of processing or converting the feedstocks into bioethanol as surveyed by USDA in 2002 (Shapouri and Gallagher, 2005, p. 8); and the cost of the feedstock used is based on the implicit cost of producing and transporting the feedstock from the farm-gate to the national/regional market centres (which in this case represents the feedstock warehouse of the ethanol refining industry). To be more precise, the total operating cost includes the following: electricity, fuels, waste management, water, enzymes, yeast, chemicals, denaturant, maintenance, labour, administrative and others (miscellaneous) as well as the modelled feedstock cost.

Figure 4.15a, Ethanol Production Gross Margin (GM) without Co-products Revenue



	NW	NE	NC	SW	SS	SE
Reg.E-GM (US$M)	552	729	589	200	220	75
% reg.GM share	23	31	25	8	9	3

To determine the actual viability and profitability of the contemplated bioethanol project, the resultant co-product credits needs to be factored into the achievable ethanol production GM.

One metric tonne of DDGS (which can be sold to the animal feed industry or used as fuel for electricity co-generation depending if it is of starch or cellulose origin) is valued at US$88 according to (Wallace et al., 2005, p. 25); while the local market price of organic fertilizer (treated wastewater) is estimated at US$197/MT based on the information provided by Abia State ADP. However, information about the quantity of wastewater generated per litre of ethanol produced is lacking (not reported in the available literature), making monetary valuation of the wastewater (organic fertilizer) by-product difficult. Consequently, it is not included in the total co/by-products revenue used to augment the model's ethanol production gross margin. Further, Kyoto Protocol addendum (UNFCCC, 2005, p. 7) defined one unit of 'certified emission reduction' (CER) credit (or simply carbon credit) obtainable for implementing qualified clean development mechanism (CDM) projects as equal to one metric tonne of CO_2. Ranola et al. (2007, p. 64) further reported that the monetary value of one carbon credit unit is between US$5 and US$10. They also proposed a 96% CO_2 recovery from the fermentation of simple sugar (e.g. glucose) into ethanol and CO_2. It is already established that one molecule of simple sugar (e.g. glucose) hydrolyses and ferments into 2 molecules of ethanol and 2 molecules of CO_2 (i.e. Glucose → 2 Ethanol + 2 CO_2) (Aden et al., 2002, p. 31). Therefore the amount of money that could be realised from the sale of emission reduction credits was calculated by multiplying the quantity of CO_2

saved by the ethanol produced (when blended with gasoline) by the lower unit value of the carbon credits (US$5). The quantity of CO_2 saved by the volume of ethanol produced is estimated as described earlier in the model description section (page 65). Similarly, revenue from the sale of CO_2 produced and recovered from the production system during the fermentation process was estimated by multiplying the quantity of CO_2 produced (which is approximately the same with the quantity of ethanol produced since they have the same production proportion, i.e. a ratio of 1:1) by the CO_2 market price (US$0.0016/li) (Shapouri and Gallagher, 2005, p. 8). Details of the technical financial assumptions used to compute the potential co/by-products revenues are listed in Table 4.10.

On a national scale, the total quantity of ethanol produced (Figure 4.14a) could displace (substitute) about 514 million litres of gasoline under 10 percent ethanol blending with 90% gasoline. The substituted gasoline would save about 1.19 MMT of CO_2 emissions and this could yield about US$5.96M in carbon credit value- a 2% of the potential total co-products GM if carbon credit revenue is included. However, in this study, carbon credit revenue is excluded from the potential total co-products revenue due to lack of consensus on the actual single value of carbon credit and other factors that affects its market value (e.g. national and international conventions and agreements on emission reductions). Similarly, the produced ethanol will lead to the production of 4,929 MMT of CO_2 (assuming 96% CO_2 recovery), since they are jointly produced in the same proportion. The recovered CO_2 could in turn add about US$7.89M to the potential total co-products revenue, if sold. In all, the potential total co-products' revenue (including and excluding potential carbon credit revenue) will be US$360M (Figure 4.15b) and US$354M (Figure 4.15c), respectively. In terms of DDGS revenue, a total of US$347M is realisable from the sale of the produced DDGS (3.94 MMT). In addition, the produced ethanol could save about US$36.15 billion foreign exchange revenue that could have been used for the importation of the substituted gasoline, if ethanol were not produced.

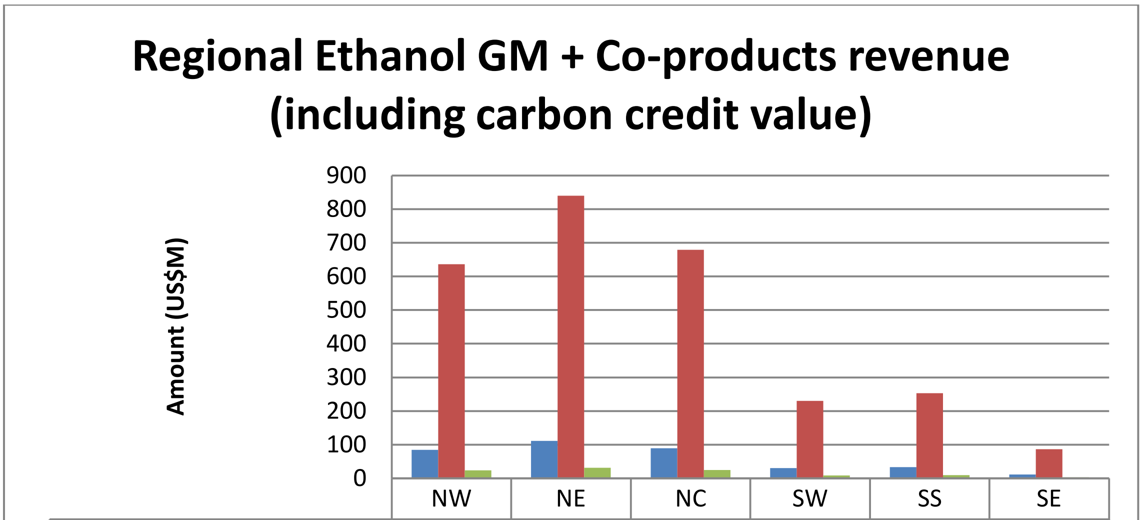
A recalculated ethanol production gross margin (Figure 4.15b), after adding the total co-product revenue, shows a greater GM potential, adding to the apparent viability of ethanol production in Nigeria. From Figure 4.15b, the estimated co-products' revenue share is 13% of the total ethanol GM (US$2,725M) while the GM from the sales of the produced ethanol contributes 87%. This result corroborates several previous research findings (Shapouri and Gallagher, 2005, Wallace et al., 2005, Shapouri et al., 2002a, McAloon et al., 2000) which report that ethanol co-products revenue is relatively significant, accounting for a considerable fraction of the total ethanol production revenues. The result implies that bioethanol production is viable and profitable as the invested capital can be recouped given the indicated large positive GM, especially since the earlier commodity price impact result from this study suggested that impact on food prices will be insignificant. In other words, a well-articulated ethanol policy that can ensure a sustainable supply of motor fuel (ethanol) and food, boost food availability/access and improve the living standard of the citizens, especially the rural poor masses since the rural poor masses are the peasant farmers that produce the majority of food in Nigeria (NBS, 2010b, 2009, Aregheore, 2005, Babatunde and Oyatoye, 2005). It is logical to think that a local farmer, having no alternative food supply access, would first prioritise his household and himself before supplying the excess energy-food crops as ethanol feedstocks.

Table 4.10, Additional Technical Parameters (Assumptions) for Total Ethanol Revenue Estimation

Ethanol Co-Products	Value per unit	Quantity	Source(s)
DDGS	US$88/MT	0.000765974 MT/Li and 0.003770026 MT/Li of ethanol from corn and corn Stover respectively.	Estimated from Wallace et al. (2005, pp.8, 25)
Carbon credit: CO_2 saved per litre of gasoline substituted by the ethanol produced	US$5/MT	0.002318216 MT of CO_2 per litre of gasoline saved or substituted	Ranola et al. (2007, p.64) and estimated from US EPA (2004, p. 1)
Sale of CO_2 recovered from the fermentation process	0.0016US$/li	95.90% of CO_2 per litre of ethanol produced	Shapouri and Gallagher (2005, p. 8) and Ranola et al. (2007, p.64)
*Foreign exchange savings from Refined Petroleum Products Importation (RPPIMPS)	US$70/litre of imported RPP	Varies	EIA (2012)
Capital Cost for a Combined Starch and Lignocellulosic Ethanol Refinery			
Per litre capital cost for corn starch to ethanol refinery		US$3.35/Li	Estimated from Wallace et al. (2005, p.34)
Per litre capital cost for corn stover to ethanol refinery		US$12.74/Li	Estimated from Wallace et al. (2005, p.36)
Per litre capital cost for combined corn stover and corn stover to ethanol refinery		US$8.01/Li	Estimated from Wallace et al. (2005, p.36)
Per litre capital cost for corn stover to ethanol refinery		US$18.28/Li	Estimated from (Humbird et al., 2011, p. 62)

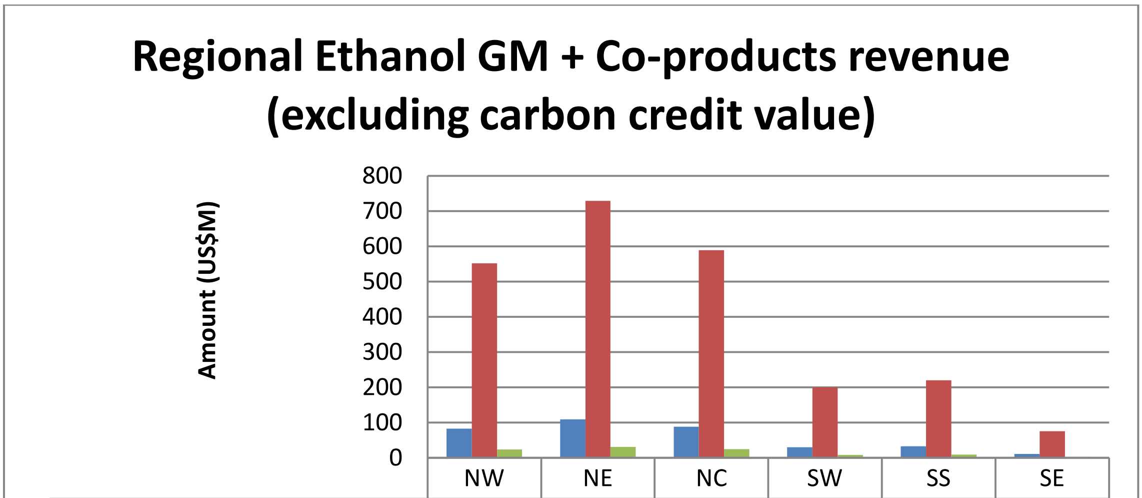
* - Not used for real/actual ethanol GM calculation.

Figure 4.15b, Ethanol Production Revenue with Carbon Credits included in the Co-products Revenue



	NW	NE	NC	SW	SS	SE
Co-products Revenue with Carbon Credit (US$M)	84.09	111.04	89.76	30.43	33.51	11.48
Ethanol GM + Co-products Revenue with Carbon Credit (US$M)	636	840	679	230	253	87
% reg.GM share	23	31	25	8	9	3

Figure 4.15c, Ethanol Production Revenue with Carbon Credits excluded from the Co-products Revenue



	NW	NE	NC	SW	SS	SE
Co-products Revenue without Carbon Credit (US$M)	83	109	88	30	33	11
Ethanol GM + Co-products Revenue without Carbon Credit (US$M)	552	729	589	200	220	75
% reg.GM share	23	31	25	8	9	3

4.2.10 Ethanol Export and Import from the Energy-Food Model

The ethanol export and import reduced costs in Tables 4.11a and 4.11b respectively indicate that exporting and importing one litre of ethanol from any of the regions would reduce the achievable gross margin by the corresponding reduced cost values. The export reduced cost implies that at the current world market (export) price and export cost, it is not profitable for Nigeria to export ethanol to the world market. In other words, the ethanol export price would have to be increased (or the cost of exporting ethanol would have to be reduced) by the corresponding export reduced cost values before it would be profitable enough to export ethanol from any of the regions. On the other hand, the import reduced cost implies that importing ethanol from the world market to Nigeria at the current domestic supply (production) cost and import market price is unprofitable. Alternatively, this means that the cost of importing ethanol from the world market would have to be reduced (or the domestic ethanol market price increased) by the corresponding import reduced cost values before it would be profitable enough to import ethanol into any of the regions. Hence, producing for domestic demand is the best decision at current market conditions.

Table 4.11a, Ethanol Export Reduced Costs from the Energy-Food Model

Regions	**NW**	**NE**	**NC**	**SW**	**SS**	**SE**
Export Reduced Cost (US$/Li)	0.7774	0.7878	0.7968	0.8173	0.7962	0.8046

Table 4.11b, Ethanol Import Reduced Costs from the Energy-Food Model

Regions	**NW**	**NE**	**NC**	**SW**	**SS**	**SE**
Import Reduced Cost (US$/Li)	-0.9974	-1.0078	-1.0168	-1.0373	-1.0162	-1.0246

Chapter 5. Scenarios and Sensitivity Analyses

The aim of this chapter is to explore different policy and market change options for ethanol and food production using the applied Energy-Food Production Model in order to evaluate the potential impacts of such future policy and market changes on the domestic ethanol and food demand and supply. Considered scenarios are presented in Section 5.1 while the sensitivity analyses are presented in Section 5.2. Finally, a brief summary of the scenario and sensitivity analysis results are presented in Section 5.3.

5.1 Scenarios

To evaluate the potential effects of future policy changes and/or changes in market forces such as increase in domestic food and ethanol demands, the Energy-Food Production Model (EFPM) is run under different scenarios as described below. The marketing cost for each crop is exactly the same as the Base Model and S0 (initial EFPM) values (Table 4.1c) and are constant in the total unit cost of producing each crop (i.e. the marginal cost of producing each crop) in all the scenarios and/or sensitivity analyses considered in this study. The marketing cost is included with the input cost and opportunity cost of production to give the total unit cost of production (MC).

5.1.1 Mechanization 1 (S1)

In the first mechanization scenario (S1), the model was implemented to consider the use of tractors in replacing (substituting) half of the monthly manual labour required to perform the land preparation and planting operations and decide, based on the associated factor costs, whether to use tractor and manual labour in executing the land preparation and planting operations or only manual labour. In other words, tractor use in the model was implemented according to the seasonal cropping pattern like land and labour, but its use was optionally restricted to only land preparation and planting operations. This specification is consistent with a previous recommendation (Hazell and Norton, 1986, p. 251) and was done to test if the returns are sufficient to encourage farmers to hire tractor services. In doing so, labour requirement was converted from per hectare man-day requirement per month in the un-mechanized Energy-Food Model (S0) to per hectare service hour requirement per month, assuming 1 man-day to be equivalent to 8 hours of service, in order to ensure labour-tractor unit consistency and compatibility for factor substitution. Hence, the previous monthly per hectare labour requirement in man-day, 0.17 in the NW for example, is converted to monthly per hectare labour requirement in hours by multiplying 0.17 by 8, which is 1.39 service hours. In turn, half of this figure is implemented as the monthly per ha labour service hour required to perform the land preparation and planting operations if tractor service is employed, since all the land preparation and planting operations (e.g., sowing for some crops) cannot be performed by tractor. Similarly, the available monthly regional family labours in man-days were also converted to available monthly regional family labours service hours by multiplying the available monthly regional family labour in man-days by service hours in a day (8). Finally, the unit cost of family (US$3.5) and hired labour (US$4.5) were divided by 8 to arrive at their hourly rates: US$0.44/hr and US$0.56/hr, respectively. The same unit conversion procedure is maintained in other scenarios and sensitivity analyses. In S1, the sum of the monthly labour plus tractor service hours required to cultivate all the crops in the model is implemented as less than or equal to the sum of the family labour plus hired labour plus tractor service variables in the model. It is also important to add that these scenarios and sensitivity analyses are implemented under *ceteris paribus* (i.e., by implementing a change in one parameter, labour in this case, at a time while other parameters remain constant or unchanged). Recall that conversion of monthly tractor service stock availability has been earlier described in the model description section (page 63). The monthly per hectare tractor demand for each crop is estimated by dividing the annual per hectare service in one day (8 hours) by the number of months in one year (12), (i.e. 8/12 = 0.67 hours).

5.1.2 Mechanization 2 (S2)

However, in S2, the model was ‘forced’ to replace (substitute) half of the monthly manual labour required to perform the land preparation and planting operations with the use of tractor service without allowing the model to decide, based on the associated factor costs, whether to use tractor and manual labour in executing the land preparation and planting operations or only manual labour. This is done to examine the potential of commercial and/or large scale farming in Nigeria since economic growth could lead to large scale investment in crop farming by corporate organisations and individuals- which would likely tend towards partial and/or full mechanised system of farming. In S2, the monthly labour and tractor service hours required to cultivate all the crops in the model are implemented separately, not as a vector of 3 labour alternatives (family, hired and tractor labour services) in the land preparation and planting operation.

5.1.3 Mechanization 1 (S1) Key Results

The key result in this scenario is that the model did not hire tractor services for the land preparation and planting operations due to its relatively higher cost compared to family and hired labour costs; but instead utilized manual labour (family and hired labour) to perform all farm operations as in the initial un-mechanized Energy-Food Simulation run (S0). This result is purely consistent with the expected rational economic agent's decision since it will not make economic sense for the farmers to hire tractor service with the attendant higher cost for what their family members or even hired labour could do for less. It also corroborates Hazell and Norton (1986, pp. 254 - 255) remark that "the observation that smaller farms tend to use less mechanized technique is not necessarily explained by lesser access to mechanization but rather by relative factor endowments and factor prices. A smaller farm has more family labour per hectare than a larger farm, and family labour often is cheaper (calculating the implicit wages) than hired labour. Thus it is rational for the family farm to utilize more labour-intensive techniques of production". The reduced costs of using tractor service for the land preparation and planting operations are highlighted in Table 5.1. As said earlier, they represent how much the achievable gross margin will reduce by if one hour tractor service is utilized in the land preparation and planting operations.

Another important result of this simulation run is that wheat is selected as the best feedstock for ethanol production in the NW while cassava remained the selected best feedstock for other regions. Therefore, on the national level, the production of wheat increased by 228% while that of cassava decreased by 10% from their S0 production levels. This is because with the reduction of the per ha labour requirement of each crop during land preparation and sowing operation, due to the assumption that tractor engagement would reduce labour utilization at this period by half, wheat becomes more competitive as ethanol feedstock than cassava in the NW. Consequently, the total national labour employment increased by 8% from the S0 level. Further, the shadow price of hired labour rose to US$0.57 per hour from the input hourly rate of US$0.56 (a 2% increase), while the family labour shadow price declined from the input hourly rate of US$0.44 to US$0.16 per hour. Other results of S1 are essentially the same with that of S0 as highlighted in Appendix 11a. The implication of this result is that wheat would be better used as ethanol feedstock in the NW and cassava in other regions if the per ha labour requirement of each crop is halved during land preparation and sowing operation, since tractor was neither used in the baseline scenario (S0) nor in the S1. Also the cost of hiring labour would increase by an insignificant margin in order to attract the required number of labour to do the farm operations at the peak of labour demand (usually during the land preparation and planting season) when the available family labour is exhausted. Finally, the domestic consumption demand is the same as in the base year.

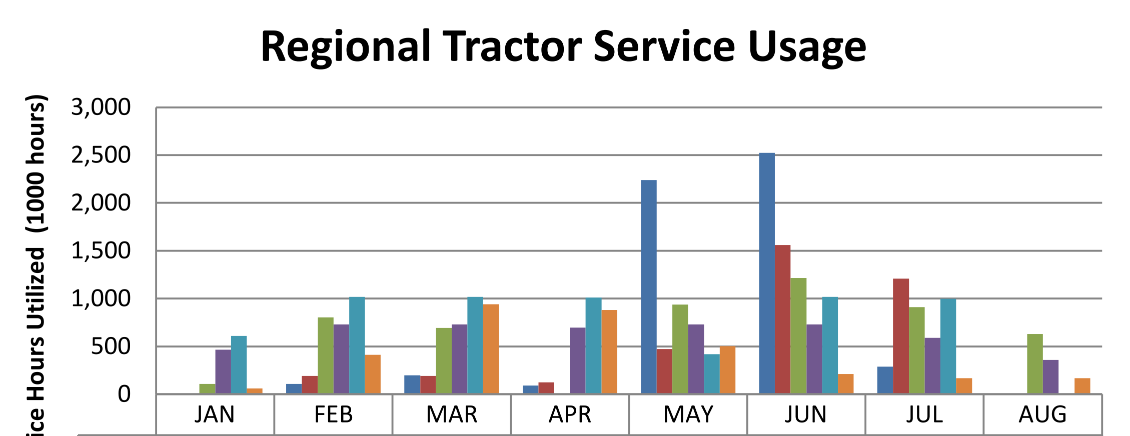
Table 5.1, Reduced Costs of Mechanization (Tractor Use) Variable

Region	JAN	FEB	MAR	APR	MAY	JUN
NW	-19.2	-19.2	-19.2	-19.2	-19.0	-19.0
NE	-19.2	-19.2	-19.2	-19.2	-19.2	-19.0
NC	-19.2	-19.2	-19.2	-19.2	-19.0	-19.0
SW	-19.2	-19.2	-19.2	-19.2	-19.2	-19.2
SS	-19.2	-19.2	-19.2	-19.2	-19.2	-19.2
SE	-19.2	-19.2	-19.2	-19.2	-19.2	-19.2
	JUL	AUG	SEP	OCT	NOV	DEC
NW	-19.0	-19.0	-19.0	-19.0	-19.2	-19.2
NE	-19.0	-19.0	-19.2	-19.2	-19.2	-19.2
NC	-19.0	-19.0	-19.2	-19.0	-19.2	-19.2
SW	-19.2	-19.2	-19.2	-19.2	-19.2	-19.2
SS	-19.0	-19.0	-19.2	-19.2	-19.2	-19.2
SE	-19.2	-19.0	-19.2	-19.2	-19.2	-19.2

5.1.4 Mechanization 2 (S2) Key Results

The main results of S2 are summarized as shown in Appendix 11a, while the tractor service utilization result is highlighted in Figure 5.1. As expected, based on the earlier reduced cost information from S1, implementation of outright tractor use (i.e. forcing tractor use) into the model's optimal plan for land preparation and planting operations had varying consequences on the model results, leading to the overall reduction of the achievable total GM by 7% relative to the total GM from S0. The major consequence of S2 is the overall increase in the unit cost of producing each crop (input cost) as shown in Table 5.2. At the national average level, the minimum rise in the cost of production when S2 was implemented compared to the S0 unit cost is 12% (for plantain) while the maximum is 1,817% for maize production (see Appendix 13 for the S2 input cost utilized in the percentage change estimation). Consequently, the opportunity cost of producing each crop (individual crop GM) reduced significantly as reflected in Table 5.3 (see Appendix 14 for the S2 opportunity cost of crop production). Further, the increase in the production cost led to a significant reduction in the total quantity of land cultivated and the total quantity of crops produced by 36% and 4%, respectively. In terms of crop production, it resulted in over-specialization in the domestic crop production, with regions with the greatest comparative advantage for the production of each crop producing majority of such crops while others produce little or nothing. For examples, maize production is only undertaken by producers in the NW, SW, SS and SE, with no maize production in the NE and NC (see Appendix 12). And this is a typical characteristic of commercial and/or mechanised farming system (Turner and Brush, 1987, pp. 3 - 29). The reduction in the total cultivated land is because it became more profitable, with the increase in the unit cost of production, to import some crops than to produce them locally. For example, sorghum and sesame which were not produced locally (Appendix 12) due to their costs of production relative to their market prices and import costs, were totally imported in order to meet their domestic consumption demands. Hence, the aggregate national import quantity increased by 595% compared to the S0 level. It is important to add that the import variable in this scenario was implemented with greater than or equal (=g=) constraint in order to give the model the flexibility to import more than the base year import levels, unlike the S0 or S1 scenarios where the model was implemented to import up to the base year import level at the maximum using less than or equal to constraint (=l=). In addition, the total labour employment also fell by 38% compared to the S0 level due to the reduction in crop production. Most importantly, the results reveal that wheat and sugarcane would be the best ethanol feedstocks in the NW and NE, respectively; while cassava will still remain the best feedstock for ethanol production in other regions. It is remarkable that sugarcane would become the best feedstock for ethanol production, at least in one region of Nigeria, as the Nigerian agriculture shifts from peasant to commercial or mechanised agricultural system or as the unit cost of production become significantly higher than the current (base year) cost of production. It is also important to note that the base year domestic consumption demand is not compromised in this scenario, despite the revealed production specialization, due to the inter-regional trade variable which ensured that crops are transferred (imported) from regions of surplus (production point) to the regions of scarcity. However, the domestic consumption and the inter-regional trade results are not presented here due to brevity. The results from S2 are consistent with *a priori* knowledge of the impacts or effects of mechanized agriculture on the unit cost of production, labour, land allocation and the specialization tendency in crop production. It also validates previous results (Base Model, S0 and S1 results) and the conformity of the model to the expected behaviour under certain policy change. Hence, the model can be used to study, examine, and explain the potential impacts of future agricultural production and/or trade policies on one hand and to describe the reaction or behaviour of the producing/supplying and consuming economic agents to such policies on the other hand.

Figure 5.1, Tractor Service Employment for Land Preparation Operations



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
NW		108	199	91	2,238	2,525	287	
NE		191	191	124	472	1,558	1,210	
NC	109	802	694		936	1,217	912	631
SW	467	731	731	696	731	731	588	360
SS	610	1,017	1,017	1,010	418	1,017	999	
SE	61	413	942	882	502	210	168.66	169

Table 5.2, Percentage Change in the S2 Unit Costs of Production from the S0 Levels.

Crops	NWIC (% change)	NEIC (% change)	NEIC (% change)	SWIC (% change)	SSIC (% change)	SEIC (% change)	Nig (% change)
MAIZE	1,957	1,642	2,735	1,875	1,372	1,323	1,817
CASSAVA	136	109	164	111	98	109	121
POTATO	76	80	91	33	8	15	51
YAM	6	7	7	51	47	49	28
COCOYAM	21	22	22	171	152	154	90
PLANTAIN	17	2	17	21	13	5	12
BEANS	1,721	1,980	2,505	565	687	139	1,266
SORGHUM	1,332	2,115	2,623	912	N/A	N/A	1,164
SUGARCANE	296	245	363	78	114	59	192
WHEAT	1,377	1,896	1,506	1,126	N/A	N/A	968
MILLET	1,829	2,160	2,668	1,363	N/A	N/A	1,333
RICE	1,106	922	927	605	188	298	674
GROUNDNUT	828	1,961	2,485	1,488	867	675	1,384
COTTON	1,413	1,562	2,063	205	N/A	N/A	845
SESAME	520	966	622	N/A	N/A	N/A	352
SOYBEAN	1,309	1,348	1,792	899	N/A	N/A	878
COCOA	N/A	794	101	93	104	168	197
CASHEW	1,400	1,488	1,956	987	564	250	1,107
RUBBER	N/A	N/A	167	202	200	226	119
OILPALM	54	93	101	140	142	169	117
MELON	173	288	319	537	862	92	378

Table 5.3, Percentage Change in the S2 Opportunity Costs of Crop Production from the S0 Levels.

Crops	NWOC (% change)	NEOC (% change)	NEOC (% change)	SWOC (% change)	SSOC (% change)	SEOC (% change)	Nig (% change)
MAIZE	-42	-66	-73	-92	-79	-67	-70
CASSAVA	-34	-23	-29	-16	-21	-21	-24
POTATO	-44	-45	-52	-18	-5	-9	-29
YAM	-2	-5	-3	-18	-24	-17	-11
COCOYAM	-5	-10	-4	-50	-61	-26	-26
PLANTAIN	-22	-3	-22	-25	-16	-6	-16
BEANS	-143	-132	-132	-86	-74	-81	-108
SORGHUM	-100	-138	-139	-140	N/A	N/A	-129
SUGARCANE	-9	-17	-32	-5	-13	-3	-13
WHEAT	-82	-78	-74	-52	N/A	N/A	-72
MILLET	-100	-138	-132	-89	N/A	N/A	-115
RICE	-57	-51	-45	-39	-4	-16	-35
GROUNDNUT	-141	-138	-137	-138	-140	-142	-139
COTTON	-21	-20	-17	-7	N/A	N/A	-16
SESAME	-142	-138	-141	N/A	N/A	N/A	-141
SOYBEAN	-60	-48	-61	-86	N/A	N/A	-64
COCOA	N/A	-21	-15	-19	-21	-23	-20
CASHEW	-58	-67	-52	-40	-41	-29	-48
RUBBER	N/A	N/A	-18	-11	-18	-17	-16
OILPALM	-6	-9	-5	-7	-8	-10	-8
MELON	-5	-18	-21	-34	-28	-25	-22

5.1.5 Scenario 3 (S3)

In the third scenario (S3), we assumed and implemented a 100% increase in the current domestic crop consumption and ethanol demands due to the current consistent population and economic average growth rates of 2.47% and 3.21%, respectively; (Factbook, 2013, IMF, 2013) in order to examine if domestic ethanol and food demands would still be met with the available production resources (land, family labour and tractor) and what the corresponding potential effects on food prices will be. It is expected that consistent increase in population together with a rise in income as witnessed for some years now would, as a highest impact ('worst' case) scenario, double the domestic crop consumption and domestic ethanol consumption demands. It is important to note that tractor demand and supply in this scenario is implemented as in S1 since it is logically the first step towards full mechanization (Hazell and Norton, 1986, p. 251) and possibly the prevailing current production technique in Nigeria. It is unlikely that the full mechanization option of the land preparation and planting operations (S2) would easily be adopted by the local farmers in Nigeria, without any subsidy on the cost of hiring tractor, given the associated economic impacts on the cost of production and the farmers' gross income (individual crop GM or opportunity cost of producing each crop) as illustrated earlier.

The results from the scenario (S3) run indicate that Nigeria has the resources to produce sufficient crops to meet the double domestic food and feedstock demands for the ethanol production while still exporting up to the base year export levels and without any import. The specific impacts on key model parameters are discussed below.

The potential GM from the S3 run is 99% greater than that of the S0 (Appendix 11a) due to the increase in crop and ethanol production and marketing activities. As in S1, wheat is selected as the best feedstock for ethanol production in the NW while cassava is retained as the best feedstock for ethanol production in other regions. Hence, wheat production increased by 556% while cassava production rose by 79% from their S0 national aggregate levels as reflected in Figure 5.2 (see Appendix 15 for the S3 individual crop production levels). In addition, tractor was not utilized for the land preparation and planting operations due to its hiring cost, instead manual labour (family and hired labour) was used. As a result, the total labour employment on the national level increased by 94% compared to the S0 level (see Appendix 11a). Notably, the crop production level required to meet the implemented domestic food and ethanol demands in S3 utilized all the available arable land in the SE, SS, SW and NW, revealing their respective shadow prices (potential land rents) as indicated in Appendix 11c. Remarkably, the shadow price of land in the SS region is –US$4.2, implying the amount by which the objective function value will increase if additional one unit of the scarce resource (land in this case) is further utilized in the production process (Hazell and Norton, 1986, p. 118). The SE potential land rent from the S3 result (US$79) compares very closely to the Base Model land rent for the region (US$86). However, the revealed shadow prices of land in the SS, SW and NW do not reflect the initial land rents in these regions from the Base Model (Table 4.5); suggesting that the limitation of land in the production activities of these regions are very minimal and negligible and that land rent might be better implemented explicitly at least to the extra hectares of land required to actualise the expected domestic food consumption and ethanol consumption demands after the initial base year regional land endowments are exhausted. This is further pursued in the land rent sensitivity analysis below.

Consequent on the revealed land rents, the cost of producing each crop increased significantly from their S0 levels as highlighted in Table 5.4 while the opportunity cost of producing each crop (individual crop production GM) declined as reflected in Table

5.5 (see Appendices 16 and 17 for the S3 cost of production and the individual crop production GM, respectively). Note that the percentage decrease and increase in the input cost and opportunity cost of crop production in the SS (instead of increase and decrease as in other regions) is due to the negative shadow price of land in that region which is implicitly factored in the cost of production and the opportunity cost of production. Hence, the percentage decrease in the SS cost of production and increase in the opportunity cost from their S0 levels should be interpreted as increase and decrease respectively. Nevertheless, the overall market effect measured using the shadow prices at the demand-supply balance (and/or via the concept of marginal cost being equal to marginal revenue, where marginal cost is equal to the explicit input cost plus the opportunity cost of production) show that the product prices are exactly the same as in the S0. As in S0, this result therefore implies that using food crops for ethanol production does not have any significant effect on food prices, but rather on the production resources.

Figure 5.2, Percentage Change in the S3 Crop Production from the S0 Level (National Aggregate Level).

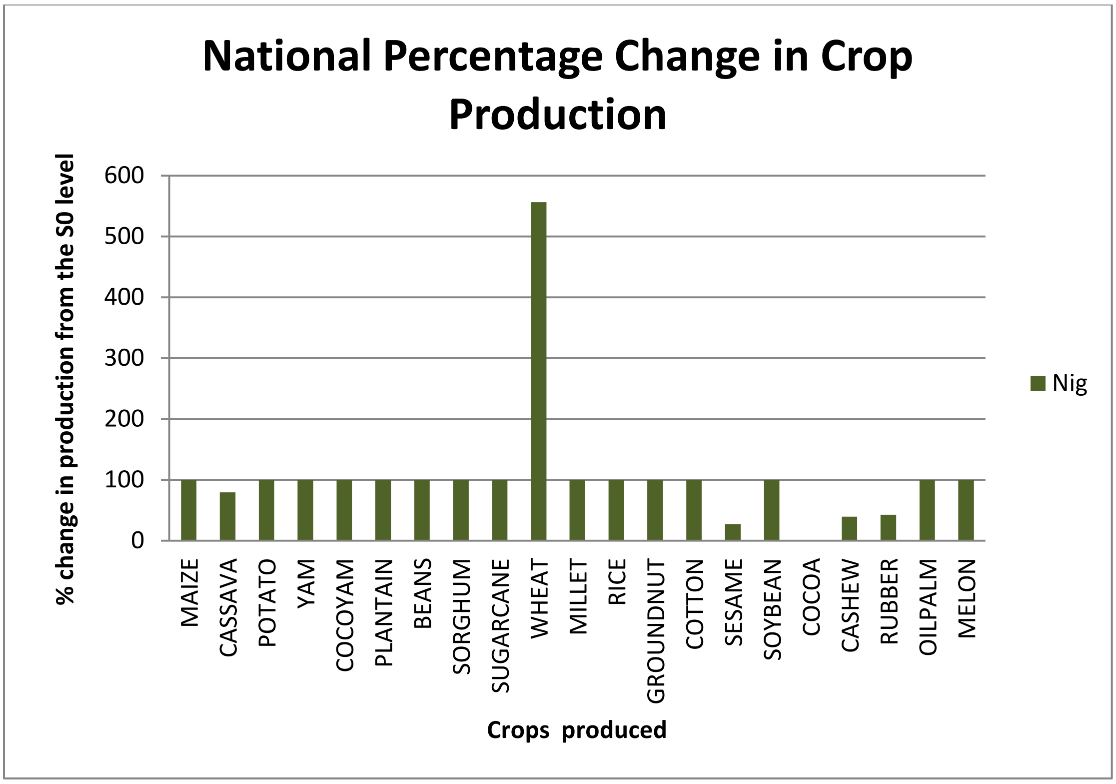


Table 5.4, Percentage Change in the S3 Unit Costs of Crop Production from their S0 Levels.

Crops	NWIC (% change)	NEIC (% change)	NEIC (% change)	SWIC (% change)	SSIC (% change)	SEIC (% change)	Nig (% change)
MAIZE	122	6	7	40	-30	542	114
CASSAVA	9	0	0	2	-2	45	9
POTATO	5	0	0	1	-1	25	5
YAM	4	0	0	1	-1	20	4
COCOYAM	12	0	0	4	-3	63	13
PLANTAIN	15	0	15	0	0	7	6
BEANS	89	6	7	170	-30	-50	32
SORGHUM	113	7	7	39	N/A	N/A	41
SUGARCANE	19	1	1	5	-5	94	19
WHEAT	502	6	6	33	N/A	N/A	137
MILLET	114	7	7	39	N/A	N/A	42
RICE	106	6	7	38	-28	132	43
GROUNDNUT	105	8	8	40	-30	21	25
COTTON	89	5	6	32	N/A	N/A	33
SESAME	7	4	4	N/A	N/A	N/A	5
SOYBEAN	82	4	5	26	N/A	N/A	29
COCOA	N/A	3	2	16	-13	37	9
CASHEW	88	5	5	63	-20	395	89
RUBBER	N/A	N/A	3	23	-18	92	25
OILPALM	34	2	2	16	-13	19	10
MELON	106	5	6	41	-48	-8	17

Table 5.5, Percentage Change in the S3 Opportunity Costs of Crop Production from the S0 Levels.

Crops	NWOC (% change)	NEOC (% change)	NEOC (% change)	SWOC (% change)	SSOC (% change)	SEOC (% change)	NIGOC (% change)
MAIZE	-3	0	0	-2	2	-27	-5
CASSAVA	-2	0	0	0	0	-8	-2
POTATO	-3	0	0	-1	1	-15	-3
YAM	-1	0	0	0	0	-7	-1
COCOYAM	-3	0	0	-1	1	-11	-2
PLANTAIN	-19	0	-19	0	0	-9	-8
BEANS	-19	-1	-1	-26	3	29	-2
SORGHUM	-12	0	-1	-6	N/A	N/A	-5
SUGARCANE	-1	0	0	0	1	-4	-1
WHEAT	-30	0	0	-2	N/A	N/A	-8
MILLET	-15	0	-1	-3	N/A	N/A	-5
RICE	-5	0	0	-2	1	-7	-3
GROUNDNUT	-18	-1	0	-4	5	-4	-4
COTTON	-3	0	0	-1	N/A	N/A	-1
SESAME	-2	-1	-1	N/A	N/A	N/A	-1
SOYBEAN	-6	0	0	-2	N/A	N/A	-2
COCOA	N/A	0	0	-3	3	-5	-1
CASHEW	-4	0	0	-8	1	0	-2
RUBBER	N/A	N/A	0	-1	2	-7	-2
OILPALM	-4	0	0	-1	1	-1	-1
MELON	-3	0	0	-3	15	2	2

5.2 Sensitivity Analyses

The sensitivity analyses are performed based on the assumption of future increase in the prices of production resources, particularly land and labour based on the assumptions below. It is important to note that mechanization implementation in the land and labour rent sensitivity analyses followed the S1 procedure described earlier.

5.2.1 Land Rent Sensitivity Run (S4)

To test the sensitivity of the initial Energy-Food Simulation (S0) results to changes in land rent, we assume that the increase in the demand of land will drive the cost of renting land up even though the initial Energy-Food Simulation run suggests that the land rent will be zero due to unutilized stock of arable land. The rationale for this assumption is that the available uncultivated arable lands are probably farther away from residential areas in the farming communities; hence, it will be more expensive to cultivate them since the cost of transporting raw materials (e.g. seeds) to the farms and/or evacuating farm produce from the farms would normally be higher than that of the currently cultivated lands. To implement this assumption, the minimum regional land rent from the Base Model (US$52 in Table 4.5) was uniformly imposed across the regions; only on the additional hectares of land required to meet the food and ethanol demands in the model after the base year land is exhausted. In addition, the extra-land variable is restricted to the un-cultivated arable land in each region, obtained by subtracting the currently cultivated regional land endowment in the Base Model from the estimated total available arable land in each region (i.e. the regional land endowment in the initial Energy-Food Production Model). Hazell and Norton (1986, p. 271) suggest that explicit land rent can be implemented in primal model (as in this study) and that the revealed land rent (shadow price of land) should be added to the implemented explicit land rent in order to obtain the actual potential annual land rent for the modelled land. This is adopted in estimating the potential regional annual land rents under the above specified land sensitivity condition.

Results from the land rent sensitivity analysis (S4) are similar to that of the S0 and S1 in terms of feedstock selection, total potential GM, land and labour usage, domestic crop production and consumption levels, export and import levels and ethanol production level; suggesting the robustness of the initial model results (Models 1 and 2 results). Nevertheless, it differs from the S0 (Model 2 – the initial Energy-Food Simulation Model) result in terms of the revealed potential annual land rents due to the implementation of explicit land rent in S4. The potential regional land rent from S4 (Appendix 11c) is equal to the explicit land rent (US$52) plus the revealed regional land use shadow prices at the land use balance constraint. The specific key results from S4 justify this assertion as illustrated below.

As expected, the potential GM from S4 is 0.43% smaller than that of the S0 (see Appendix 11b). In comparison with the S0 cost of production and opportunity cost of crop production, implementation of explicit land rent in S4 increased significantly the cost of production (Table 5.6) and substantially reduced the achievable gross margin from the production of each crop (Table 5.7) as expected (see Appendices 19 and 20 for their respective monetary values). The increase in the input cost, of course, affected the regional crop production pattern and the resources (e.g. land and labour) allocated for the production of the crops. The national total production output declined by 3% compared to the S0 output level (see Appendix 18), while the total (national) quantity of land and labour allocated for the crop production decreased by 4% and 3%, respectively (see Appendix 11b). Importantly, the land use result indicates that only NC will require an additional 2,135 thousand hectares of land to actualize the production (and supply) of the total crop demanded in the model (domestic crop consumption, feedstock and export demands). This is possibly because of the region's comparative advantage to produce both northern- and southern-adapted crops due to the dual climatic and soil conditions in the region. Nevertheless, in S4, the inter-regional trade variable is very useful in re-distributing crops from points of surplus/production to points of scarcity/demand in order to ensure that domestic consumption demand is satisfied. Further, as in S1, wheat and cassava are respectively selected as choice feedstocks for ethanol production in the NW and other regions against only cassava in S0. Hence, wheat production in S4 increased by 228% while cassava production decreased by 10% from their S0 levels (Figure 5.3). In addition, the decrease in the production of other crops (e.g. sesame) led to a 33% reduction in the total quantity exported whereas imports remain zero as in S0. Also the domestic crop consumption demand remains unchanged from the S0 level. Finally, comparing the obtained product prices from S4 (estimated by adding the input cost (Appendix 19) and the opportunity cost of producing each crop (Appendix 20)) with the product prices from S0 shows that the overall market effect is not evident as the product prices are exactly the same in the two cases (i.e. the product prices from S4 are not different from the S0 and the actual input product prices).

Figure 5.3, Percentage Change in the S4 Crop Production from the S0 Level (National Aggregate Level).

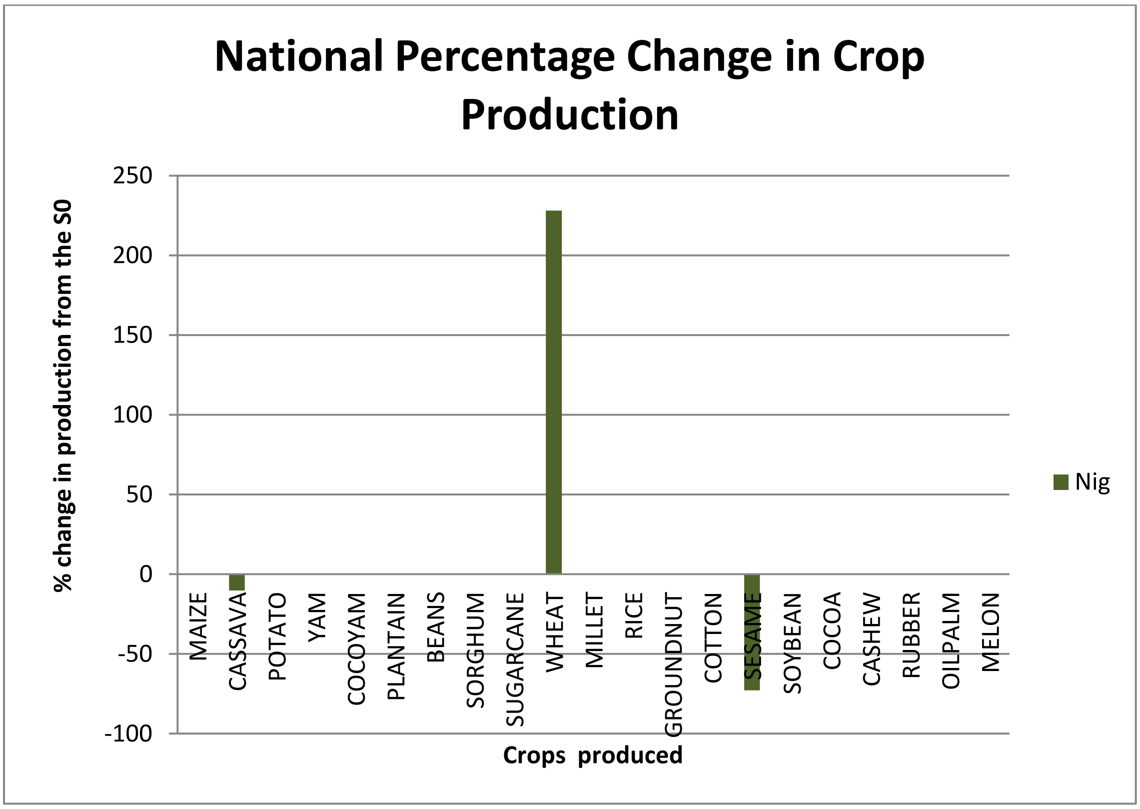


Table 5.6, Percentage Change in the S4 Unit Costs of Crop Production from their S0 Levels.

Crops	NWIC (% change)	NEIC (% change)	NEIC (% change)	SWIC (% change)	SSIC (% change)	SEIC (% change)	Nig (% change)
MAIZE	368	834	507	427	376	501	502
CASSAVA	26	40	30	25	27	41	32
POTATO	14	22	17	14	15	23	18
YAM	12	18	13	11	12	18	14
COCOYAM	37	59	45	37	39	59	46
PLANTAIN	4	7	5	23	15	7	10
BEANS	326	733	466	408	348	49	388
SORGHUM	340	783	487	596	N/A	N/A	551
SUGARCANE	56	90	68	56	58	87	69
WHEAT	762	642	413	358	N/A	N/A	544
MILLET	345	799	655	434	N/A	N/A	558
RICE	320	713	455	398	341	441	445
GROUNDNUT	299	726	462	418	369	304	429
COTTON	266	578	383	343	N/A	N/A	393
SESAME	291	422	287	N/A	N/A	N/A	333
SOYBEAN	247	499	333	412	N/A	N/A	373
COCOA	N/A	248	205	174	162	248	208
CASHEW	263	552	363	225	289	370	344
RUBBER	N/A	N/A	195	253	240	264	238
OILPALM	108	125	206	175	173	198	164
MELON	318	358	477	421	104	111	298

Table 5.7, Percentage Change in the S4 Opportunity Costs of Crop Production from the S0 Levels.

Crops	NWOC (% change)	NEOC (% change)	NEOC (% change)	SWOC (% change)	SSOC (% change)	SEOC (% change)	NIGOC (Ave % change)
MAIZE	-8	-34	-27	-21	-22	-25	-23
CASSAVA	-6	-8	-5	-4	-6	-8	-6
POTATO	-8	-13	-10	-8	-8	-13	-10
YAM	-4	-12	-6	-4	-6	-6	-7
COCOYAM	-9	-28	-8	-7	-15	-10	-13
PLANTAIN	-5	-8	-6	-28	-18	-9	-12
BEANS	-69	-72	-41	-62	-37	-29	-52
SORGHUM	-36	-56	-51	-91	N/A	N/A	-58
SUGARCANE	-2	-6	-6	-4	-7	-4	-5
WHEAT	-45	-26	-20	-17	N/A	N/A	-27
MILLET	-47	-51	-68	-28	N/A	N/A	-48
RICE	-16	-39	-22	-25	-7	-24	-22
GROUNDNUT	-51	-50	-25	-39	-60	-64	-48
COTTON	-8	-13	-11	-12	N/A	N/A	-11
SESAME	-80	-60	-65	N/A	N/A	N/A	-68
SOYBEAN	-18	-18	-17	-39	N/A	N/A	-23
COCOA	N/A	-37	-31	-35	-33	-34	-34
CASHEW	-11	-20	-17	-29	-21	-33	-22
RUBBER	N/A	N/A	-21	-14	-21	-20	-19
OILPALM	-12	-13	-11	-8	-10	-12	-11
MELON	-9	-22	-25	-27	-33	-30	-24

5.2.2 Combination of S3 and S4 Runs (S5)

Results from the implementation of double domestic crop consumption and double ethanol demands (S3) simultaneously with the explicit land rent (S4) are summarized in Appendix 11b. As shown in Appendix 11b, the results are similar to S3 results (Appendix 11a) in many aspects except from the revealed regional shadow price of land (Appendix 11c). As expected, the potential total GM from all production and marketing activities in S5 is slightly lower than that of S3 due to the imposed explicit land rent on the additional hectares of land required to actualise the production of crops needed to meet the total crop demand in this scenario. This is because the implemented explicit land rent increased the unit cost of production beyond the S3 (and S0) levels as expected; and this reduced the potential gross margin from the production of each crop as a consequence (see Tables 5.8 and 5.9). Nevertheless, the marginal cost of production (which is equal to the input cost plus the opportunity cost of production plus the marketing cost) is still exactly the same with the revealed product prices (shadow prices at demand-supply balance) on one hand and the actual product prices on the other hand; implying that the overall effect of using food crops for ethanol production is not visible on product prices. Figure 5.4 highlights the additional hectares of land that will be required in all the regions to meet the double domestic crop consumption and double ethanol demands considered under this scenario. On a national scale, a total of 34,445 thousand hectares of land would be required. Importantly wheat and cassava are retained as the best ethanol feedstock in the NW and other regions, respectively; hence, confirming the robustness of the model results.

Figure 5.4, Extra-land (1000 ha) Required to meet Double DCD and Double DETD in S5

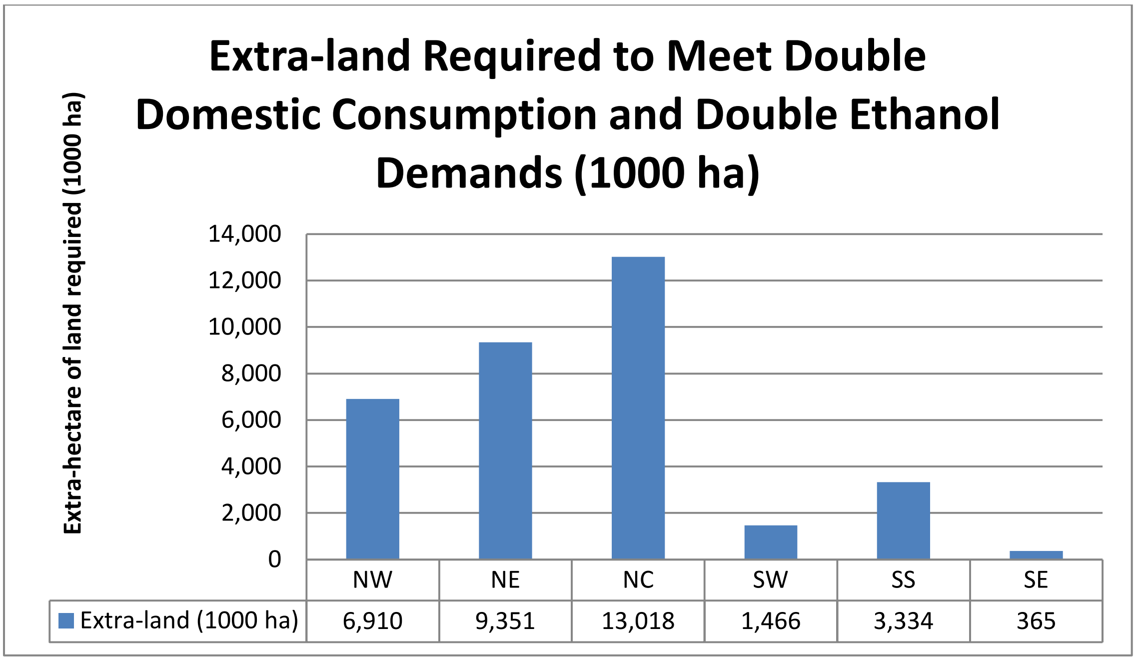


Table 5.8, Percentage Change in the S5 Unit Costs of Crop Production from their S0 Levels.

Crops	NWIC (% change)	NEIC (% change)	NEIC (% change)	SWIC (% change)	SSIC (% change)	SEIC (% change)	Nig (% change)
MAIZE	427	636	293	520	420	1,302	600
CASSAVA	30	31	18	31	30	107	41
POTATO	17	17	10	17	17	28	18
YAM	13	14	8	14	13	48	18
COCOYAM	43	45	26	45	44	152	59
PLANTAIN	20	5	20	5	5	18	12
BEANS	376	561	269	396	389	60	342
SORGHUM	394	599	281	452	N/A	N/A	432
SUGARCANE	65	69	39	68	65	226	89
WHEAT	344	491	239	433	N/A	N/A	377
MILLET	478	611	286	524	N/A	N/A	475
RICE	369	545	263	515	381	297	395
GROUNDNUT	229	557	268	543	413	343	392
COTTON	309	442	221	627	N/A	N/A	400
SESAME	193	323	241	N/A	N/A	N/A	252
SOYBEAN	286	382	192	367	N/A	N/A	307
COCOA	N/A	159	118	106	117	194	139
CASHEW	305	421	210	166	321	957	397
RUBBER	N/A	N/A	224	307	270	384	296
OILPALM	63	119	118	212	194	218	154
MELON	368	383	275	628	110	117	313

Table 5.9, Percentage Change in the S5 Opportunity Costs of Crop Production from the S0 Levels.

Crops	NWOC (% change)	NEOC (% change)	NEOC (% change)	SWOC (% change)	SSOC (% change)	SEOC (% change)	NIGOC (Ave % change)
MAIZE	-9	-26	-16	-26	-24	-66	-28
CASSAVA	-7	-6	-3	-5	-7	-20	-8
POTATO	-10	-10	-6	-10	-10	-17	-10
YAM	-5	-9	-4	-5	-7	-16	-8
COCOYAM	-10	-21	-5	-9	-18	-26	-15
PLANTAIN	-25	-6	-25	-6	-6	-22	-15
BEANS	-80	-55	-23	-60	-42	-35	-49
SORGHUM	-42	-43	-29	-69	N/A	N/A	-46
SUGARCANE	-2	-5	-3	-4	-7	-10	-5
WHEAT	-20	-20	-12	-20	N/A	N/A	-18
MILLET	-65	-39	-30	-34	N/A	N/A	-42
RICE	-19	-30	-13	-33	-8	-16	-20
GROUNDNUT	-39	-38	-15	-50	-67	-72	-47
COTTON	-10	-10	-6	-21	N/A	N/A	-12
SESAME	-53	-46	-55	N/A	N/A	N/A	-51
SOYBEAN	-21	-14	-10	-35	N/A	N/A	-20
COCOA	N/A	-23	-18	-21	-24	-27	-23
CASHEW	-13	-22	-10	-22	-23	-26	-19
RUBBER	N/A	N/A	-24	-17	-24	-29	-23
OILPALM	-7	-12	-6	-10	-11	-13	-10
MELON	-11	-23	-27	-40	-35	-32	-28

5.2.3 Labour Rent Sensitivity Run (S6)

In this run, we assume that the cost of labour would have to increase beyond the current hired labour wage (US$4.5) in order to provide enough incentive to persuade labour engaged in other sectors to migrate to agriculture (crop farming) or even to persuade an unemployed labour to give up the satisfaction that s/he derives in staying idle, despite the fact that the initial Energy-Food Simulation run (S0) suggests that the labour rent will be the same as in the base year due to un- and under-employment of the available labour. The aim of this sensitivity analysis is to examine the impacts of increasing the cost of labour on the model results.

To operationalise this assumption, a 100% increase in the cost of engaging both hired and family labours was implemented on all available labour (both on the initial base year and the extra-required labour) since labour wage differentiation between the initial base year labour and the additional labour that will be required to actualise the expected or targeted production level might in reality not be feasible. The initial labour force in the farm are most-likely to refuse the smaller wage rate or resign from their initial place of engagement and look for a new place where they will be paid higher wage as new entrants. Note that the labour rent sensitivity is implemented alongside the uniform land rent and 1st mechanization scenario, but under the S0 total crop demand (domestic crop consumption, feedstock and export demands).

As expected, the implementation of S6 (double labour cost under minimum explicit land rent and optional tractor use conditions) would respectively reduce the achievable total GM approximately by 1% and less than 1% (0.3) from the S0 and S4 levels (where only minimum explicit land rent and optional tractor use conditions are considered), as shown in Appendix 11b. This is because the implementation of S6 would significantly reduce the quantity of crops produced (on the national output basis) by 62% from the S0 level as reflected in Figure 5.5 (see Appendix 21 for the individual crop production levels from this run). This, of course, would affect the quantity of resources (e.g. land and labour employed) and the quantity of crops exported. The total hectares of land cultivated on a national scale would fall by 5% while the total labour employed for the cultivation of the crops would reduce approximately by 3% from their S0 levels. In terms of export, the total quantity of crops exported would decline by 29% from the S0 (and/or base year) level because the increase in the unit cost of producing each crop, considering the domestic market and export prices, would make it unprofitable to produce and export some crops (e.g. sesame) up to their S0 and base levels. Further, the S6 results reveal that the quantity of crops that would be imported will be zero as in the S0 run while the domestic crop consumption would be exactly the same as in S0 and base year levels; implying that domestic food supply (food security) would not be compromised if ethanol is produced from the local staple food crops, even if land rent and labour cost are significantly increased beyond their base year values. In addition, the implementation of S6 would increase the unit cost of production significantly from the S0 level as shown in Table 5.10; and this would substantially reduce the opportunity cost of producing each crop as highlighted in Table 5.11 (see Appendices 22 and 23 for the respective unit input cost of production and opportunity cost of producing each crop from this run). Nevertheless, the resultant marginal cost (MC) of production (input cost plus opportunity cost of production plus the marketing cost), which is equal to the marginal revenue (MR) (product prices), would still be exactly the same as the product prices from the S0 run and/or the actual base year product prices in reality; thereby underscoring the fact that producing ethanol from the locally produced energy-food crops does not necessarily increase food prices nor reduce domestic food supply (availability) and consumption, even though impacts on resource use are significant. Importantly, the best feedstock selected for ethanol production in all the regions from this run is the same as in S0 (i.e. cassava); thus, confirming the robustness of the S0 results. Further, the land use result suggests that 1,832 thousand hectares of extra-uncultivated land would be cultivated in the NE (the region with the highest available uncultivated land) in order to meet the total crop demand (domestic crop consumption, feedstock and export demands) in this run. As a result, NE would produce the highest volume of ethanol (31%) among other region, followed by NC (25%) and NW (23%) in a decreasing order of magnitude whereas the SS, SW and SE would respectively produce 9%, 8% and 3% of the current total (national) ethanol demand (5.14 billion litres per annum), as in S0. Other results from this run are summarised in Appendix 11b.

5.3 Summary of the Scenarios and Sensitivity Analyses

As shown from the results of different scenarios and sensitivity analyses considered above (and especially from S4, S5 and S6 results), cassava and wheat (to some extent) would be the best and second best feedstock for ethanol production in Nigeria. Further, production of ethanol from the local energy-food crops might not have any significant negative impact on domestic food prices and supply, but will definitely affect resource use demand for the production of the feedstock. In addition, different policy scenarios would have varying impacts on the unit cost of producing each crop as well as their corresponding opportunity cost of production (i.e. the achievable gross margin from the production of each crop). The most-likely worst case scenarios being S5 and S6 would most-probably still conform to this product price impact result.

Figure 5.5, Percentage Change in the S6 Crop Production from the S0 Level (National Aggregate Level).

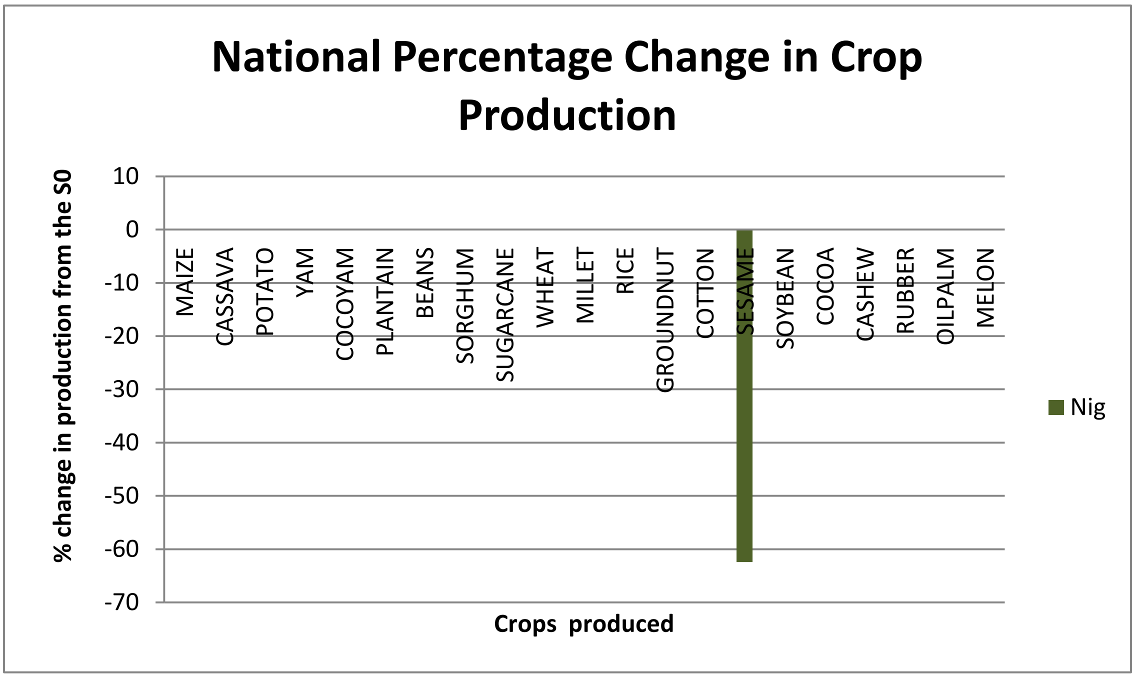


Table 5.10, Percentage Change in the S6 Unit Costs of Crop Production from their S0 Levels.

Crops	NWIC (% change)	NEIC (% change)	NEIC (% change)	SWIC (% change)	SSIC (% change)	SEIC (% change)	Nig (% change)
MAIZE	433	678	680	498	418	581	548
CASSAVA	31	33	41	29	30	48	35
POTATO	18	19	23	17	18	29	20
YAM	14	15	18	13	14	23	16
COCOYAM	47	50	61	44	45	72	53
PLANTAIN	5	5	7	24	5	8	9
BEANS	395	606	629	478	393	61	427
SORGHUM	407	645	655	496	N/A	N/A	551
SUGARCANE	69	75	92	67	67	105	79
WHEAT	355	529	556	417	N/A	N/A	464
MILLET	413	658	667	505	N/A	N/A	561
RICE	388	589	615	467	386	522	494
GROUNDNUT	385	603	624	487	411	316	471
COTTON	328	484	521	402	N/A	N/A	434
SESAME	207	347	258	N/A	N/A	N/A	271
SOYBEAN	295	411	448	333	N/A	N/A	372
COCOA	N/A	240	265	202	191	288	237
CASHEW	318	455	493	275	326	438	384
RUBBER	N/A	N/A	218	295	267	296	269
OILPALM	148	126	277	204	192	222	195
MELON	391	394	649	498	123	512	428

Table 5.11, Percentage Change in the S6 Opportunity Costs of Crop Production from the S0 Levels.

Crops	NWOC (% change)	NEOC (% change)	NEOC (% change)	SWOC (% change)	SSOC (% change)	SEOC (% change)	NIGOC (Ave % change)
MAIZE	-9	-27	-37	-24	-24	-29	-25
CASSAVA	-8	-7	-7	-4	-6	-9	-7
POTATO	-10	-11	-13	-9	-10	-17	-12
YAM	-5	-10	-8	-5	-7	-8	-7
COCOYAM	-11	-23	-11	-9	-18	-12	-14
PLANTAIN	-7	-7	-9	-30	-6	-10	-11
BEANS	-84	-60	-55	-73	-42	-36	-58
SORGHUM	-43	-46	-69	-76	N/A	N/A	-58
SUGARCANE	-2	-5	-8	-4	-8	-5	-5
WHEAT	-21	-22	-27	-19	N/A	N/A	-22
MILLET	-56	-42	-69	-33	N/A	N/A	-50
RICE	-20	-32	-30	-30	-8	-29	-25
GROUNDNUT	-66	-42	-34	-45	-66	-66	-53
COTTON	-10	-11	-15	-14	N/A	N/A	-12
SESAME	-57	-50	-58	N/A	N/A	N/A	-55
SOYBEAN	-22	-15	-23	-32	N/A	N/A	-23
COCOA	N/A	-35	-40	-41	-38	-39	-39
CASHEW	-13	-23	-23	-36	-24	-27	-24
RUBBER	N/A	N/A	-23	-16	-24	-22	-21
OILPALM	-16	-13	-15	-10	-11	-13	-13
MELON	-11	-24	-28	-31	-39	-36	-28

Having explored different policy and market change options for ethanol and food production using the applied model, we proceed to highlight some of the important study conclusions, policy recommendations, contributions to knowledge as well as limitations and suggestions for future research as pursued in the next chapter.

Chapter 6. Conclusions, Recommendations and Future Research

The broad objective of this study was to develop and apply a sectoral Energy-Food Model (EFM) in order to: 1) analyse the supply capacity and economic viability of the feedstock and food suppliers (the farmers in Nigeria) to the conceived ethanol policy, given the available production resources; 2) estimate the bioethanol production potential in Nigeria; 3) identify the regional potential 'best' feedstock; 4) estimate the potential foreign exchange savings from RPP import based on the ethanol produced; 5) assess the impacts of the potential feedstock and bioethanol demands and supplies on the national energy and food securities; and 6) proffer some policy recommendations based on the EFM results. This has been generally addressed through the analysis of the model results. Important conclusions, policy recommendations and contributions to knowledge based on the findings of this study are presented in Sections 6.1, 6.2 and 6.3, respectively. Finally, the study limitations and suggestions for future research are presented in Section 6.4.

6.1 Conclusions

Having examined the potential impacts of different policy and market change options on the Nigerian ethanol and food demand and supply conditions using the applied model, we conclude based on the results from this study:

First, that Nigeria has the potential (i.e. the required production resources such as land and labour) to produce sufficient feedstock and food crops required to meet the current domestic ethanol and crop consumption demands and can still meet the domestic total crop demand (domestic crop consumption, feedstock and export demands) if the current ethanol and crop consumption demands are doubled and/or if the cost of the main production resources (land and labour) are increased significantly from their current base year values.

Second, that cassava is the best feedstock for ethanol production in all the regions of Nigeria and that wheat can be used as a substitute for cassava in the NW.

Third, that ethanol production has significant indirect impacts, through the production (supply) of the feedstock demand, on resource use and that the supply of the feedstock, depending on the market conditions, has varying degrees of impact on the unit cost of production and the potential gross margin from such production. Hence, feedstock production could lead to the re-allocation of resources (e.g. land) that are formerly used for food crop production to energy crop production in a country where the major production resource (land) is limited and especially if the potential gross margin from the food/cash crop is lower than the potential gross margin from the production and use of the energy crop for ethanol production.

Fourth, that using first generation feedstock (food crops) for ethanol production does not affect domestic food supply and prices in Nigeria; or that the impact of using first generation feedstock for ethanol production on food prices are not detectable and/or explained using the applied partial equilibrium model.

Fifth, that farmers' income would increase in the event of an increase in commodity/crop prices since they are part of the feedstock supply chain (Hazell, 2006, UNCTAD, 2006, Von Braun and Pachauri, 2006) and this would increase farmers' purchasing power and access to food.

Sixth, that the annual potential ethanol production based on the estimated current national ethanol demand would substitute about 514 million litres of gasoline under E-10 blending.

Seven, that ethanol production could in general impact positively on the Nigerian economy as the potential ethanol production could save about US$36.15 billion in foreign exchange revenue per annum which could have been used for the importation of the substituted gasoline, if ethanol were not produced. In addition, ethanol production would lead to the productive use of vast uncultivated fertile arable land in Nigeria which is currently lying fallow, thereby creating additional jobs in the crop farming sub-sector for the numerous unemployed labours in Nigeria. Also reasonable off-farm employment could be created through the establishment or location of the ethanol refinery in the rural areas where the feedstocks are produced. Further, siting the ethanol refinery in the rural areas where feedstocks are produced has considerable developmental impacts on the farming communities and their economy. In addition, an estimated sum of US$354M per annum excluding the potential revenue from carbon credits could accrue to the economy from the co-products of the ethanol produced. Of course, the cost of transporting the feedstock from the rural areas (points of production) to any other location in the city would constitute a significant extra feedstock transportation cost to the cost of moving the feedstock from the farm to the refinery which is reported to be within US$41 per tonne on the average by Wallace et al. (2005, p. 2), which could even be higher in the Nigerian situation due to lack of adequate transportation facilities (e.g. good farm road network, bridge), and this could discourage siting the ethanol refinery outside the feedstock production location.

6.2 Policy Recommendations

Expansion of agricultural production, developing export markets for agricultural produce, ensuring competitive market prices for the national agricultural commodities and improving local market channels for efficient distribution and marketing of agricultural produce as well as proper dissemination and implementation of agricultural research information such as newly available plant breeding techniques, technology and/or high-yielding and disease-resistant crop/seed varieties among others are highly recommended to foster an increase in agricultural production. This is because the increase in cultivated land area, agricultural labour force and even the maximum total gross margin obtainable from the entire enterprise considered in Scenarios 3 and 5 signify an overall greater positive contribution to the national economy compared to the current (base year) production levels. Therefore expanding agricultural crop demand should be the major focus and priority of the national government, Ministry of Agriculture and/or farmers in order to reap the desired positive outcomes identified and outlined in this study.

Provision of annual short-term, medium and/or long-term credits (cash loans), with reduced interest rate (at least with a single-digit interest rate), to all farmers via commercial banks, agricultural banks and/or agricultural associations such as growers associations are essential to provide the necessary incentive required to boost agriculture, achieve optimum crop production in Nigeria and bridge the gap between food consumption and food production since they are required to fund all farm operations prior to harvesting and selling of farm produce. This might have been one of the major constraints to the Nigerian agricultural development and growth since the primary factors of production (land and labour) have been available in abundance before now. Therefore, the government could and should evolve an effective way of ensuring that the disbursed credits reach the targeted peasant farmers who are feeding the nation. The farmers should be monitored to ensure that the funds are invested in farming sector as planned to ensure repayment of loans immediately after harvest and sale of farm produce, as this will foster continuity and sustainability of such policy.

A policy of subsidizing the cost of hiring tractors by local farmers, although, it distorts market and reduces government revenue, can be introduced and pursued by the government in order to encourage mechanization of agriculture in Nigeria while reducing production cost, since the cost of hiring is currently high and affects the farmers potential gross profit as shown by the results of S2. Such a policy would reduce the drudgery from the current manual labour and subsistence farming system, encourage agricultural mechanisation which could serve as an incentive for the younger generations to see crop farming as means of livelihood and participate in it.

In order to ensure a successful and sustainable implementation of the ethanol policy with reduced impacts on food availability and food prices, a possible policy implementation strategy could be to create a government monitored feedstock growers association that will ensure that farmers cultivate the same and other staple food crops for the purpose of domestic consumption before they are allowed to enlist in the feedstock growers' association. This of course will require collaboration with the ethanol industry (where the farmers and/or the growers' association supply their feedstocks) in order to ensure that the ethanol industries do not buy from farmers who are not enlisted with the feedstock suppliers and that they report their feedstock supply sources on a quarterly basis for verification. For example, a farmer who wants to supply 20 metric tonnes of cassava per annum as feedstock could be mandated to have other inspected plots of land where he produces additional 20 MT of maize, 20 MT of cassava, 20 MT of yam and 20 MT of rice (depending on the regional food consumption and feedstock demands) without reducing any of the initial crops that s/he used to cultivate. In that case, domestic production and supply of all crops (food and cash) will be ensured while producing enough feedstocks for ethanol production since farmers who do not meet these criteria will be 'forced' to remain in the production of food crops where they will still receive the associated increase in their income in case of an increase in food-crop market prices. The above described policy procedure could help Nigeria maximize the identified positive benefits of ethanol production such as utilizing more of her productive agricultural resources (e.g., land and labour) that are currently lying idle or being under-utilized; creating more jobs; increasing farmers' income; boosting Nigerian motor fuel supply via the produced biofuel; and increasing the national GDP and national income through the accruing GM, thereby boosting the entire national economy while reducing the impact on food prices.

6.3 Contributions to Knowledge

The models developed and applied in this study are the first crop production and marketing programming models ever constructed to: 1) describe Nigerian crop production system via quantitative approach; 2) study the supply response of subsistent farmers in Nigeria to changes in market forces (demand and supply); 3) evaluate the profitability of Nigerian crop farming system in a sectoral level while utilizing farm level data; 4) simulate market equilibrium under market imperfection condition by utilizing a Samuelsonian competitive market concept which says that the sum of consumer and producer surpluses is equal to the maximization of the objective function[17]; 5) make a quantitative inference that is consistent with micro-economic theories and principles about the regional crop production, export and import comparative advantage for all the crops produced in each region as captured in the model; 6) demonstrate how feedstock can be produced (and supplied), converted to ethanol and marketed; and 7) simulate and examine the impacts of future agricultural policies and/or changes in market conditions (as demonstrated using the Ethanol-Food Production Model). These empirical analyses and simulations can be useful in designing agricultural and/or biofuel policies in Nigeria and can also be adapted to other developing countries with similar characteristics. In summary, this study is therefore novel- being the first quantitative ethanol production impact analysis study in Nigeria.

The study also contributes empirically to the filling of the identified research gaps in Ikeme (2001), Sambo (2009) and Iye and Bilsborrow (2013a, 2013b) and satisfying the recommendations of previous studies (Hazell and Pachauri, 2006a, von Braun, 2008), especially in the Nigerian case.

The complementary approach adopted in estimating the national total primary energy consumption (TPEC) in Section 2.1.1 appears to be a unique but consistent method of estimating TPEC, especially in developing countries' context where wood fuel supply the greater proportion of the household energy consumption, since it integrates the energy from wood fuel consumption from FAO with the fossil fuel (petroleum, natural gas, coal, electricity and renewable) energy from EIA; thus providing a comprehensive and accurate data on the national total primary energy consumption analysis. This approach is different from the method applied in previous studies (e.g. EIA and IEA TPEC reports), where TPEC is only estimated using the fossil fuel energy consumption data. Hence, this study further contributes to knowledge through this complementary method of estimating TPEC.

---

[17] Samuelson (1952) in Hazell and Norton (1986, p.162), first showed that the maximization of a model´s objective function is able to simulate or replicate a competitive market outcome (equilibrium market system) only if the objective function is equal to the area between the demand and supply functions (Area = $aX - 0.5bX^2$) and further demonstrated that this area is equal to the sum of producer and consumer surplus (for application details, see Hazell and Norton (1986, pp. 162 - 168), McCarl and Spreen (1980, pp. 87 -102) and Bauer and Kasnakoglu (1990, pp. 278 - 280)).

Further, the implementation of land, labour and tractor demand and supply according to the seasonal cropping pattern of each crop modelled in this study is the first of its kind among crop production analysis studies in Nigeria. Defining and implementing fixed and semi-fixed production resources according to seasonal patterns incorporates timing of farm operations into programming models and consequently enhances the models' realism (Hazell and Norton, 1986, p. 42).

The regional per hectare crop yield information provided in this study, among other data, could serve as reference for future studies.

The study also adds to the available literature on the subject area, at least in developing countries like Nigeria where empirical literature on economic analysis of sectoral crop and/or biofuel production is limited.

6.3 Study Limitations and Suggestions for Future Research

This study provides useful information on the analysis of biofuel potential in Nigeria. However, it is envisaged that future research could offer further contributions by addressing some of the challenges encountered in this study and other issues that are outside the scope of this study but generally relevant to the research area.

First, since the most important and valuable achievement of this study is the development of the analytical model applied in this study, the first effort in the right direction would be to further develop, apply and extend (and/or adapt) the model to other relevant sectors and/or sub-sectors that was not possible within the research period and due to resource constraint. An example would be to extend the model by including livestock production sub-sector into it, considering that an increase in meat demand in Nigeria due to continuous rise in per capita income and consistent economic growth, would lead to an increase in land and labour demand in order to ensure the production of more feed crops and livestocks. In addition, the regional farming sector could further be disaggregated into two broad farm classes; namely, the peasant and commercial farming in order to examine the policy implications of full-scale mechanisation and commercial farming in Nigeria. Also changes in world market prices of both crops and ethanol could be a useful additional sensitivity analysis. Further, positive impact of research and innovations on crop yield could be tested as well as the potential negative impact of climate change effects (e.g. drought, flood) on crop yield.

Second, as earlier stated, the per ha labour demand (i.e. per ha labour coefficient) for each crop employed in the study models is derived by dividing the total number of labours employed in the crop farming sector in each region by the total harvested hectares of land cultivated in those regions at the base year instead of the observed number of labour required to produce each crop in each region due to lack of such data and the mixed cropping system of farming practiced widely across Nigeria. In addition, the cost and time requirement of conducting such survey across the six different regions of Nigeria and for the twenty two crops modelled in this study are other constraints limiting the availability and utilization of such preferred per ha observed data. Therefore future studies could improve on this (if possible, given the highlighted constraints), by conducting surveys on the labour required by each crop cultivated in each region so as to gather the required observed labour data. At the government level, the Nigerian Bureau of Statistics (NBS), despite the recent initiative taken to conduct regularly agricultural (farm) and socio-economic surveys, collate and harmonise data from some national agencies, ministries and parastatals in Nigeria; could also set up regional farm survey projects that are specifically designed to collect and gather the observed per ha labour requirement data for each crop grown in each region. This can be achieved through collaboration with the staff of the Agricultural Development Programmes (ADPs) in each state of the federation since these staff members are directly interacting with the farmers in each state and/or region. Employing data from such surveys in the applied models will help improve the competitiveness of each crop in terms of their unit cost of production and their opportunity cost of production (per unit GM of each crop).

Third, lack of reliable export and import data, especially export and import prices from the NBS in addition to the wide discrepancy between data from international organisations (e.g. FAO, IMF and World Bank) and the data from NBS as well as the lack of comprehensive commodity price data for all the crops captured in the model from the international organisations' databases is another challenge of this study. To overcome this challenge, the world market export prices for the crops modelled were assumed to be exactly the same with the domestic market prices of those crops while the world market import prices were assumed to be 10% higher than the domestic market prices in the study models as remarked earlier. Having a unified and comprehensive commodity price data (domestic, export and import prices) for all crops at the national and international level could help eliminate the potential impacts of the export and import price assumptions on the results of this study.

Fourth, information on the optimum seed rate of each crop cultivated in Nigeria as well as their per hectare fertilizer and pesticide requirements implemented in the models were gathered from different sources in this study, making it very labourious and time consuming. National and international crop research institutes such as National Tuber Crop Research Institute at Umudike, National Cereal Research Institute at Oshodi, ADPs in each state, Nigerian Institute for Oil-palm Research (NIFOR) at Benin, Agricultural Research Council of Nigeria (ARCN) at Abuja, National Agricultural Extension and Research Liaison Services (NAERLS) at Zaria and International Institute of Tropical Agriculture (IITA) at Ibadan among others could cooperate to provide a database with a comprehensive information about the optimum per ha seed, fertilizer and pesticide requirement of each crop grown in Nigeria in order to reduce the time spent on searching for such information by researchers and/or policy makers. Doing so can encourage and promote future research.

Finally, this study shows that Nigeria has the potential to produce sufficient feedstock and food crops required to meet the domestic ethanol and crop consumption demands without reducing domestic food supply or increasing domestic commodity prices. The achievable total gross margin (GM) from the Energy-Food Model indicates that Nigeria can make a substantial annual gross profit of US$45.71 billion from the sale of the domestically produced ethanol and crops, with less than 1% of this amount (US$2.36B) coming from the sale of the produced ethanol. Nevertheless, the total capital investment (TCI) of establishing (designing, manufacturing and installing) multi-feedstock bio-refinery was not included in the ethanol GM analysis as it is outside the scope of this study as noted earlier. Aden et al. (2002, pp. 60 - 70) and Humbird et al. (2011, pp 58 - 68) provide a detailed information on how to calculate TCI of an ethanol refinery. The ethanol GM analysis from this study can be easily extended to adjust for the computed total capital investment by using the discounted cash-flow analysis or net-present value (NPV) method and assuming a refinery lifespan of 20 years (as recommended in many engineering texts: Garrett (1989), Peters and Timmerhaus (2003) in Aden et al. (2002, p. 67)), a suitable depreciation method (e.g., declining balance or straight line method – see (Aden et al., 2002, pp. 66 - 70) for details), the prevailing income tax rate and an appropriate discounting factor (Short et al. (1995) in Humbird et al. (2011, p. 65) and an in-built MS Excel NPV formula recommend 10%). Of course, information about the project financing scheme (i.e. whether the project is 100% financed with borrowed capital or with 100% equity and/or combination of the two, the applicable interest rate and the loan repayment duration) is also important in working out the NPV of the project over its lifespan and the corresponding internal rate of return (IRR).

References

ABDULKADRI, A. O. & AJIBEFUN, I. A. 1998. Developing alternative farm plans for cropping system decision making. *Agricultural Systems*, 56**,** 431-442.

ACHEBE, C. 2012. *There Was a Country: A Personal History of Biafra,* USA, Penguin Press.

ADEN, A., RUTH, M., IBSEN, K., JECHURA, J., NEEVES, K., SHEEHAN, J., WALLACE, B., MONTAGUE, L., SLAYTON, A. & LUKAS, J. 2002. Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover. Colorado, USA: National Renewable Energy Laboratory (NREL) and Haris Group.

AFDC. 2014. *Ethanol Feedstocks* [Online]. U.S Department of Energy, Alternative Fuel and Advance Vehicles Data Centre. Available: http://www.afdc.energy.gov/afdc/ethanol/feedstocks.html [Accessed 08/03/02014].

AKINYELE, I. O. 2009. Ensuring Food and Nutritional Security in Rural Nigeria: An Assessment of the Challenges, Information Needs, and Analytical Capacity. Washington, USA: International Food Policy Research Institute (IFPRI).

ANDERSON, J. R., DILLON, J. L. & HARDAKER, J. B. 1977. *Agricultural Decision Analysis*, Iowa State University Press, Ames, IA, USA.

AREGHEORE, E. M. 2005. Country Pasture/Forage Resource Profiles (Nigeria). Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

ARRIAZA, M. & GÓMEZ-LIMÓN, J. A. 2003. Comparative performance of selected mathematical programming models. *Agricultural Systems,* 77**,** 155-171.

BABATUNDE, R. & OYATOYE, E. Year. Food Security and Marketing Problems in Nigeria: the Case of Maize Marketing in Kwara State. *In:* Tropentag, 2005 University of Hohenheim, Germany. Germany: Tropentag.

BALAT, M. & BALAT, H. 2009. Recent trends in global production and utilization of bio-ethanol fuel. *Applied Energy,* 86**,** 2273-2282.

BALAT, M., BALAT, H. & ÖZ, C. 2008. Progress in bioethanol processing. *Progress in Energy and Combustion Science,* 34**,** 551-573.

BARNETT, D., BLAKE, B. & MCCARL, B. A. 1982. Goal Programming via Multidimensional Scaling Applied to Senegalese Subsistence Farms. *American Journal of Agricultural Economics,* 64**,** 720-727.

BAUER, S. & KASNAKOGLU, H. 1990. Non-linear programming models for sector and policy analysis: Experiences with the Turkish agricultural sector model. *Economic Modelling,* 7**,** 275-290.

BERG, C. 2004. *World Fuel Ethanol. Analysis and Outlook* [Online]. Distill .com. Available: http://www.distill.com/World-Fuel-Ethanol-A&O-2004.html [Accessed October 15 2010].

BOTHAST, R. J. & SCHLICHER, M. A. 2005. Biotechnological processes for conversion of corn into ethanol. *Spinger,* 67**,** 19 - 25.

CASAVANT, K. L. & INFANGER, C. L. 1984. *Economics and Agricultural Management: An Introduction,* Virginia, USA, Prentice-Hall, Inc.

CBN. 2013. *Data and Statistics: Money Market Indicators (in percentage)* [Online]. Abuja, Nigeria: Central Bank of Nigeria (CBN). Available: http://www.cenbank.org/rates/mnymktind.asp?year=2013
http://www.cenbank.org/rates/mnymktind.asp?year=2012
http://www.cenbank.org/rates/mnymktind.asp?year=2011 [Accessed 14/03/ 2013].

DAWSON, B., DICKSON, A., NAUGHTEN, B., NOBLE, K. & FISHER, B. 1996. ABARE MARKAL Workshop. *Asia Least Cost Greenhouse Gas Abatement*

Strategies (ALGAS) project. Canberra, Australia: Asian Development Bank (ADB).

DE LA TORRE UGARTE, D. G. 2006. Developing Bioenergy -- Economic and Social Issues. *In:* HAZELL, P. & PACHAURI, J. K. (eds.) *Bioenergy and Agriculture -- Promises and Challenges.* Washington, DC: International Food Policy Research Institute (IFPRI).

DEMIRBAS, A. 2007. Progress and recent trends in biofuels. *Progress in Energy and Combustion Science,* 33**,** 1-18.

DEMİRBAŞ, A. 2005. Bioethanol from Cellulosic Materials: A Renewable Motor Fuel from Biomass. *Energy Sources,* 27**,** 327-337.

DEMIRBAS, M. F. & BALAT, M. 2006. Recent advances on the production and utilization trends of bio-fuels: A global perspective. *Energy Conversion and Management,* 47**,** 2371-2381.

DIAO, X., NWAFOR, M. & ALPUERTO, V. 2009. Options for Agricultural Growth for Poverty Reduction in Nigeria. Washington DC, USA: International Food Policy Research Institute (IFPRI)

DIAO, X., NWAFOR, M., ALPUERTO, V., AKRAMOV, K. & SALAU, S. 2010. Agricultural Growth and Investment Options for Poverty Reduction in Nigeria. Washington DC, USA: International Food Policy Research Institute (IFPRI).

DRUD, A. 2012. CONOPT. *GAMS - The Solver Manuals.* Bagsvaerd, Denmark and Washington D.C. USA: ARKI Consulting and Development A/S and GAMS Development Corporation.

E.C. 2003. Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport. *In:* ENERGY, R. (ed.). European Commission.

EERE. 2014. *Biomass Program, Bioethanol Feedstocks* [Online]. U.S Department of Energy, Energy Efficiency and Renewable Energy. Available: http://www1.eere.energy.gov/biomass/abcs_biofuels.html#feed
http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html
http://www1.eere.energy.gov/biomass/feedstock_databases.html
http://www.afdc.energy.gov/biomass/progs/search1.cgi [Accessed 08/03/ 2014].

EIA. 2011. *Nigerian Energy Profile* [Online]. Washington, USA: Energy Information Administration Available: http://www.eia.doe.gov/countries/cab.cfm?fips=NI [Accessed April 3 2014].

EIA 2012. Table 12. Petroleum Product Prices. Washington, D.C. USA: United States Energy Information Administration

ENCYCLOPEDIA, N. 2011. Nigerian Agriculture. *Encyclopedia of the Nations* Illinois, USA: Nations Encyclopedia.

EPA 2004. Unit Conversions, Emissions Factors, and Other Reference Data. Washington, D.C. USA: United States Environmental Protection Agency.

ESMAP 2005. Potential for Biofuels for Transport in Developing Countries. Washington Energy Sector Management Assistance Programme, The World Bank Group.

FACTBOOK. 2011. *The World Factbook: Nigeria Profile* [Online]. Washington: Central Intelligence Agency Available: https://www.cia.gov/library/publications/the-world-factbook/geos/ni.html [Accessed November 5 2011].

FACTBOOK. 2013. *The World Factbook: Nigeria Profile* [Online]. Washington: Central Intelligence Agency. Available: https://www.cia.gov/library/publications/the-world-factbook/geos/ni.html [Accessed March 04 2013].

FAO 2005. 2005 Yearbook of Forest Products. Rome, Italy: United Nation Food and Agriculture Organization.

FAO 2007-2009. FAO Food Balance Sheet. *Year.* Food and Agriculture Organisation of The United Nations (FAO).

FAO 2008. The State of Food and Agriculture. *An international Journal of Forest and Forest Industries.* Rome, Italy: Agricultural Organization of the United Nations.

FAO 2010. 2010 Yearbook of Forest Products. Rome, Italy: United Nation Food and Agriculture Organization.

FAO/WHO 2002. Joint FAO/WHO Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases. Geneva, Switzerland: World Health Organization and Food and Agriculture Organization.

FAO/WHO/UNU 2001. Joint FAO/WHO/UNU Expert Consultation on Human Energy Requirements. *FAO Food and Nutrition Technical Report Series 1.* Rome: Food and Agricultural Organisation of the United Nations

FAOSTAT 2014a. Nigerian Land Use Data. 09/05/2013 ed.: Food and Agricultural Organisation of the United Nations (FAO).

FAOSTAT 2014b. World Crop Production Database: Cassava Production Data. 07/02/2014 ed. Rome, Italy: Food and Agricultural Organisation of the United Nations.

FMARD 2012. Agricultural Machinery and Implements Survey. *Farm Mechanization Census.* Abuja, Nigeria: Federal Ministry of Agriculture and Rural Development

FOODANDWATERWATCH. 2008. *The Rush to Ethanol: Not All Biofuels are Created Equal* [Online]. FoodandWaterWatch. Available: http://www.foodandwaterwatch.org/food/pubs/reports/rush-to-ethanol [Accessed 19/11/2008].

GALLAGHER, P., DIKEMAN, M., FRITZ, J., WAILES, E., GAUTHIER, W. & SHAPOURI, H. 2003. Supply and Social Cost Estimates for Biomass from Crop Residues in the United States. *Environmental and Resource Economics,* 24**,** 335-358.

GAMS. 2013. *Solver Descriptions* [Online]. New York, Washington DC, USA: GAMS Development Corporation. Available: http://www.gams.com/solvers/solvers.htm [Accessed 21/02/ 2013].

GLEN, J. J. 1987. Feature Article--Mathematical Models in Farm Planning: A Survey. *OPERATIONS RESEARCH,* 35**,** 641-666.

GNANSOUNOU, E. 2010. Production and use of lignocellulosic bioethanol in Europe: Current situation and perspectives. *Bioresource Technology,* 101**,** 4842-4850.

GOLDEMBERG, J., COELHO, S. T., NASTARI, P. M. & LUCON, O. 2004. Ethanol learning curve—the Brazilian experience. *Biomass and Bioenergy,* 26**,** 301-304.

HARVEY, D. R. 1990. Agricultural Modelling for Policy Development. *In:* JONES, J. G. W. & STREET, P. R. (eds.) *System Theory Applied to Agriculture and The Food Chain.* Crown House, Linton Road, Barking Essex 1G11 8JU, England: Elsevier Science Plublishers Ltd.

HAZELL, P. 2006. Developing Bioenergy: A Win-Win Approach That Can Serve the Poor and the Environment. *In:* HAZELL, P. & PACHAURI, J. K. (eds.) *BIOENERGY AND AGRICULTURE: PROMISES AND CHALLENGES.* Washington, DC: International Food Policy Research Institute (IFPRI).

HAZELL, P. & PACHAURI, J. K. 2006a. Overview. *In:* HAZELL, P. & PACHAURI, J. K. (eds.) *Bioenergy and Agriculture: Promises and Challenges.* Washington, DC: International Food Policy Research Institute (IFPRI).

HAZELL, P. & PACHAURI, R. 2006b. *Bioenergy and Agriculture: Promises and Challenges*, IFPRI Washington, DC.

HAZELL, P. B. R. & NORTON, R. D. 1986. *Mathematical Prgramming for Economic Analysis in Agriculture,* New York, USA, Macmillian publishing company.

HECKELEI, T. & BRITZ, W. 2005. Models based on positive mathematical programming: state of the art and further extensions. *Modelling Agricultural Policies: State of the Art and New Challenges, Parma, Italy***,** 48-73.

HECKELEI, T., BRITZ, W. & ZHANG, Y. 2012. Positive Mathematical Programming Approaches - Recent Developments in Literature and Applied Modelling *Bio-based and Applied Economics,* 1**,** 109 - 124.

HOUGHTON, J. T., CALLENDER, B. A. & VARNEY, S. K. E. 1992. The Supplementary Report to The IPCC Scientific Assessment Intergovernmental Pannel on Climate Change.

HOWITT, R. E. 1995a. Positive Mathematical Programming. *American Journal of Agricultural Economics,* 77**,** 329-342.

HOWITT, R. E. 1995b. A CALIBRATION METHOD FOR AGRICULTURAL ECONOMIC PRODUCTION MODELS. *Journal of Agricultural Economics,* 46**,** 147-159.

HUMBIRD, D., DAVIS, R., TAO, L., KINCHIM, C., HSU, D., ADEN, A., SCHOEN, P., LUKAS, J., OLTHOF, B., WORLEY, M., SEXTON, D. & DUDGEON, D. 2011. Processing Design and Economics for Biochemical Conversion of Lignocellulosic Biomass and Enzymatic Hydrolysis of Corn Stover. Colorado: National Renewable Energy Laboratory and Harris Group Inc.

ICS-NIGERIA/IITA 2011. Crop Production Manuals: Maize, Cassava, Cowpea, Cocoyam, Yam, Groundnut, Millet, Rice, Soybean, Plantain. Ibadan, Nigeria: Information and Communication Support for Agricultural Growth in Nigeria (ICS-Nigeria) and International Institute of Tropical Agriculture (IITA).

IKEME, J. 2001. Assessing the future of Nigeria Economy: Ignored Threats from the Global Climate. *African Economic Analysis*.

ILOEJE, N. P. 2001. *A New Geography of Nigeria,* Longman Nigeria PLC.

IMF 2013. World Economic Outlook. *Annual.* October, 2013 ed.: International Monetary Fund (IMF).

IPCC 1990. IPCC First Assessment Report, Working Group II: Impacts Assessment of Climate Change. Intergovernmental Panel on Climate Change

IPCC 1992. Supplementary Report to The IPCC Impact Assessment. Intergovernmental Pannel on Climate Change

IPCC 2001. IPCC Third Assessement Report, Working Group III:Mitigation. Intergovernmental Panel on Climate Change

IPCC 2007. Summary for Policymakers. *In:* METZ, B., DAVIDSON, O., BOSCH, P., DAVE, R. & MEYER, L. (eds.) *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.* Intergovernmental Panel on Climate Change.

IPCC 2014. Summary for Policymakers *In:* EDENHOFER, O., PICHS-MADRUGA, R., SOKONA, Y., FARAHANI, E., KADNER, S., SEYBOTH, K., ADLER, A., BAUM, I., BRUNNER, S., EICKEMEIER, P., KRIEMANN, B., SAVOLAINEN, J., SCHLÖMER, S., VON STECHOW, C., ZWICKEL, T. & MINX, J. C. (eds.) *Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*

IPCC, W. G. 1993. Global Warming: Myth or Reality? The Conclusions of the IPCC (Working Group 1). *Environmental Science*.

IYE, E. & BILSBORROW, P. 2013a. Cellulosic ethanol production from agricultural residues in Nigeria. *Energy Policy,* 63**,** 207-214.

IYE, E. L. & BILSBORROW, P. E. 2013b. Assessment of the availability of agricultural residues on a zonal basis for medium- to large-scale bioenergy production in Nigeria. *Biomass and Bioenergy,* 48**,** 66-74.

JEFFREY, S. R., GIBSON, R. R. & FAMINOW, M. D. 1992. Nearly optimal linear programming as a guide to agricultural planning. *Agricultural Economics,* 8**,** 1-19.

JOHNSTON, M., FOLEY, J. A., HOLLOWAY, T., KUCHARIK, C. & MONFREDA, C. 2009. Resetting global expectations from agricultural biofuels. *IOP Science*.

JUST, R. E., ZILBERMAN, D. & HOCHMAN, E. 1983. Estimation of Multicrop Production Functions. *American Journal of Agricultural Economics,* 65**,** 770-780.

KAY, R. D. 1986. *Farm Management: Planning, Control and Implementation,* New York, USA, MCGraw-Hill Inc.

KIM, S. & DALE, B. E. 2004. Global potential bioethanol production from wasted crops and crop residues. *Biomass and Bioenergy,* 26**,** 361-375.

KOVARIK, B. 1998. Henry Ford, Charles F. Kettering and the Fuel of the Future *Automative History Review* 7 - 27.

KUTCHER, G. P. 1980. egypt.gms: Egypt Agricultural Model. *Large Model of Type: LP*. Washington, DC. USA: The World Bank.

KUTCHER, G. P., MEERAUS, A. & O´MARA, G. T. 1988. qdemo7.gms: Nonlinear Simple Agricultural Sector Model QCP. *Small Model of Type: QCP*. Washington, D.C., USA: World Bank.

KUTCHER, G. P. & SCANDIZZO, P. L. 1981. nebrazil.gms : North-East Brazil Regional Agricultural Model. *Large Model of Type: LP*. Washington, DC. USA: The World Bank.

LAL, R. 1995. The Role of Residues Management in Sustainable Agricultural Systems. *Journal of Sustainable Agriculture,* 5**,** 51 - 78.

LAL, R. 2005. World crop residues production and implications of its use as a biofuel. *Environment International,* 31**,** 575-584.

LAL, R. 2008. Crop residues as soil amendments and feedstock for bioethanol production. *Waste Management* 28**,** 747 - 758.

LE-SI, V., SCANDIZZO, P. L. & KASNAKOGLU, H. 1982. turkey.gms: Turkey Agricultural Sector Model. Tech rep. *Large Model of Type: NLP*. Washington, DC. USA: The World Bank.

MACEDO, I. C., SEABRA, J. E. A. & SILVA, J. E. A. R. 2008. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. *Biomass and Bioenergy,* 32**,** 582-595.

MACEDO, I. D. C. 1998. GREENHOUSE GAS EMISSIONS AND ENERGY BALANCES IN BIO-ETHANOL PRODUCTION AND UTILIZATION IN BRAZIL (1996). *Pergamon: Biomass and Bioenergy* Vol. 14, **,** pp. 77 - 81.

MACLEAN, H. L. & LAVE, L. B. 2003. Evaluating automobile fuel/propulsion system technologies. *Progress in energy and combustion science,* 29**,** 1-69.

MANOS, B. & KITSOPANDIS, G. 1988. Mathematical Programming Models for Farm Planning. *Oxford Agrarian Studies (now known as Oxford Development Studies),* 17**,** 163 – 172.

MCALOON, A., TAYLOR, F., YEE, W., IBSEN, K. & WOOLEY, R. 2000. Determinining the cost of producing ethanol from corn starch and lignocellulosic feedstocks. Colorado, USA: National Renewable Energy Laboratory (NREL).

MCCARL, B. A. 1998. *So Your GAMS Model Didn't Work Right: A Guide to Model Repair,* Texas, USA, Texas A&M University.

MCCARL, B. A., MEERAUS, A., VAN DER EIJK, P., BUSSIECK, M., STEACY, P. & NELISSEN, F. 2012. McCarl GAMS User Guide. Washington, DC, USA: Texas A&M University and GAMS Development Corporation.

MCCARL, B. A. & NUTHALL, P. 1982. Linear programming for repeated use in the analysis of agricultural systems. *Agricultural Systems,* 8**,** 17-39.

MCCARL, B. A. & SPREEN, T. H. 1997. Applied Mathematical Programming using Algebraic Systems. Texas, USA: Texas A&M University.

MCCONNELL, D. J. & DILLON, J. L. 1997. Farm Management for Asia: a system approach. FAO Farm Systems Management Food and Agriculture Organization of the United Nations (FAO), Rome.

METZ, H. C. 1991. Nigeria: A Country Study. Washington: US Library of Congress.

MINOT, N. 2009. Using GAMS for Agricultural Policy Analysis. *Technical Guides: Training Material.* GAMS Training Manual ed. Washington, DC, USA.: International Food Policy Research Institute (IFPRI).

MITCHELL, D. 2010. *Biofuels in Africa: Opportunities, Prospects, and Challenges,* Washington, DC USA, The World Bank.

MURTAGH, B. A., SAUNDERS, M. A., MURRAY, W. & GILL, P. E. 2012. MINOS. *GAMS - The Solver Manuals.* Washington, DC, USA: GAMS Development Corporation.

NBS 2008. Agriculture Filling Data Gap 2005 - 2006. Abuja, Nigeria: Nigeria Bureau of Statistics.

NBS 2009. Nigerian Social Statistics Survey Abuja, Nigeria: Nigeria Bureau of Statistics.

NBS 2010a. Revised 2008 and Q1, Q2, Q3, & Q4 2009, Gross Domestic Product for Nigeria. Abuja, Nigeria: Nigerian Bureau of Statistics

NBS 2010b. Nigerian Farm Survey Data. *Nigerian Farm Survey.* 2 ed. Abuja: Nigerian Bureau of Statistics.

NNPC 2011. History of the Nigerian Petroleum Industry. Nigerian National Petroleum Cooperation.

NNPCRED. 2005. *Nigerian Renewable Energy* [Online]. Nigerian National Petroleum Cooperation Renewable Energy Development. Available: http://www.nnpcred.com/ [Accessed 15/11/ 2008].

NNPCRED 2007. Official Gazette of the Nigerian Biofuel Policy and Incentives. Nigerian National Petroleum Cooperation Renewable Energy Development

NNPCSTAT 2011. Oil and Gas Annual Statistics Bulletin. Abuja: Nigerian National Petroleum Corporation

NNPCSTAT 2012. NNPC Annual Statistical Bulletin (ASB): Refined Petroleum Product (RPP) Distribution Data. Abuja, Nigeria: Nigerian National Petroleum Cooperation (NNPC).

NPC. 2006. *Nigerian Census 2006* [Online]. National Population Commission. Available: http://www.population.gov.ng/ [Accessed November 12 2010].

NWACHUKWU, C. C. & LEWIS, C. 1986. A Net Energy Analysis of Fuels from Biomass: the Case of Nigeria. *Biomass,* 11**,** 271 - 289.

NWAJIUBA, C. 2000. Food Insecurity: An Overview. Department of Agricultural Economics, Federal University of Technology, Owerri, Imo State, Nigeria: Department of Agricultural Economics.

OECD-FAO 2008. The OECD-FAO Agricultural Outlook Organisation for Economic Co-operation and Development (OECD)

Food and Agricultural Organisation of the United Nations (FAO).

OHIMAIN, E. I. 2010. Emerging bio-ethanol projects in Nigeria: Their opportunities and challenges. *Energy Policy,* 38**,** 7161-7168.

OKOLO, D. A. 2004. Regional Study on Agricultural Support, Nigeria's case. Rome, Italy: United Nation Food and Agriculture Organization.
OLAYIDE, S. O. & HEADY, E. O. 1982. *Introduction to Agricultural Production Economics*, Ibadan, Nigeria, Ibadan University Press.
ONWUKA, N. D. 1984. Fossil fuels and Nigeria's energy situation by the year 2000. *Energy*, 9**,** 17 - 22.
OYENUGA, V. A. 1967. Agriculture in Nigeria. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO)
PSU. 2013. The Pennsylvania State University. Available: https://www.courses.psu.edu/for/for466w_mem14/Ch11/HTML/Sec4/ch11sec4.htm
https://www.courses.psu.edu/for/for466w_mem14/Ch11/HTML/Intro/ch11intro.htm [Accessed 30/10/ 2013].
QIU, H., HUANG, J., YANG, J., ROZELLE, S., ZHANG, Y., ZHANG, Y. & ZHANG, Y. 2010. Bioethanol development in China and the potential impacts on its agricultural economy. *Applied Energy*, 87**,** 76-83.
RAJAGOPAL, D. & ZILBERMAN, D. 2007. *Review of environmental, economic and policy aspects of biofuels*, World Bank Publications.
RAÑOLA JR, R. F., DEMAFELIS, R. B., DEL ROSARIO, E. & BATALLER, B. G. 2009. Enhancing the viability of cassava feedstock for bioethanol in the Philippines. *Jurnal (terhubung berkala). http://www. issaas. org/journal/v15/02/journal-issaas-v15n2-13-ranolaet_al. pdf (3 Mei 2010).*
RANOLA, R. F., DEMAFELIS, R. B., DEL ROSARIO, E. & BATALLER, B. G. 2009. Enhancing the Viability of Cassava Feedstock for Bioethanol in the Philippines. *J.ISSAAS* 15**,** 147 - 158.
RANOLA, R. F., LAYAOEN, H. L., COSTALES, C., HALOS, A. L. & BARACOL, L. A. 2007. Feasibility Study for an Integrated Anhydrous Alcohol Production Plant Using Sweet Sorghum as Feedstock Laguna, Philippine International Society for Southeast Asian Agricultural Sciences (ISSAAS).
RFA 2008. Industrial Statistics of Bioethanol. Renewable Fuel Association (RFA).
RFA. 2013. *World Fuel Ethanol Production* [Online]. Washington, D.C.: Renewable Fuel Association (RFA). Available: http://ethanolrfa.org/pages/World-Fuel-Ethanol-Production [Accessed July 3 2014].
ROSEGRANT, M. W. 2008. Biofuels and Grain Prices: Impacts and Policy Responses. . *Testimony for the US Senate Committee on Homeland Security and Government Affairs* Washington, DC: International Food Policy Research Institute (IFPR).
ROSEGRANT, M. W., MSANGI, S., SULSER, T. & VALMONTE-SANTOS, R. 2006. Biofuels and the Global Food Balance. *In:* HAZELL, P. & PACHAURI, J. K. (eds.) *Bioenergy and Agriculture: Promises and Challenges*
ROSEN, S., SHAPOURI, S., QUANBECK, K. & MEADE, B. 2008. *Food Security Assessment, 2007*, US Department of Agriculture, Economic Research Service.
ROSENTHAL, R. E. 2012. GAMS Tutorial *GAMS - A User's Guide.* Washington DC, USA: GAMS Development Corporation.
ROSILLO-CALLE, F. & WALTER, A. 2006. Global market for bioethanol: historical trends and future prospects. *Energy for Sustainable Development,* 10**,** 20-32.
ROTHMAN, H., GREENSHIELDS, R. & ROSILLO, C. F. 1983. *Energy from alcohol: the Brazilian experience*, University Press of Kentucky.
SAMBO, A. S. 2009. Strategic Developments in Renewable Energy in Nigeria. *International Association of Energy Economics***,** 15 - 19.

SCHMER, M. R., VOGEL, K. P., MITCHELL, R. B. & PERRIN, R. K. 2008. Net energy of cellulosic ethanol from switchgrass. *Proceedings of the National Academy of Sciences,* 105**,** 464-469.

SHAPOURI, H., DUFFIELD, J., MCALOON, A. & WANG, M. 2001. THE 2001 NET ENERGY BALANCE OF CORN-ETHANOL. *Agricultural Economic Report.* Washington, USA: USDA.

SHAPOURI, H., DUFFIELD, J. A. & WANG, M. 2002b. The Energy Balance of Corn Ethanol: An Update. *Agricultural Economic Report* United States Department of Agriculture (USDA).

SHAPOURI, H. & GALLAGHER, P. 2005. USDA's 2002 Ethanol Cost-of-Production Survey. *Agricultural Economic Report.* United States Department of Agriculture (USDA).

SHAPOURI, H., GALLAGHER, P. & GRABOSKI, M. S. 2002a. USDA´s 1998 Ethanol Cost-of-Production Survey. *Agricultural Economic Report.* Washington, USA: USDA.

SHAPOURI, H., GALLAGHER, P., NEFSTEAD, W., SCHWARTZ, R., NOE, S. & CONWAY, R. 2010. 2008 Energy Balance for the Corn-Ethanol Industry. *Agricultural Economic Report.* Washington, USA: USDA.

SHAPOURI, S. & ROSEN, S. 1997. *International Agriculture and Trade Reports,* Washington, USA, United States Department of Agriculture, Economic Research Service (USDA-ERS).

SMEETS, E. M. W., FAAIJ, A. P. C., LEWANDOWSKI, I. M. & TURKENBURG, W. C. 2007. A bottom-up assessment and review of global bio-energy potentials to 2050. *Progress in Energy and Combustion Science,* 33**,** 56-106.

SRIROTH, K., PIYACHOMKWAN, K., WANLAPATIT, S. & NIVITCHANYONG, S. 2010. The promise of a technology revolution in cassava bioethanol: From Thai practice to the world practice. *Fuel,* 89**,** 1333-1338.

TIMILSINA, G. R., BEGHIN, J. C., VAN DER MENSBRUGGHE, D. & MEVEL, S. 2012. The impacts of biofuels targets on land use change and food supply: A global CGE assessment. *Agricultural Economics,* 43**,** 315-332.

TIMILSINA, G. R., MEVEL, S. & SHRESTHA, A. 2011. Oil price, biofuels and food supply. *Energy Policy,* 39**,** 8098-8105.

TURNER, B. L. & BRUSH, S. B. 1987. *Comparative farming systems*, Guilford Press.

UNCTAD 2006. UNCTAD Biofuels Initiative: Opportunity for Developing Countries. Geneva, Switzerland: United Nations Conference on Trade and Development.

UNDP 2001. The Millenium Development Goals - MDG. United Nations Development Programme.

UNFCCC 1998. The Kyoto Protocol. Kyoto, Japan: United Nations.

UNFCCC 2005. CONFERENCE OF THE PARTIES SERVING AS THE MEETING OF THE PARTIES TO THE KYOTO PROTOCOL. Montreal, Canada: Uniited Nations Framework Conventions on Climate Change (UNFCCC).

UNSTAT 2011. Nigeria Country Profile. United Nations Statistical Division.

USA 2005. Energy Policy Act *In:* ENERGY (ed.). U.S. Department of Energy.

USDA-ARS. 2013. *National Nutrient Data Laboratory* [Online]. USA: United States Depertment of Agriculutre, Agricultural Research Service. Available: http://ndb.nal.usda.gov/ndb/search/list

http://www.nal.usda.gov/fnic/foodcomp/search/ [Accessed 16/09/ 2013].

USDA-ERS 1996. ERS Report on Cross-Price Elasticities of Demand Across 114 Countries (TB-1925), using the 1996 ICP data. . USA: United States Department of Agriculture , Economic Research Service.

VON BRAUN, J. 2008. Biofuels, International Food Prices, and the Poor. . *Testimony to the United States Committe on Energy and Natural Resources.* Washington, DC: International Food Policy Research Institute (IFPRI).

VON BRAUN, J. & PACHAURI, J. K. 2006. The Promises and Challenges of Biofuels for the Poor in Developing Countires

In: VON BRAUN, J. & PACHAURI, J. K. (eds.) *Essay: The Promises and Challenges of Biofuels for the Poor in Developing Countires.* Washington, DC: Internation Food Policy and Research Institute (IFPRI).

WALLACE, R., IBSEN, K., MCALOON, A. & YEE, W. 2005. Feasibility Study for Co-Locating and Integrating Ethanol Production Plants from Corn Starch and Lignocellulosic Feedstocks. Colorado, USA: National Renewable Energy Laboratory (NREL).

WALTER, A., ROSILLO-CALLE, F., DOLZAN, P. B., PIACENTE, E. & BORGES DA, K. 2007. Task 40 Sustainable Bio-energy Trade; securing Supply and Demand, Deliverable 8; Market Evaluation: Fuel Ethanol. *IEA Bioenergy.* International Energy Agency (IEA).

WBSTAT 2011. Nigeria profile. World Bank Statistical Division.

WONG, J. 2007. US Energy Policies: what is currently being done and what needs to be done? Presentation made to the Embassy of Sweden & Swedish Trade Council on Creating Sustainable Cities. *In:* ENERGY (ed.). Washington, D.C

WTO. 2013. *The General Agreement on Tariffs and Trade (GATT)* [Online]. Geneva, Switzerland: World Trade Organisation (WTO). Available: http://www.wto.org/english/tratop_e/gatt_e/gatt_e.htm [Accessed December 11 2013].

YOOSIN, S. & SORAPIPATANA, C. 2007. A study of ethanol production cost for gasoline substitution in Thailand and its competitiveness. *Thammasat Int J Sci Technol,* 12**,** 69-80.

ZILBERMAN, D., HOCHMAN, G., RAJAGOPAL, D., SEXTON, S. & TIMILSINA, G. 2013. The impact of biofuels on commodity food prices: Assessment of findings. *American Journal of Agricultural Economics,* 95**,** 275-281.

Appendices

Appendix 1: The Models' Input Tables:

Appendix 1.1, TABLE Y (C, R) REGIONAL AVERAGE CROP YIELDS (MT PER HA)

	NW	**NE**	**NC**	**SW**	**SS**	**SE**
MAIZE	4.57	1.67	1.61	1.68	1.77	2.37
CASSAVA	9.93	11.06	12.82	14.78	10.73	12.22
POTATO	3.27	3.27	3.27	3.27	3.27	3.27
YAM	11.96	7.98	10.35	12.13	9.57	12.88
COCOYAM	6.18	3.59	7.70	6.84	4.12	8.32
PLANTAIN	6.10	6.10	6.10	6.10	6.10	6.10
BEANS	0.71	0.94	1.27	0.71	1.22	0.39
SORGHUM	1.29	1.23	1.06	0.70	0.00	0.00
SUGARCANE	25.31	10.89	9.07	12.04	7.32	18.13
WHEAT	1.49	1.49	1.49	1.49	1.49	1.49
MILLET	1.03	1.43	1.13	1.59	0.00	0.00
RICE	2.40	1.53	2.05	1.48	5.26	2.56
GROUNDNUT	0.85	1.28	1.90	1.05	0.78	0.73
COTTON	1.42	1.44	1.25	0.99	0.00	0.00
SESAME	0.37	0.50	0.38	0.00	0.00	0.00
SOYBEAN	1.36	2.05	1.62	0.88	0.00	0.00
COCOA	0.00	0.37	0.27	0.29	0.22	0.24
CASHEW	1.76	0.80	1.33	0.49	0.99	0.78
RUBBER	0.00	0.00	0.49	0.87	0.63	0.82
OIL-PALM	0.41	0.38	0.74	0.80	0.75	0.78
MELON	2.82	0.89	0.99	0.96	0.44	0.44

Appendix 1.2, TABLE DP (C, R) OUTPUT DOMESTIC REAL FARMGATE PRICES (US$ PER MT)

	NW	NE	NC	SW	SS	SE
MAIZE	117	117	117	117	117	117
CASSAVA	85	85	85	85	85	85
POTATO	330	330	330	330	330	330
YAM	130	130	130	130	130	130
COCOYAM	111	111	111	111	111	111
PLANTAIN	618	618	618	618	618	618
BEANS	122	122	122	122	122	122
SORGHUM	118	118	118	118	118	118
SUGARCANE	116	116	116	116	116	116
WHEAT	390	390	390	390	390	390
MILLET	111	111	111	111	111	111
RICE	132	132	132	132	132	132
GROUNDNUT	126	126	126	126	126	126
COTTON	399	399	399	399	399	399
SESAME	272	272	272	272	272	272
SOYBEAN	272	272	272	272	272	272
COCOA	687	687	687	687	687	687
CASHEW	253	253	253	253	253	253
RUBBER	386	386	386	386	386	386
OIL-PALM	680	680	680	680	680	680
MELON	190	190	190	190	190	190

Appendix 1.3, TABLE DCP (C, R) REGIONAL DOMESTIC CROP PRODUCTION (MT PER Yr)

	NW	**NE**	**NC**	**SW**	**SS**	**SE**
MAIZE	2852317	1525507	1396757	707647	472237	468430
CASSAVA	2214215	2551303	9489083	7328383	7712223	7097350
POTATO						
YAM	1921043	2240173	8873227	4774353	4458733	5415357
COCOYAM	7207	13872	236627	1133270	580023	867673
PLANTAIN						
BEANS	871877	788493	452317	14408	977	3257
SORGHUM	2621190	1681370	983467	24947		
SUGARCANE	1134887	110173	89247	20547	46840	3143
WHEAT						
MILLET	2370730	1785643	408768	2703		
RICE	1100427	801633	1137643	76733	84482	297473
GROUNDNUT	974803	859067	1041600	9040	7783	7590
COTTON	362707	145113	23440	483		
SESAME	41600	17070	62210			
SOYBEAN	167523	24403	194697	4007		
COCOA		5753	2433	254423	97797	3377
CASHEW	15267	1180	46953	11543	9133	23393
RUBBER			143	8850	37480	297
OIL-PALM	3610	6050	116613	351073	411870	346997
MELON	1990	22513	212530	46242	48850	49497

Appendix 1.4, TABLE PED (C, R) CROP PRICE ELASTICITY OF DEMAND

	NW	**NE**	**NC**	**SW**	**SS**	**SE**
MAIZE	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
CASSAVA	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
POTATO	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
YAM	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
COCOYAM	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
PLANTAIN	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14
BEANS	-0.31	-0.31	-0.31	-0.31	-0.31	-0.31
SORGHUM	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
SUGARCANE	-0.303	-0.303	-0.303	-0.303	-0.303	-0.303
WHEAT	-0.337	-0.337	-0.337	-0.337	-0.337	-0.337
MILLET	-0.337	-0.337	-0.337	-0.337	-0.337	-0.337
RICE	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
GROUNDNUT	-0.305	-0.305	-0.305	-0.305	-0.305	-0.305
COTTON	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
SESAME	-0.305	-0.305	-0.305	-0.305	-0.305	-0.305
SOYBEAN	-0.305	-0.305	-0.305	-0.305	-0.305	-0.305
COCOA	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14
CASHEW	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14
RUBBER	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14
OIL-PALM	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14
MELON	-0.14	-0.14	-0.14	-0.14	-0.14	-0.14

Appendix 1.5, TABLE EXP (C, R) COMMODITY REAL EXPORT PRICES (US$ PER MT)

	NW	**NE**	**NC**	**SW**	**SS**	**SE**
MAIZE	117	117	117	117	117	117
CASSAVA	85	85	85	85	85	85
POTATO	273	273	273	273	273	273
YAM	130	130	130	130	130	130
COCOYAM	111	111	111	111	111	111
PLANTAIN	320	320	320	320	320	320
BEANS	122	122	122	122	122	122
SORGHUM	118	118	118	118	118	118
SUGARCANE	116	116	116	116	116	116
WHEAT	192	192	192	192	192	192
MILLET	111	111	111	111	111	111
RICE	132	132	132	132	132	132
GROUNDNUT	126	126	126	126	126	126
COTTON	399	399	399	399	399	399
SESAME	272	272	272	272	272	272
SOYBEAN	207	207	207	207	207	207
COCOA	687	687	687	687	687	687
CASHEW	253	253	253	253	253	253
RUBBER	386	386	386	386	386	386
OIL-PALM	680	680	680	680	680	680
MELON	190	190	190	190	190	190

Appendix 1.6, TABLE IMP (C, R) COMMODITY REAL IMPORT PRICES (US$ PER MT)

	NW	**NE**	**NC**	**SW**	**SS**	**SE**
MAIZE	129	129	129	129	129	129
CASSAVA	93	93	93	93	93	93
POTATO	300	300	300	300	300	300
YAM	143	143	143	143	143	143
COCOYAM	122	122	122	122	122	122
PLANTAIN	353	353	353	353	353	353
BEANS	134	134	134	134	134	134
SORGHUM	130	130	130	130	130	130
SUGARCANE	127	127	127	127	127	127
WHEAT	212	212	212	212	212	212
MILLET	122	122	122	122	122	122
RICE	145	145	145	145	145	145
GROUNDNUT	138	138	138	138	138	138
COTTON	438	438	438	438	438	438
SESAME	299	299	299	299	299	299
SOYBEAN	228	228	228	228	228	228
COCOA	755	755	755	755	755	755
CASHEW	279	279	279	279	279	279
RUBBER	425	425	425	425	425	425
OIL-PALM	748	748	748	748	748	748
MELON	209	209	209	209	209	209

Appendix 1.7, TABLE EXD (C, R) AVEREAGE REGIONAL EXPORT DEMAND (MT PER YR)

	NW	NE	NC	SW	SS	SE
MAIZE	6.31	3.38	3.09	1.57	1.04	1.04
CASSAVA	7.37	8.5	31.6	24.4	25.68	23.63
YAM	0.2	0.23	0.93	0.5	0.47	0.56
COCOYAM	0.22	0.43	7.38	35.33	18.08	27.05
BEANS	19.78	17.89	10.26	0.33	0.02	0.07
SORGHUM	2.22	1.43	0.83	0.02		
SUGARCANE	44.42	22.95	18.59	4.28	9.76	3.65
MILLET	1.25	0.94	0.21	0.002		
RICE	75.19	54.77	77.73	15.24	15.77	20.33
GROUNDNUT	8.96	7.9	9.57	0.08	0.07	0.07
COTTON	118.64	107.5	33.52	0.69		
SESAME	920	463	600			
SOYBEAN	47.14	13.74	58.79	12.26		
COCOA		576.32	243.62	900.61	809.57	338.08
CASHEW	134.16	100.99	260.09	107.06	100.09	109.4
RUBBER			34.4	27.19	21.52	9.11
OILPALM	0.23	0.38	7.28	21.93	25.73	21.67
MELON						

Appendix 1.8, TABLE IMD (C, R) AVEREAGE REGIONAL IMPORT DEMAND (MT PER YR)

	NW	NE	NC	SW	SS	SE
POTATO	500.4	265.3	283.4	385.7	293.8	229.1
PLANTAIN	711.1	377.0	402.8	548.1	417.6	325.6
BEANS	246.2	130.5	139.4	189.8	144.6	112.7
WHEAT	455.9	241.7	258.3	351.4		
MILLET	0.3	0.2	0.2	0.2		
RICE	540.7	286.7	306.3	416.8	317.5	247.5
GROUNDNUT	11.0	5.8	6.2	8.5	6.5	5.1
COTTON	41.3	21.9	23.4			
SESAME	96.3	51.1	54.6			
SOYBEAN	206.2	109.3	116.8	159.0		
COCOA		73.4	78.4	100.6	81.3	63.3
RUBBER			29.1	39.6	30.1	23.5
OILPALM	160.2	84.9	90.9	123.5	94.1	73.3
MELON						

Appendix 1.9, TABLE RE (B, R) AVERAGE REGIONAL FIXED RESOURCE ENDOWNMENTS

	NW	NE	NC	SW	SS	SE
LAN (ha)	18299782	24165794	19533498	6622909	7291991	2498026
LAB (pers)	22027818	9610344	7495854	3562984	7548086	10432639
TRAC (units)	6415	5270	10408	6064	5741	6102

Appendix 1.10, TABLE BR (B, R) AVERAGE REGIONAL BASE RESOURCE USE

	NW	NE	NC	SW	SS	SE
LAN (ha)	8716425	6289383	5982128	3000395	2792808	2037848
LAB (pers)	18127820	7908844	6168723	2932162	6211707	8585553
TRAC (units)	6415	5270	10408	6064	5741	6102

Appendix 1.11, TABLE RR1 (C, B, ´NW´) NW RESOURCE REQUIREMENT (Coefficients)

*	LAN (ha)	LAB (pers)	SEED (MT)	FERT (MT)	PEST (MT)	TRAC (day)
MAIZE	1	2.08	0.02	0.003	0.002	0
CASSAVA	1	2.08	1.5	0.003	0.002	0
POTATO	1	2.08	0.85	0.003	0.002	0
YAM	1	2.08	2.25	0.003	0.002	0
COCOYAM	1	2.08	0.75	0.003	0.002	0
PLANTAIN	1	2.08	2.5	0.003	0.002	0
BEANS	1	2.08	0.02	0.003	0.002	0
SORGHUM	1	2.08	0.02	0.003	0.002	0
SUGARCANE	1	2.08	0.46	0.003	0.002	0
WHEAT	1	2.08	0.02	0.003	0.002	0
MILLET	1	2.08	0.02	0.003	0.002	0
RICE	1	2.08	0.02	0.003	0.002	0
GROUNDNUT	1	2.08	0.02	0.003	0.002	0
COTTON	1	2.08	0.01	0.003	0.002	0
SESAME	1	2.08	0.03	0.003	0.002	0
SOYBEAN	1	2.08	0.03	0.003	0.002	0
CASHEW	1	2.08	0.02	0.003	0.002	0
RUBBER	0	0	0	0.000	0	0
OIL-PALM	1	2.08	0.02	0.003	0.002	0
MELON	1	2.08	0.01	0.003	0.002	0

Appendix 1.12, TABLE RR2 (C, B, ´NE´) NE RESOURCE REQUIREMENT (Coefficients)

*	LAN (ha)	LAB (pers)	SEED (MT)	FERT (MT)	PEST (MT)	TRAC (day)
MAIZE	1	1.3	0.02	0.002	0.001	0
CASSAVA	1	1.3	1.5	0.002	0.001	0
POTATO	1	1.3	0.85	0.002	0.001	0
YAM	1	1.3	2.25	0.002	0.001	0
COCOYAM	1	1.3	0.75	0.002	0.001	0
PLANTAIN	1	1.3	2.5	0.002	0.001	0
BEANS	1	1.3	0.02	0.002	0.001	0
SORGHUM	1	1.3	0.02	0.002	0.001	0
SUGARCANE	1	1.3	0.46	0.002	0.001	0
WHEAT	1	1.3	0.02	0.002	0.001	0
MILLET	1	1.3	0.02	0.002	0.001	0
RICE	1	1.3	0.02	0.002	0.001	0
GROUNDNUT	1	1.3	0.02	0.002	0.001	0
COTTON	1	1.3	0.01	0.002	0.001	0
SESAME	1	1.3	0.03	0.002	0.001	0
SOYBEAN	1	1.3	0.03	0.002	0.001	0
COCOA	1	1.3	0.02	0.002	0.001	0
CASHEW	1	1.3	0.02	0.002	0.001	0
OIL-PALM	1	1.3	0.02	0.002	0.001	0
MELON	1	1.3	0.01	0.002	0.001	0

Appendix 1.13, TABLE RR3 (C, B, ´NC´) NC RESOURCE REQUIREMENT (Coefficients)

*	LAN (ha)	LAB (pers)	SEED (MT)	FERT (MT)	PEST (MT)	TRAC (day)
MAIZE	1	1.03	0.02	0.004	0.002	0
CASSAVA	1	1.03	1.5	0.004	0.002	0
POTATO	1	1.03	0.85	0.004	0.002	0
YAM	1	1.03	2.25	0.004	0.002	0
COCOYAM	1	1.03	0.75	0.004	0.002	0
PLANTAIN	1	1.03	2.5	0.004	0.002	0
BEANS	1	1.03	0.02	0.004	0.002	0
SORGHUM	1	1.03	0.02	0.004	0.002	0
SUGARCANE	1	1.03	0.46	0.004	0.002	0
WHEAT	1	1.03	0.02	0.004	0.002	0
MILLET	1	1.03	0.02	0.004	0.002	0
RICE	1	1.03	0.02	0.004	0.002	0
GROUNDNUT	1	1.03	0.02	0.004	0.002	0
COTTON	1	1.03	0.01	0.004	0.002	0
SESAME	1	1.03	0.03	0.004	0.002	0
SOYBEAN	1	1.03	0.03	0.004	0.002	0
COCOA	1	1.03	0.02	0.004	0.002	0
CASHEW	1	1.03	0.02	0.004	0.002	0
RUBBER	1	1.03	0.02	0.004	0.002	0
OIL-PALM	1	1.03	0.02	0.004	0.002	0
MELON	1	1.03	0.01	0.004	0.002	0

Appendix 1.14, TABLE RR4 (C, B, ´SW´) SW RESOURCE REQUIREMENT (Coefficients)

*	LAN (ha)	LAB (pers)	SEED (MT)	FERT (MT)	PEST (MT)	TRAC (day)
MAIZE	1	0.98	0.02	0.003	0.003	0
CASSAVA	1	0.98	1.5	0.003	0.003	0
POTATO	1	0.98	0.85	0.003	0.003	0
YAM	1	0.98	2.25	0.003	0.003	0
COCOYAM	1	0.98	0.75	0.003	0.003	0
PLANTAIN	1	0.98	2.5	0.003	0.003	0
BEANS	1	0.98	0.02	0.003	0.003	0
SORGHUM	1	0.98	0.02	0.003	0.003	0
SUGARCANE	1	0.98	0.46	0.003	0.003	0
WHEAT	1	0.98	0.02	0.003	0.003	0
MILLET	1	0.98	0.02	0.003	0.003	0
RICE	1	0.98	0.02	0.003	0.003	0
GROUNDNUT	1	0.98	0.02	0.003	0.003	0
COTTON	1	0.98	0.01	0.003	0.003	0
SOYBEAN	1	0.98	0.03	0.003	0.003	0
COCOA	1	0.98	0.02	0.003	0.003	0
CASHEW	1	0.98	0.02	0.003	0.003	0
RUBBER	1	0.98	0.02	0.003	0.003	0
OIL-PALM	1	0.98	0.02	0.003	0.003	0
MELON	1	0.98	0.01	0.003	0.003	0

Appendix 1.15, TABLE RR5 (C, B, ´SS´) SS RESOURCE REQUIREMENT (Coefficients)

*	LAN (ha)	LAB (pers)	SEED (MT)	FERT (MT)	PEST (MT)	TRAC (day)
MAIZE	1	2.22	0.02	0.003	0.002	0
CASSAVA	1	2.22	1.5	0.003	0.002	0
POTATO	1	2.22	0.85	0.003	0.002	0
YAM	1	2.22	2.25	0.003	0.002	0
COCOYAM	1	2.22	0.75	0.003	0.002	0
PLANTAIN	1	2.22	2.5	0.003	0.002	0
BEANS	1	2.22	0.02	0.003	0.002	0
SUGARCANE	1	2.22	0.46	0.003	0.002	0
RICE	1	2.22	0.02	0.003	0.002	0
GROUNDNUT	1	2.22	0.02	0.003	0.002	0
COCOA	1	2.22	0.02	0.003	0.002	0
CASHEW	1	2.22	0.02	0.003	0.002	0
RUBBER	1	2.22	0.02	0.003	0.002	0
OIL-PALM	1	2.22	0.02	0.003	0.002	0
MELON	1	2.22	0.01	0.003	0.002	0

Appendix 1.16, TABLE RR6 (C, B, ´SE´) SE RESOURCE REQUIREMENT (Coefficients)

*	LAN (ha)	LAB (pers)	SEED (MT)	FERT (MT)	PEST (MT)	TRAC (day)
MAIZE	1	4.21	0.02	0.002	0.001	0
CASSAVA	1	4.21	1.5	0.002	0.001	0
POTATO	1	4.21	0.85	0.002	0.001	0
YAM	1	4.21	2.25	0.002	0.001	0
COCOYAM	1	4.21	0.75	0.002	0.001	0
PLANTAIN	1	4.21	2.5	0.002	0.001	0
BEANS	1	4.21	0.02	0.002	0.001	0
SUGARCANE	1	4.21	0.46	0.002	0.001	0
RICE	1	4.21	0.02	0.002	0.001	0
GROUNDNUT	1	4.21	0.02	0.002	0.001	0
COCOA	1	4.21	0.02	0.002	0.001	0
CASHEW	1	4.21	0.02	0.002	0.001	0
RUBBER	1	4.21	0.02	0.002	0.001	0
OIL-PALM	1	4.21	0.02	0.002	0.001	0
MELON	1	4.21	0.01	0.002	0.001	0

Appendix 1.17, TABLE RC (B, R) AVERAGE REGIONAL PER UNIT RESOURCE COSTS (US$)

*	**NW** (US$)	**NE** (US$)	**NC** (US$)	**SW** (US$)	**SS** (US$)	**SE** (US$)
LAN	345	246	296	443	394	493
LAB	4.5	4.5	4.5	4.5	4.5	4.5
SEED	680	680	680	680	680	680
FERT	500	500	500	500	500	500
PEST	0.3	0.3	0.3	0.3	0.3	0.3
CASH	30%	30%	30%	30%	30%	30%
TRAC	345	246	296	443	394	493

Appendix 1.18, TABLE EPF (E, EP, R´) REGIONAL ETHANOL PRODUCTION FACTORS

*	GCE (Li/Mt)	GFDS (gm/Li)	SGR	RCE (Li/Mt)	RFDS (gm/Li)	VCG (US$/Li)	VCR (US$/Li)	EREV. (US$/Li)
MAIZE	410	2.4	1.	290	3.4	.11	.8	.57
CASSAVA	180	5.6	.25	280	3.6	.11	.8	.57
POTATO	125	8.	.25	280	3.6	.11	.8	.57
SORGHUM	402	2.5	1.5	270	3.7	.11	.8	.57
SUGARCANE	81	12.3	.25	280	3.6	.11	.8	.57
WHEAT	389	2.6	1.5	290	3.4	.11	.8	.57
MILLET	389	2.6	1.5	290	3.4	.11	.8	.57
RICE	430	2.3	1.5	280	3.6	.11	.8	.57

Appendix 1.19, Table RegTransC (R,R) Regional Crop Transportation Cost (US$ per MT)

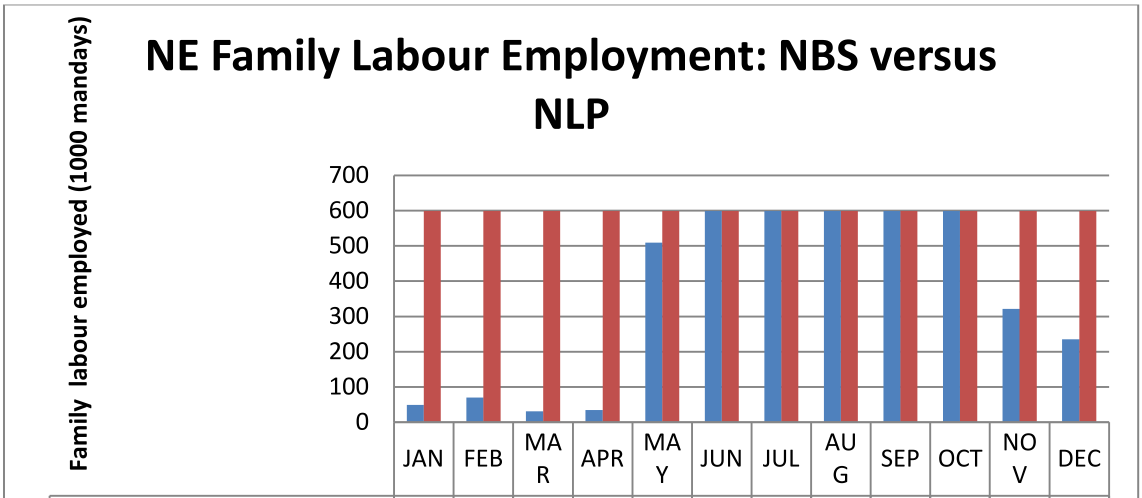
	NW	NE	NC	SW	SS	SE
NW	0.00	26.27	32.84	52.55	65.68	59.11
NE	26.27	0.00	32.84	45.98	59.11	52.55
NC	32.84	26.27	0.00	39.41	52.55	45.98
SW	52.55	45.98	39.41	0.00	32.84	26.27
SS	65.68	59.11	52.55	32.84	0.00	13.14
SE	59.11	52.55	45.98	26.27	13.14	0.00

Appendix 2, Average Regional Crop-farming Labour Distribution in Nigeria b/w 2008 and 2010

Item Description/Region	NW	NE	NC	SW	SS	SE	Nig
Farm Holder (1000 persons)	5,094	3,146	2,453	1,474	2,055	1,905	16,127
Percentage Regional Farm Holder	32	20	15	9	13	12	100
Family Labour (1000 persons)	7,336	4,048	3,514	1,300	3,239	5,064	24,501
Percentage Regional Family Labour	30	17	14	5	13	21	100
Hired Labour (1000 persons)	5,698	715	201	184	918	1,616	9,332
Percentage Regional Hired Labour	61	8	2	2	10	17	100
Total Regional Labour Used (1000 persons)	18,189	7,945	6,198	2,972	6,238	8,618	50,160
% Regional Labour to Total Labour	36.3	15.8	12.4	5.9	12.4	17.2	100.0

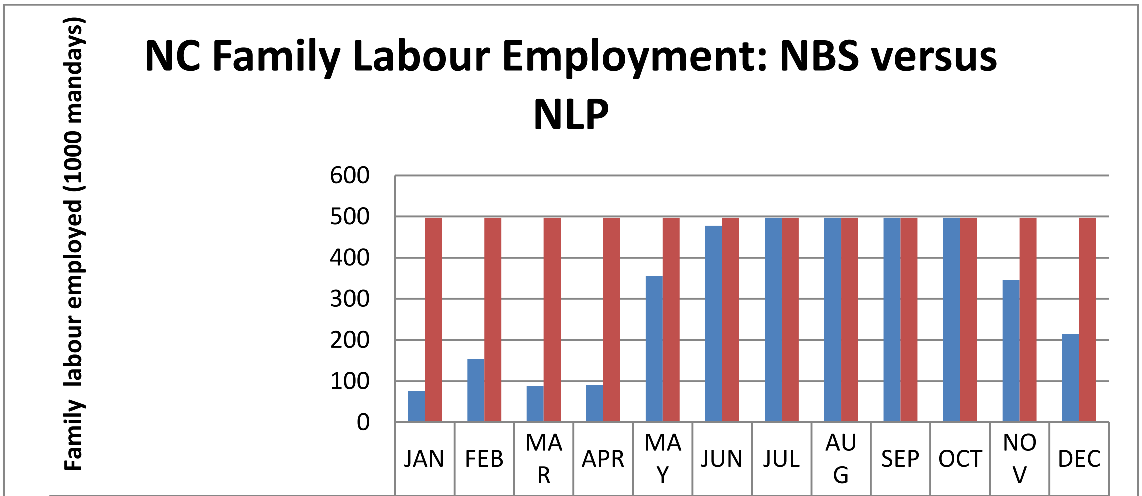
Appendix 3, Regional Labour Employment at the Base Year (Figures 4.7b to 4.7f):

Appendix 3.1 (Figure 4.7b) NE Family Labour Employment



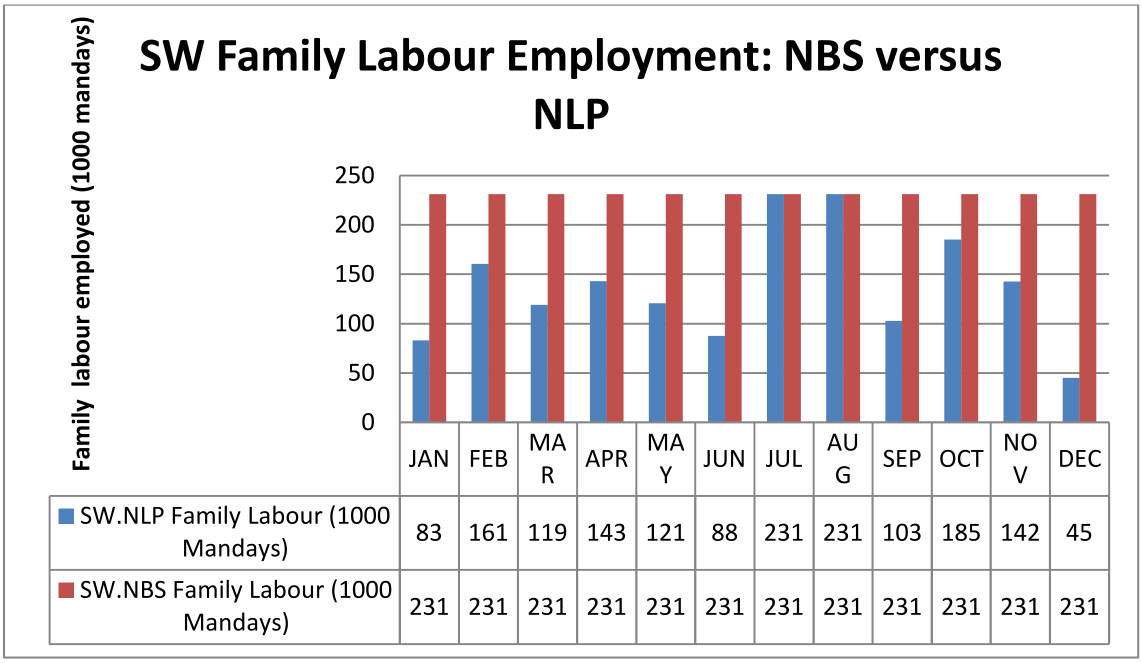
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NE.NLP Family Labour (1000 Mandays)	49	70	31	35	509	599	599	599	599	599	321	235
NE.NBS Family Labour (1000 Mandays)	599	599	599	599	599	599	599	599	599	599	599	599

Appendix 3.2 (Figure 4.7c) NC Family Labour Employment



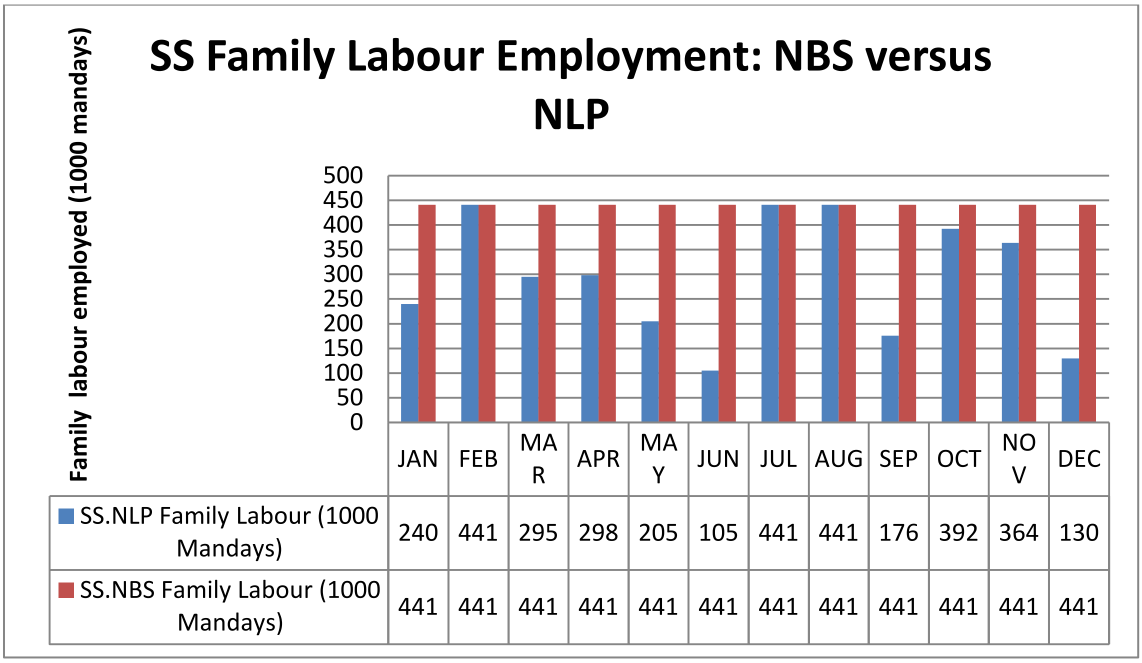
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NC.NLP Family Labour (1000 Mandays)	76	154	88	91	356	478	497	497	497	497	346	215
NC.NBS Family Labour (1000 Mandays)	497	497	497	497	497	497	497	497	497	497	497	497

Appendix 3.3 (Figure 4.7d) SW Family Labour Employment



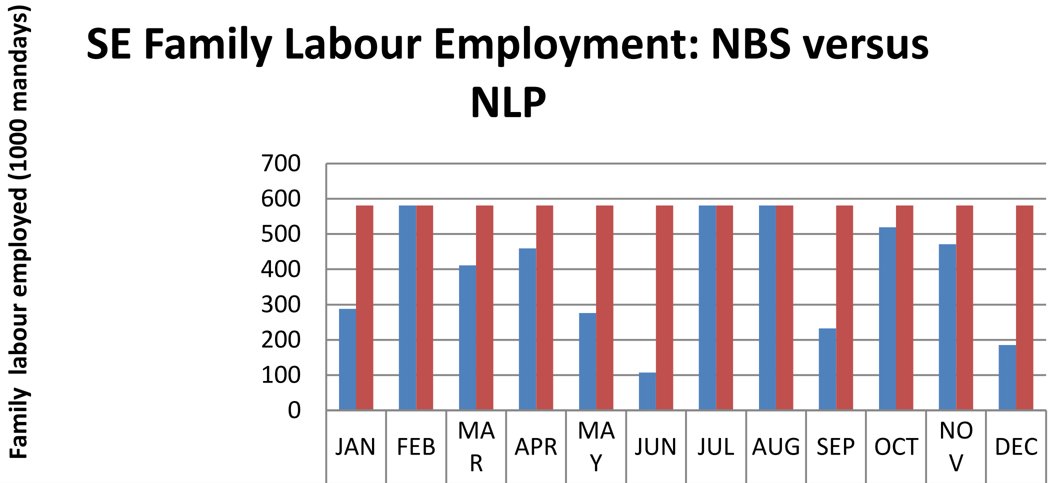
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SW.NLP Family Labour (1000 Mandays)	83	161	119	143	121	88	231	231	103	185	142	45
SW.NBS Family Labour (1000 Mandays)	231	231	231	231	231	231	231	231	231	231	231	231

Appendix 3.4 (Figure 4.7e) SS Family Labour Employment



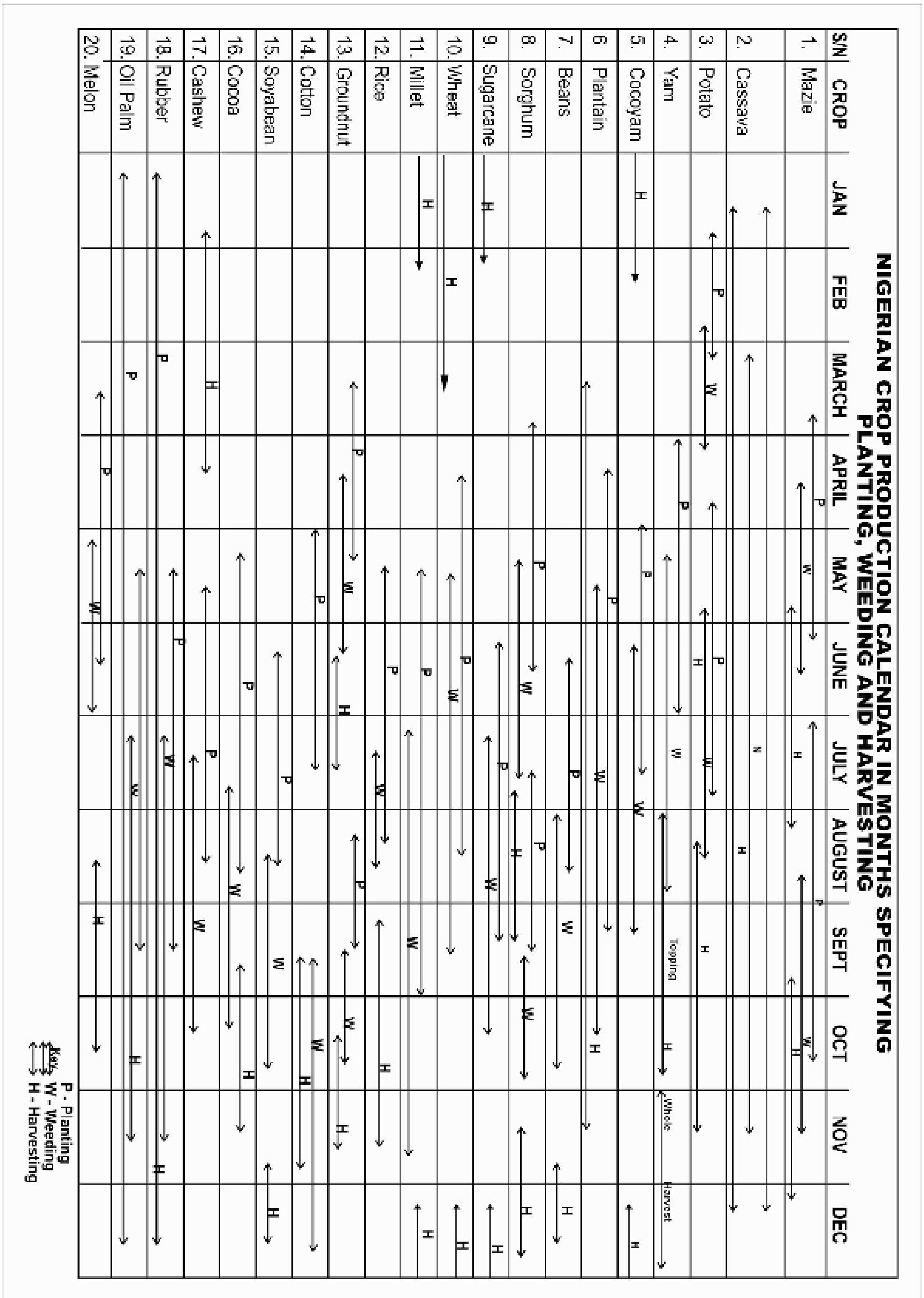
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SS.NLP Family Labour (1000 Mandays)	240	441	295	298	205	105	441	441	176	392	364	130
SS.NBS Family Labour (1000 Mandays)	441	441	441	441	441	441	441	441	441	441	441	441

Appendix 3.5 (Figure 4.7f) SE Family Labour Employment

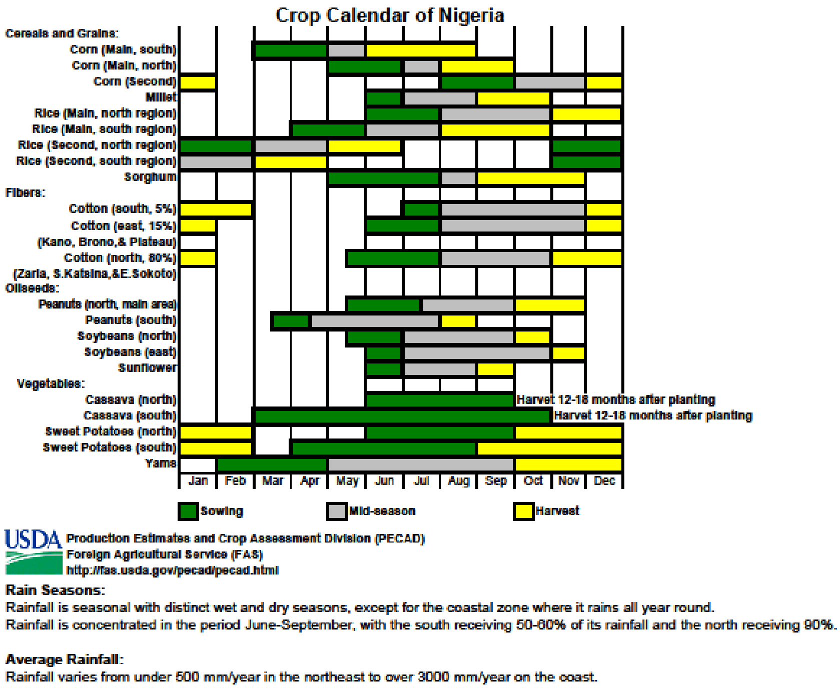


	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SE.NLP Family Labour (1000 Mandays)	288	581	411	460	276	107	581	581	232	519	471	185
SE.NBS Family Labour (1000 Mandays)	581	581	581	581	581	581	581	581	581	581	581	581

Appendix 4a, Nigerian Cropping Calendar from Abia State ADP



Appendix 4b, Nigerian Cropping Calendar from USDA, accessed from the website below:
http://www.pecad.fas.usda.gov/cropexplorer/al/wafrica_crop_cal.htm

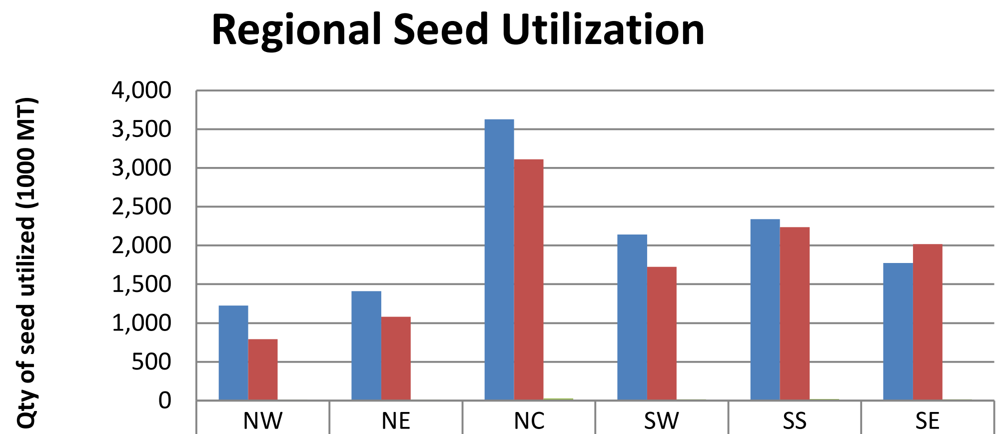


Appendix 5: Continuation of Base Year Resource Allocation

Appendix 5.1: Base Model Seed Utilization

In terms of seed utilization, Figure 1 shows that the seed used in the model is greater than that of the observed data due to the fact that more crops were produced in the model than reported in the observed (NBS) data. The figure also shows that NC used the highest quantity of seed, followed by SS, SE and SW. North-West utilized the least quantity of seed following after NE. In general, more seeds were used in the southern part (SW, SS and SE) than in the core northern part (NW and NE), due to the fact that heavier tuber and tree crops are majorly grown in the southern part with more humid climate. On the regional basis, NC utilized the highest quantity of seed (29%), followed by the SS (19%) and the SE (14%). The NE utilized 11% of total seed applied while NW applied the least quantity of seed (10%).

Appendix 5.1 (Figure 1), Regional Comparison of NLP and NBS (Observed) Seed Utilization Data



	NW	NE	NC	SW	SS	SE
NLP Seed (1000 MT)	1,224	1,413	3,629	2,140	2,338	1,774
NBS Seed (1000 MT)	791	1,082	3,112	1,724	2,237	2,019
Baseyr Reg. % share	10	11	29	17	19	14

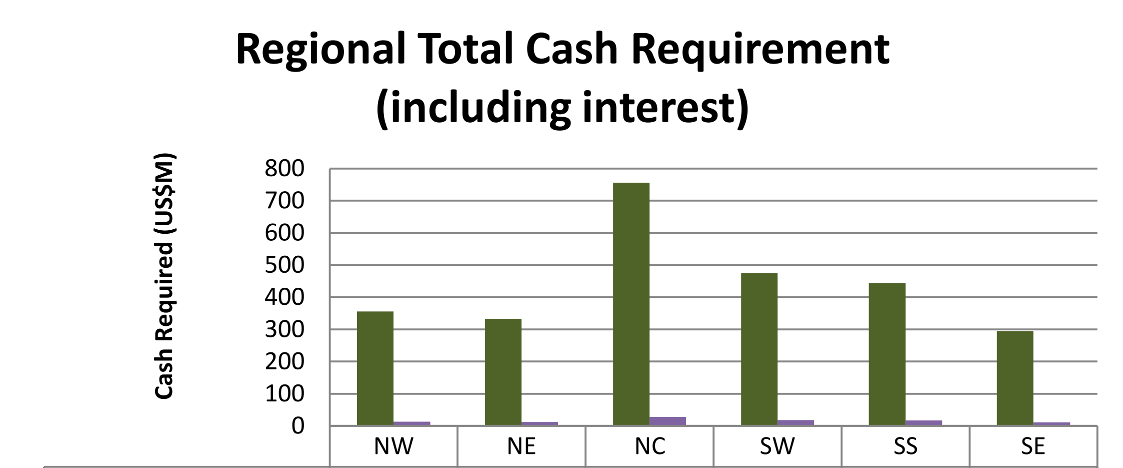
Appendix 5.2: Base Model Cash Capital Requirement

Although not reported in the NBS (observed) data, the regional cash required to fund all the farm operations (including interest paid on borrowed funds) prior to harvest and sale of the farm produce is implemented in the models. Estimation of the total regional funds can assist the government's allocation of the available national funds (N50 billion agricultural fiscal policy incentive set aside to provide soft loans to farmers)[18]. Expectedly, the result (Figure 2a) shows that NC will require the greatest amount of cash to fund farm operations among other regions. North-Central share of the total cash required is 28%. Following NC, in a descending order, are SW (18%), SS (17%) and NW (13%). The SE will require the least amount of cash (11%), coming behind NE with 12.5% share of the total cash required. Figure 2b further shows that cash required for seed purchase constitutes the highest component of the total cash required in all the regions. Seed cost is therefore the most significant part of the regional cost of production, followed by the cost of borrowed cash capital (interest). Hence, the cash required by the southern region (SW, SS and SE) which cultivates the bulk of the heavier tuber and tree crops is higher than that of the core northern region (NW and NE) which produces majority of the less-bulky cereals. The North Central region has the highest share due to its unique ability to cultivate/produce both southern and northern

[18] The Official Gazette of the Nigerian Biofuel Policy and Incentive (NNPCRED, 2007, p.15) reports that Nigerian government has set aside N50 billion for the Central Bank of Nigeria (CBN) to provide of single-digit-interest loans to farmers in order to support and boost agricultural production; while The New Nigerian Agricultural Policy (NNAP, 2001) highlights numerous input incentive supports to farmers such as provision of seeds, fertilizer, tractors to farmers at very reduced price.

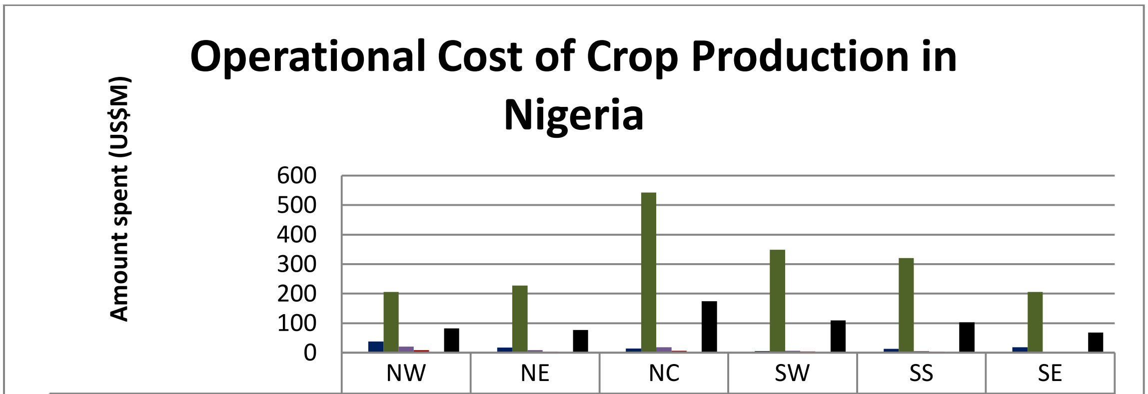
crops, given her northern and southern climatic and soil conditions advantage as earlier explained in Section 2.1.3. The result implies that the cost of producing crops in Nigeria will be significantly reduced (and farming becomes more profitable) if government's agricultural policy (incentive or subsidy) is geared towards providing free viable seeds as well as providing them with interest-free (or at least single digit interest) loan to farmers.

Appendix 5.2a (Figure 2a), Base year Regional Cash Requirement.



	NW	NE	NC	SW	SS	SE
NLP Total Cash (US$M)	356	332	756	475	444	295
Reg. % share	13.4	12.5	28.4	17.9	16.7	11.1

Appendix 5.2b (Figure 2b), Regional Cost of Crop Production for the Base Model.



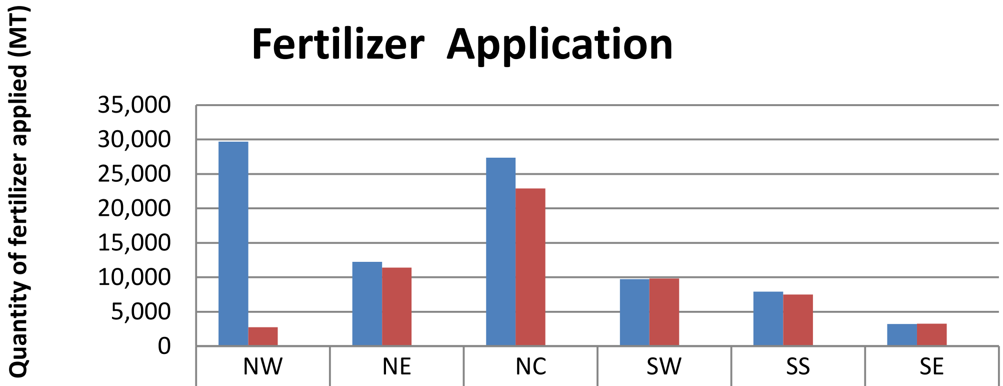
	NW	NE	NC	SW	SS	SE
LAND RENT (US$M)	0	0	0	0	0	0
LABOUR (US$M)	38	17	14	6	13	18
SEED (US$M)	206	227	542	349	320	206
FERTILIZER (US$M)	20	8	19	7	5	2
PESTICIDE (US$M)	9	3	7	5	3	1
TRACTOR HIRE (US$M)	0	0	0	0	0	0
CASH INTEREST (US$M)	82	77	174	110	103	68

Appendix 5.3: Base Model Fertilizer and Pesticide Application

Figure 3a indicates an increase in fertilizer application over the base year level due to the fact that additional crops which were not reported in the base year crop production data were included in the base model as explained earlier at the data reconciliation section. Thus the prescribed fertilizer utilization is consistent with the base year fertilizer application data. Northwest applied the highest quantity of fertilizer (33%), followed by NC (30%) and NE (14%). Southwest, SS and SE fertilizer application shares are 11%, 9% and 4%, respectively.

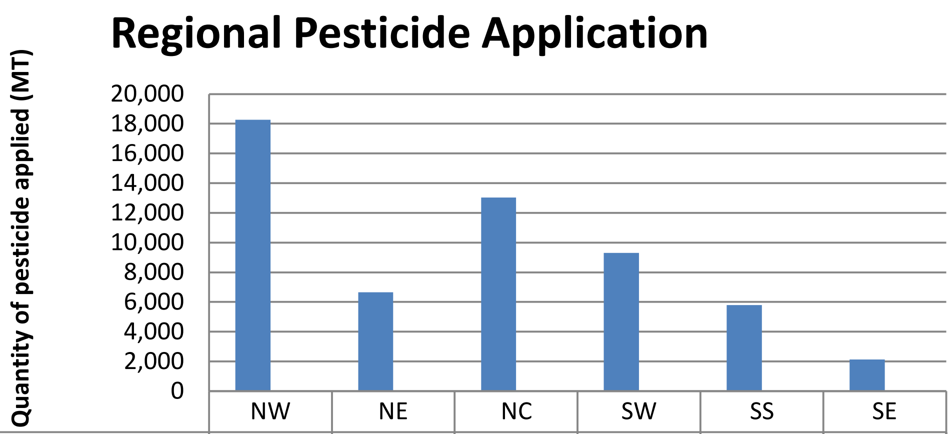
Pesticide application data were not available in the reference crop production data from (NBS, 2010b). However, to achieve optimum crop yield, we recognise the need for pesticide application in order to prevent existing and disturbing plant pests (e.g. stem borer, aphids, army worms) and diseases such as yam root-rot (nematodes), cassava mosaic/blight, rice blast, and others (ICS-Nigeria/IITA, 2011). In fact, an interaction with the Head of Crop Production Department of Abia State ADP during the study field trip revealed that pesticides and herbicides are actually used in crop production in the SE and other regions, but added that lack of proper usage records (data) are widespread among peasant farmers across the nation. Examples of the identified frequently used pesticides (insecticides) are Azodrin®/Nuvacron®, Vetrox®85/Furadan for army worms and stem borers' insecticides, respectively; and Primextra®/Lasso/Attrazine® for herbicides (ICS-Nigeria/IITA, 2011). Therefore application of pesticides/herbicides was considered for the production of crops in the NLP models. The quantity prescribed by the NLP base model for application (based on the recommended rates from different literature (ICS-Nigeria/IITA, 2011)) are as shown in Figure 3b. From the result (Figure 3b), the NW will apply the highest amount of pesticides/herbicides (33% of the applied total), followed by the NC (24%) and then the SW (17%), in a descending order. The SE will utilize the least quantity of pesticide/herbicide (4%), while NE and SS will utilize 12% and 10% of the applied total, respectively.

Appendix 5.3a (Figure 3a), Regional Fertilizer Application for the Base Model.



	NW	NE	NC	SW	SS	SE
NLP Fert.(MT)	29,679	12,260	27,363	9,731	7,906	3,199
NBS Fert. (MT)	2,732	11,423	22,892	9,806	7,519	3,280
Baseyr Reg. % share	33	14	30	11	9	4

Appendix 5.3b (Figure 3b), Regional Pesticide/Herbicide Application for the Base Model.



	NW	NE	NC	SW	SS	SE
Baseyr NLP Pesticide (MT)	18,264	6,663	13,030	9,297	5,792	2,133
Baseyr Reg. % share	33	12	24	17	10	4

Appendix 6, Regional Crop Production Levels (1000 MT) from the Baseline (S0) Model

Crops	**NW (1000 MT)**	**NE (1000 MT)**	**NC (1000 MT)**	**SW (1000 MT)**	**SS (1000 MT)**	**SE (1000 MT)**
MAIZE	2,852	1,526	1,397	708	472	468
CASSAVA	8,879	11,352	16,603	9,740	10,368	8,007
POTATO	1,254	1,104	1,339	12	11	10
YAM	1,921	2,240	8,873	4,774	4,459	5,415
COCOYAM	7	14	237	1,133	580	868
PLANTAIN	176	202	750	580	610	561
BEANS	872	789	452	15	1	3
SORGHUM	2,621	1,681	983	25	N/A	N/A
SUGARCANE	1,135	110	89	21	47	3
WHEAT	479	259	262	351	N/A	N/A
MILLET	2,371	1,786	409	3	N/A	N/A
RICE	1,209	859	1,199	160	148	347
GROUNDNUT	975	859	1,042	9	8	8
COTTON	363	145	23	0.5	N/A	N/A
SESAME	155	64	231	N/A	N/A	N/A
SOYBEAN	170	25	196	6	N/A	N/A
COCOA	N/A	6	3	255	99	4
CASHEW	39	3	119	29	23	59
RUBBER	N/A	N/A	3.56	44	174	4
OILPALM	5	7	118	352	413	348
MELON	2	23	213	95	0	49

Appendix 7, Regional Petroleum Products (RPP) Distribution Data from NNPCSTAT (2012), source: http://www.nnpcgroup.com/PublicRelations/OilandGasStatistics/AnnualStatisticsBulletin/MonthlyPerformance.aspx

Region	**% Regional RPP Demand to the Total (National) RPP Demand in 2009**	**2009**	**2010***	**2011***	**2012***
NW	8.8	1,095,873	502,223	555,669	347,545
NE	4.8	604,816	368,443	397,129	242,946
NC	18.5	2,307,722	1,827,802	1,805,544	1,891,588
SW	41.2	5,150,347	3,520,949	3,240,116	2,399,062
SS	22.3	2,788,332	2,023,097	1,973,896	1,712,108
SE	4.4	553,433	234,478	226,662	230,077
National Total (1000 litres)	**100**	**12,500,523**	**8,476,992**	**8,199,017**	**6,823,327**

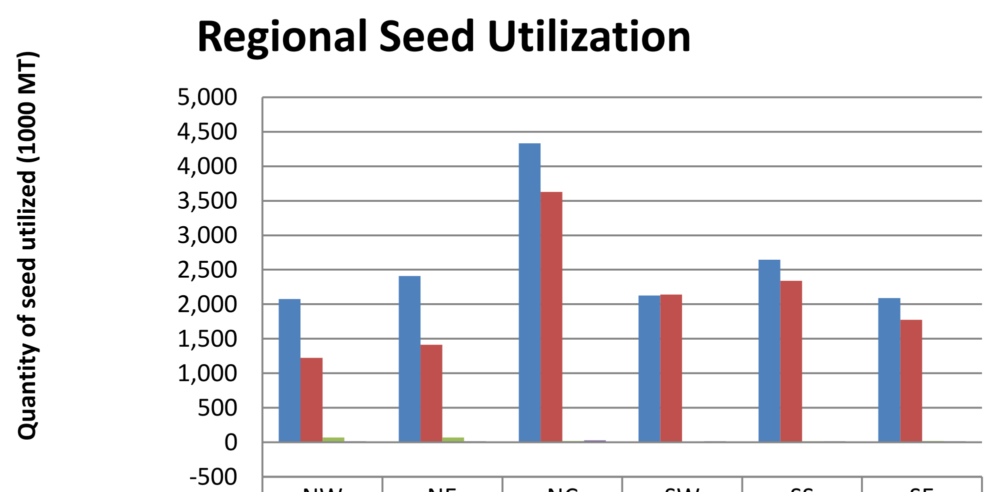
* Note that most marketing companies did not report the quantity of RPP they received and distributed in these years.

Appendix 8, Optimal Seed, Fertilizer, Pesticide and Cash Utilization for the Ethanol-Food Production Model

Appendix 8.1: Optimal Seed Utilization for the Baseline (S0) Model

Expectedly, the optimal seed usage from the Energy-Food Production Model indicates a significant increase in seed use. Compared to the seed used in the base model, Figure 1 shows that NE had the highest increase in seed utilization (71%), followed by the NW and NC with 70% and 19% increments, respectively. The SW used less seed in the Energy-Food Model compared to the Base Model due to changes in the individual crop it produced, while SS used additional 13%, following the SE (18%). The implication of this result is that there might be relatively increase in the demand for viable high-yielding and disease-resistant seeds which might create more competition for seed purchase (or seed acquisition from government) among farmers. However, supply of inputs such as seeds, fertilizer and other agrochemicals, except land and family labour, are perfectly elastic in nature in the short run at a specified cost as observed by Hazell and Norton (1986, Ch.9, p.201) and Minot (2009, p.22). Therefore the increase in seed demand will be immediately met with a corresponding increase in seed supply, thereby neutralizing the associated competition effect on factor prices. The supply of land is perfectly inelastic, while that of family labour and other fixed factors of production such as tractor are inelastic or elastic up to the available quantity.

Appendix 8.1 (Figure 1), Regional Optimal Seed Allocation for the Energy-Food Model

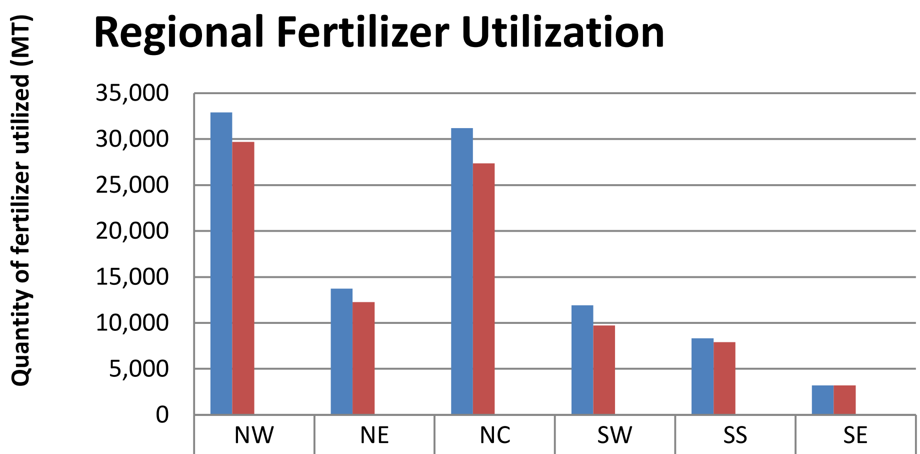


	NW	NE	NC	SW	SS	SE
S0 Seed (1000 MT)	2,078	2,408	4,333	2,128	2,646	2,092
NLP Baseyr Seed (1000 MT)	1,224	1,413	3,629	2,140	2,338	1,774
% Increase in Seed Use with respect to the NLP Baseyr	69.7	70.5	19.4	-0.6	13.2	18.0
% Regional share	13.2	15.4	27.6	13.6	16.9	13.3

Appendix 8.2:Optimal Fertilizer and Pesticide Use for the Baseline Model

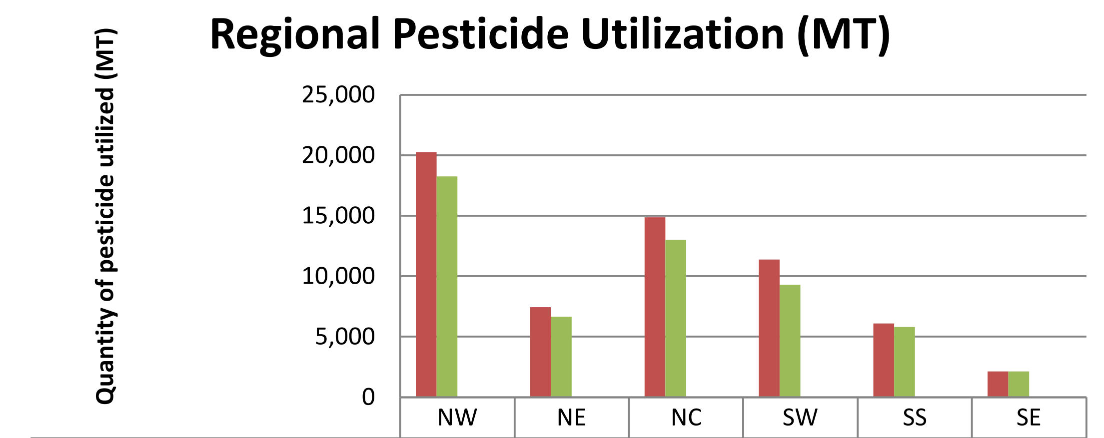
Accordingly, the optimal fertilizer allocation from the ethanol production model indicates a significant increase in fertilizer usage. From Figure 2a, increase in fertilizer usage will be highest in the SW and least in the SE following the land and labour use patterns as expected. As explained earlier in the seed supply section above, the increase in fertilizer demand will be met with a corresponding increase in fertilizer supply since fertilizer supply is perfectly elastic at a given price. Hence, the increase in fertilizer demand when ethanol production is introduced might not push the price of fertilizer up in all the regions, nor lead to an increase in commodity (food) prices. This explanation is applicable to pesticide utilization showed in Figure 2b. Further, Figure 2b shows that the utilization (demand) followed this same pattern as the land and labour use above; thus, indicating consistency in resource use specification. From the figure, the increment in pesticide usage from the base model is highest in the SW, followed by the NC and NE, in a decreasing order. Similarly, South-East has the least increase in pesticide utilization.

Appendix 8.2a (Figure 2a), Regional Optimal Fertilizer Allocation for the Energy-Food Model



	NW	NE	NC	SW	SS	SE
S0 Fertilizer (MT)	32,909	13,717	31,198	11,909	8,311	3,205
NLP Baseyr Fertilizer (MT)	29,679	12,260	27,363	9,731	7,906	3,199
% Increase in seed use with respect to the NLP Baseyr	10.9	11.9	14.0	22.4	5.1	0.2
% Regional share	32.5	13.5	30.8	11.8	8.2	3.2

Appendix 8.2b (Figure 2b), Optimal Pesticide Allocation for the Energy-Food Model

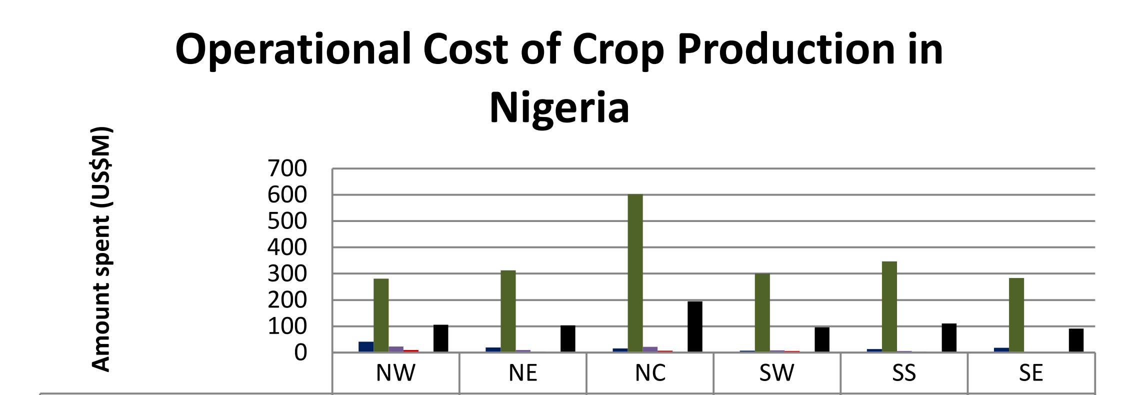


	NW	NE	NC	SW	SS	SE
S0 Pesticide (MT)	20,252	7,455	14,856	11,378	6,089	2,137
NLP Baseyr Pesticide (MT)	18,264	6,663	13,030	9,297	5,792	2,133
% Increase in Pesticide Use with respect to the NLP Baseyr	10.9	11.9	14.0	22.4	5.1	0.2
% Regional share	32.6	12.0	23.9	18.3	9.8	3.4

Appendix 8.3:Optimal Cash Capital Requirement for the Baseline Model

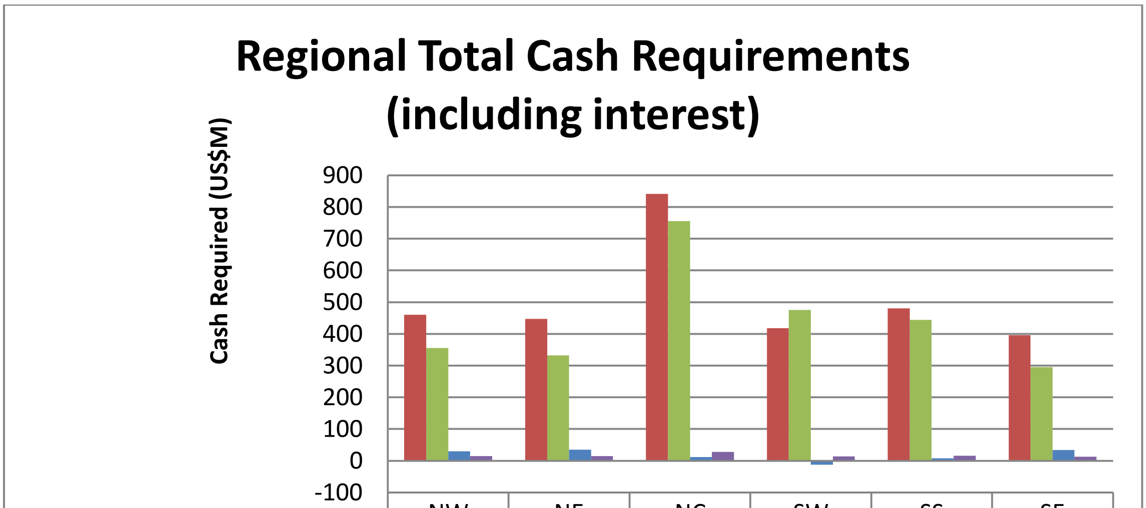
The optimum cash needed to actualise the crop-to-ethanol production model's results are shown in Figure 3b. The Figure shows that the cash required by the regions to fund their production activities prior to harvest has increased from their respective base year cash requirements, except in the SW due to the reduction in its seed requirement. It also indicates that the NE will require the largest amount of cash (US$447M – a 34% increase from the base year cash requirement) to fund her production activities while the SW will need the least amount (US$418M) among other regions. North-West will require the second largest amount of cash (US$461M) – a 30% increase in the cash it required in the base model. As said earlier in the base model cash requirement discussion, the cash requirement information can guide the national government on how much that is needed by farmers to actualise the contemplated ethanol production programme, in terms of funding the food and feedstock production activities. On the other hand, Figure 3a highlights the cost of each production activity undertaken to produce the required food and feedstock demand levels. Like the base year operational cost, seed cost is remarkably higher than other cost components; and this is followed by interest paid on borrowed cash capital. As remarked earlier, the result implies that reduction in seed and/or cash capital costs will make the crop farming business in Nigeria less expensive and consequently more profitable. Hence, government support plan, if any, could be focused on this direction.

Appendix 8.3a (Figure 3a), Regional Operational Cost for the Energy-Food Model



	NW	NE	NC	SW	SS	SE
LAND RENT (US$M)	0	0	0	0	0	0
LABOUR (US$M)	41	19	16	7	13	18
SEED (US$M)	281	312	602	301	347	283
FERTILIZER (US$M)	22	9	21	8	6	2
PESTICIDE (US$M)	10	4	7	6	3	1
TRACTOR HIRE (US$M)	0	0	0	0	0	0
CASH INTEREST (US$M)	106	103	194	97	111	91

Appendix 8.3b (Figure 3b), Regional Optimal Required Cash for the Energy-Food Model



	NW	NE	NC	SW	SS	SE
S0 Cash (US$M)	461	447	841	418	480	396
NLP Baseyr Cash (US$M)	356	332	756	475	444	295
% Increase in Cash Use with respect to the NLP Baseyr	29.6	34.4	11.3	-12.0	8.1	34.1
% Regional share	15.1	14.7	27.6	13.7	15.8	13.0

Appendix 9, Regional Shadow Prices for the Demand-Supply Balance in the Energy-Food Model

Crops	**NWSP ($)**	**NESP ($)**	**NCSP ($)**	**SWSP ($)**	**SSSP ($)**	**SESP ($)**
MAIZE	117.00	117.00	117.00	117.00	117.00	117.00
CASSAVA	84.70	84.70	84.70	84.70	84.70	84.70
POTATO	272.80	272.80	272.80	272.80	272.80	272.80
YAM	129.90	129.90	129.90	129.90	129.90	129.90
COCOYAM	111.30	111.30	111.30	111.30	111.30	111.30
PLANTAIN	320.50	320.50	320.50	320.50	320.50	320.50
BEANS	122.00	122.00	122.00	122.00	122.00	122.00
SORGHUM	118.30	118.30	118.30	118.30	N/A	N/A
SUGARCANE	115.80	115.80	115.80	115.80	115.80	115.80
WHEAT	192.50	192.50	192.50	192.50	N/A	N/A
MILLET	111.30	111.30	111.30	111.30	N/A	N/A
RICE	132.00	132.00	132.00	132.00	132.00	132.00
GROUNDNUT	125.50	125.50	125.50	125.50	125.50	125.50
COTTON	398.50	398.50	398.50	398.50	N/A	N/A
SESAME	271.60	271.60	271.60	N/A	N/A	N/A
SOYBEAN	206.90	206.90	206.90	206.90	N/A	N/A
COCOA	N/A	686.50	686.50	686.50	686.50	686.50
CASHEW	253.20	253.20	253.20	253.20	253.20	253.20
RUBBER	N/A	N/A	386.30	386.30	386.30	386.30
OILPALM	679.90	679.90	679.90	679.90	679.90	679.90
MELON	190.00	190.00	190.00	190.00	190.00	190.00

Appendix 10a, Regional Import Reduced Costs from the Energy-Food Model

Crops	**NWRC ($)**	**NERC ($)**	**NCRC ($)**	**SWRC ($)**	**SSRC ($)**	**SERC ($)**
MAIZE	-142.47	-140.56	-139.25	-141.80	-140.96	-141.68
CASSAVA	-86.18	-88.04	-89.66	-93.35	-89.55	-91.06
POTATO	-253.24	-254.78	-254.25	-256.55	-255.24	-253.70
YAM	-127.76	-112.03	-122.96	-130.72	-121.76	-131.95
COCOYAM	-116.43	-103.73	-120.68	-121.05	-108.87	-123.12
PLANTAIN	-239.67	-240.38	-239.98	-242.33	-241.98	-241.59
BEANS	-130.56	-140.11	-141.20	-137.27	-141.27	-110.50
SORGHUM	-134.93	-138.03	-135.00	-132.80	N/A	N/A
SUGARCANE	-138.74	-134.95	-133.36	-137.72	-133.14	-139.49
WHEAT	-232.93	-235.90	-234.56	-237.14	N/A	N/A
MILLET	-123.97	-129.91	-126.55	-131.82	N/A	N/A
RICE	-157.40	-156.99	-157.66	-158.11	-162.88	-159.01
GROUNDNUT	-138.09	-147.37	-148.78	-147.07	-140.73	-136.69
COTTON	-503.25	-506.87	-504.17	-504.53	N/A	N/A
SESAME	-291.58	-315.01	-299.46	N/A	N/A	N/A
SOYBEAN	-248.66	-255.33	-252.31	-246.98	N/A	N/A
COCOA	N/A	-808.57	-807.18	-783.99	-783.97	-815.87
CASHEW	-313.56	-307.62	-312.38	-297.16	-308.93	-300.18
RUBBER	N/A	N/A	-462.71	-481.39	-470.27	-474.81
OILPALM	-820.30	-825.36	-852.23	-857.73	-852.62	-851.27
MELON	-234.83	-229.54	-228.75	-231.29	-198.45	-202.98

Appendix 10b, Regional Export Shadow Prices from the Energy-Food Model

Crops	**NWSP ($)**	**NESP ($)**	**NCSP ($)**	**SWSP ($)**	**SSSP ($)**	**SESP ($)**
MAIZE	80.43	78.52	77.21	79.76	78.92	79.64
CASSAVA	42.10	43.96	45.58	49.27	45.47	46.98
POTATO	111.36	112.90	112.37	114.67	113.36	111.82
YAM	60.20	44.47	55.40	63.16	54.20	64.39
COCOYAM	58.59	45.89	62.84	63.21	51.03	65.28
PLANTAIN	73.07	73.78	73.38	75.73	75.38	74.99
BEANS	67.12	76.67	77.76	73.83	77.83	47.06
SORGHUM	73.45	76.55	73.52	71.32	N/A	N/A
SUGARCANE	78.50	74.71	73.12	77.48	72.90	79.25
WHEAT	132.89	135.86	134.52	137.10	N/A	N/A
MILLET	66.13	72.07	68.71	73.98	N/A	N/A
RICE	88.76	88.35	89.02	89.47	94.24	90.37
GROUNDNUT	72.77	82.05	83.46	81.75	75.41	71.37
COTTON	295.97	299.59	296.89	297.25	N/A	N/A
SESAME	150.30	173.73	158.18	N/A	N/A	N/A
SOYBEAN	141.18	147.85	144.83	139.50	N/A	N/A
COCOA	N/A	451.53	450.14	426.95	426.93	458.83
CASHEW	181.92	175.98	180.74	165.52	177.29	168.54
RUBBER	N/A	N/A	261.87	280.55	269.43	273.97
OILPALM	466.74	471.80	498.67	504.17	499.06	497.71
MELON	136.03	130.74	129.95	132.49	99.65	104.18

Appendix 11a, Scenarios Results (only national results are presented here for brevity, unless otherwise stated)

Scenario Parameter	Total GM (US$B)	Ethanol Produced (MLi)	Ethanol GM excluding co-products (US$B)[1]	Selected Feedstock	Cultivated National Land (1000 ha)	Annual Average Land Rent (US$)	Total Labour Employed (1000 hours)	Tractor Service Employed (1000 hours)	Product Domestic Prices (US$)	Exports (1000 MT)	Imports (1000 MT)
S0	45.71	5,140	2.36	Cassava in all regions	33,983	See Appendix 11c	255,381 service hours equivalent	Zero	Same as the actual product prices	Same as base year export levels	Zero
S1	45.76 (0.12% increase from S0 level)	As in S0 (5,140)	As in S0	Wheat in NW and Cassava in other regions	35,136 (3% increase from S0 level)	See Appendix 11c for details	274,945 (8% increase from S0 service hours equivalent)	Zero as in S0	As in S0	As in S0	Zero as in S0
S2	42.54 (7% decrease from S0 level)	As in S0 (5,140)	As in S0	Wheat in NW, Sugarcane in NE and Cassava in others regions	21,614 (36% decrease from S0)	See Appendix 11c for details	157,710 (38% decrease from S0 service hours equivalent)	28,963	As in S0	Decreased by 33% from S0 level	Increased by 595% from S0 level
S3	91.16 (99% increase from S0 level)	10,280 (double of S0 level)	4.73 (double of S0 level)	Wheat in NW and Cassava in others regions	67,037 (97% increase in S0 level)	See Appendix 11c for details	495,716 (94% increase from S0 service hours equivalent)	Zero as in S0	As in S0	As in S0	Zero as in S0

Appendix 11b, Sensitivity Analyses Results (only national results are presented here for brevity, unless otherwise stated)

Scenario Parameter	Total GM (US$B)[1]	Ethanol Produced (MLi)	Ethanol GM excluding co-products (US$B)	Selected Feedstock	Cultivated National Land (1000 ha)	Annual Average Land Rent (US$)	Total Labour Employed (1000 hours)	Tractor Service Employed (1000 hours)	Product Domestic Prices (US$)	Exports (1000 MT)	Imports (1000 MT)
S4	45.52 (0.43% decrease from S0 level)	As in S0	As in S0	As in S1: Wheat in NW and Cassava in others regions	32,572 (4% decrease from S0 level)	See Appendix 11c for details	247,121 (3% decrease from S0 service hours equivalent)	Zero as in S0	As in S0	33% decrease from S0 level	Zero as in S0
S5	89.21 (95% increase from S0 level)	10,280 (double of S0 level)	4.73 (double of S0 level)	As in S1: Wheat in NW and Cassava in others regions	64,882 (91% increase from S0 level)	See Appendix 11c for details	470,590 (84% increase from S0 level)	Zero as in S0	As in S0	As in S0	Zero as in S0
S6	45.38 (0.72% decrease from S0 level)	As in S0	As in S0	Cassava in all the regions	32,270 (5% decrease from S0 level)	See Appendix 11c for details	248,711 (3% decrease from S0 service hours equivalent)	Zero as in S0	As in S0	29% decrease from S0 level	Zero as in S0

Appendices 11a and 11b Key:

[1] Total GM excludes ethanol co-products and off-farm employment revenues;

S0 represents the 1st Energy-Food Model simulation run;

S1 denotes the Mechanization 1 scenario run;

S2 stands for the Mechanization 2 scenario run;

S3 signifies the simultaneous implementation of double base-year domestic consumption and double S0 ethanol demand demands due to future population and economic growths;

S4 denotes the implementation of imposed land rent sensitivity on additional land used;

S5 represents the simultaneous implementation of S3 and S4; and

S6 stands for the implementation of double labour rent sensitivity alongside the uniform land rent and 1st mechanization scenario.

Appendix 11c, Regional Shadow Prices of Land (Land Rents) in US$

	NW	NE	NC	SW	SS	SE
Base Model Regional annul land rents (US$)	70	95	64	52	53	86
S0 Regional annul land rents (US$)	0	0	0	0	0	0
S1 Regional annul land rents (US$)	0	0	0	0	0	9
S2 Regional annul land rents (US$)	0	0	0	0	0	24
S3 Regional annul land rents (US$)	15	0	0	3.2	-4.2	79
S4 Regional annul land rents (US$)	97	121	104	95	99	126
S5 Regional annul land rents (US$)	104	104	82	104	104	241
S6 Regional annul land rents (US$)	100	104	120	100	100	129

Appendix 12, S2 Regional Crop Production Result (1000 MT)

	NW	NE	NC	SW	SS	SE	Nig DCP (1000 MT)
MAIZE	5,963	0	0	294	225	941	7,423
CASSAVA	2,214	2,551	16,603	9,740	10,368	8,007	49,483
POTATO	1,253	0	1,338	1,116	10	10	3,726
YAM	1,921	2,240	8,873	4,774	4,459	5,415	27,683
COCOYAM	7	14	1,370	0	580	868	2,839
PLANTAIN	0	1,127	0	0	0	1,750	2,876
BEANS	0	0	0	241	1,811	0	2,052
SORGHUM	0	0	0	0	0	N/A	N/A
SUGARCANE	1,135	19,667	89	21	47	3	20,962
WHEAT	3,084	0	0	45	N/A	N/A	3,128
MILLET	0	199	0	1,137	N/A	N/A	1,337
RICE	0	0	0	0	3,124	374	3,498
GROUNDNUT	0	0	605	0	0	0	605
COTTON	0	0	0	532	N/A	N/A	532
SESAME	0	0	0	0	N/A	N/A	N/A
SOYBEAN	0	387	0	4.0	N/A	N/A	391
COCOA	N/A	0	273	0	0	91	364
CASHEW	1	0	0	0	26	245	272
RUBBER	N/A	N/A	0	213	0	0	213
OILPALM	0	0	120	362	683	71	1,236
MELON	382	0	0	0	0	0	382

Appendix 13, S2 Unit Cost of Production (Input Cost) (US$)

	NWIC (US$)	NEIC (US$)	NCIC (US$)	SWIC (US$S)	SSIC (US$)	SEIC (US$)	Nig Ave. IC (US$)
MAIZE	45.58	71.85	154.24	100.32	87.19	74.05	88.88
CASSAVA	34.76	26.82	29.58	20.50	26.76	25.13	27.26
POTATO	168.90	169.90	181.36	126.11	104.02	112.74	143.84
YAM	34.86	51.70	40.06	48.43	60.15	45.74	46.82
COCOYAM	23.54	39.30	18.59	46.20	73.83	38.18	39.94
PLANTAIN	202.21	175.94	202.21	207.26	194.13	180.99	193.79
BEANS	355.54	207.59	231.47	99.73	86.60	99.74	180.11
SORGHUM	146.74	158.18	276.87	147.36	N/A	N/A	182.29
SUGARCANE	12.62	24.03	39.74	11.40	23.54	7.35	19.78
WHEAT	150.10	143.53	136.96	99.74	N/A	N/A	132.58
MILLET	230.61	135.93	259.56	92.14	N/A	N/A	179.56
RICE	70.98	64.41	57.85	51.99	7.49	25.72	46.40
GROUNDNUT	154.77	152.52	154.77	156.96	156.96	156.96	155.49
COTTON	179.74	137.24	237.10	39.02	N/A	N/A	148.28
SESAME	347.61	347.61	347.61	N/A	N/A	N/A	347.61
SOYBEAN	188.63	97.34	184.24	172.36	N/A	N/A	160.64
COCOA	N/A	775.32	176.86	218.46	231.60	218.46	324.14
CASHEW	145.37	248.19	223.60	307.28	109.58	88.45	187.08
RUBBER	N/A	N/A	96.80	59.58	92.42	85.85	83.67
OILPALM	101.92	118.13	69.08	74.34	87.47	100.61	91.92
MELON	13.71	39.98	46.55	68.45	419.23	75.01	110.49

Appendix 14, S2 Opportunity Cost of Crop Production (Individual Crop GM) (US$)

	NWOC (US$)	NEOC (US$)	NCOC (US$)	SWOC (US$S)	SSOC (US$)	SEOC (US$)	Nig Ave. OC (US$)
MAIZE	60.47	34.20	27.63	7.92	21.05	34.19	30.91
CASSAVA	38.99	46.93	44.17	55.44	49.18	50.81	47.59
POTATO	92.95	91.95	80.49	137.93	160.02	151.30	119.11
YAM	84.09	67.25	78.89	72.71	60.99	75.40	73.22
COCOYAM	76.81	61.05	81.76	42.35	28.71	64.36	59.17
PLANTAIN	107.34	133.61	107.34	104.48	117.61	130.75	116.85
BEANS	-39.04	-32.47	-32.48	13.51	26.64	13.50	-8.39
SORGHUM	0.00	-37.82	-37.82	-37.82	N/A	N/A	-28.37
SUGARCANE	92.23	80.82	65.11	95.64	83.50	99.69	86.16
WHEAT	31.45	38.02	44.59	84.00	N/A	N/A	49.51
MILLET	0.00	-35.58	-29.01	10.40	N/A	N/A	-13.55
RICE	50.07	56.64	63.20	71.25	115.75	97.52	75.74
GROUNDNUT	-40.22	-40.22	-40.22	-40.22	-40.22	-40.22	-40.22
COTTON	298.17	304.74	311.31	350.72	N/A	N/A	316.23
SESAME	-86.96	-86.96	-86.96	N/A	N/A	N/A	-86.96
SOYBEAN	72.34	98.61	72.34	25.78	N/A	N/A	67.26
COCOA	N/A	465.85	498.69	459.28	446.14	459.28	465.84
CASHEW	96.88	75.75	110.01	129.72	134.86	155.99	117.20
RUBBER	N/A	N/A	278.55	317.96	285.12	291.69	293.33
OILPALM	567.03	550.82	599.87	596.80	583.67	570.53	578.12
MELON	165.34	139.07	132.50	112.79	99.66	106.23	125.93

Appendix 15, S3 Regional Crop Production Result (1000 MT)

	NW	NE	NC	SW	SS	SE	Nig DCP (1000 MT)
MAIZE	5,705	3,051	2,794	1,863	944	489	14,846
CASSAVA	4,428	22,704	33,205	19,481	20,736	16,014	116,568
POTATO	2,507	2,209	2,678	45	21	0	7,461
YAM	3,842	4,480	17,746	9,549	8,917	10,831	55,366
COCOYAM	14	28	473	2,267	1,160	1,735	5,677
PLANTAIN	0	2,256	0	1,160	1,220	1,123	5,758
BEANS	0	3,321	905	0	38	0	4,265
SORGHUM	5,242	3,363	1,967	50	N/A	N/A	10,622
SUGARCANE	2,270	220	178	41	94	6	2,809
WHEAT	6,167	518	524	1,661	N/A	N/A	8,871
MILLET	4,741	3,571	818	5	N/A	N/A	9,136
RICE	2,417	1,718	2,398	320	990	0	7,843
GROUNDNUT	1,155	2,513	2,083	18	31	0	5,800
COTTON	725	290	47	1.0	N/A	N/A	1,063
SESAME	0	279	294	N/A	N/A	N/A	573
SOYBEAN	339	51	392	11	N/A	N/A	793
COCOA	N/A	7	69	169	126	0	371
CASHEW	54	4	166	0	156	0	380
RUBBER	N/A	N/A	6.72	71	243	0	320
OILPALM	0	24	235	705	1,521	0	2,485
MELON	4	45	425	92	197	0	763

Appendix 16, S3 Unit Cost of Production (Input Cost) (US$)

	NWIC (US$)	NEIC (US$)	NCIC (US$)	SWIC (US$S)	SSIC (US$)	SEIC (US$)	Nig Ave. IC (US$)
MAIZE	4.92	4.37	5.81	7.13	4.14	33.40	9.96
CASSAVA	15.96	12.89	11.28	9.97	13.26	17.39	13.46
POTATO	100.50	94.56	95.14	96.08	95.09	122.35	100.62
YAM	34.03	48.56	37.63	32.35	40.61	36.91	38.35
COCOYAM	21.93	32.33	15.32	17.69	28.44	24.51	23.37
PLANTAIN	198.13	171.86	198.13	172.64	171.82	185.78	183.06
BEANS	36.87	10.60	9.50	40.58	7.74	20.88	21.03
SORGHUM	21.79	7.63	10.91	20.21	N/A	N/A	15.14
SUGARCANE	3.78	7.01	8.65	6.73	10.46	8.96	7.60
WHEAT	61.15	7.59	9.06	10.79	N/A	N/A	22.15
MILLET	25.62	6.44	10.08	8.78	N/A	N/A	12.73
RICE	12.10	6.68	6.01	10.16	1.89	15.03	8.64
GROUNDNUT	34.23	7.96	6.45	13.80	11.42	24.56	16.40
COTTON	22.40	8.65	11.57	16.85	N/A	N/A	14.87
SESAME	60.07	33.80	50.22	N/A	N/A	N/A	48.03
SOYBEAN	24.34	7.01	10.22	21.75	N/A	N/A	15.83
COCOA	N/A	88.99	90.09	131.69	98.85	111.99	104.32
CASHEW	18.17	16.39	11.47	46.06	13.22	124.97	38.38
RUBBER	N/A	N/A	37.19	24.27	25.27	50.54	34.32
OILPALM	88.50	62.23	34.94	35.93	31.40	44.54	49.59
MELON	10.32	10.86	11.77	15.16	22.81	35.95	17.81

Appendix 17, S3 Opportunity Cost of Crop Production (Individual Crop GM) (US$)

	NWOC (US$)	NEOC (US$)	NCOC (US$)	SWOC (US$S)	SSOC (US$)	SEOC (US$)	Nig Ave. OC (US$)
MAIZE	101.13	101.68	100.24	101.11	104.10	74.84	97.18
CASSAVA	57.79	60.86	62.47	65.97	62.68	58.55	61.39
POTATO	161.35	167.29	166.71	167.96	168.95	141.69	162.33
YAM	84.92	70.39	81.32	88.79	80.53	84.23	81.70
COCOYAM	78.42	68.02	85.03	84.85	74.10	78.03	78.08
PLANTAIN	111.42	137.69	111.42	139.10	139.92	125.96	127.58
BEANS	74.18	100.45	101.55	72.66	105.50	92.36	91.12
SORGHUM	85.56	99.72	96.44	89.33	N/A	N/A	92.76
SUGARCANE	101.07	97.84	96.20	100.31	96.58	98.08	98.34
WHEAT	120.40	173.96	172.49	172.95	N/A	N/A	159.95
MILLET	74.73	93.91	90.27	93.76	N/A	N/A	88.17
RICE	108.95	114.37	115.04	113.08	121.35	108.21	113.50
GROUNDNUT	80.32	106.59	108.10	102.94	105.32	92.18	99.24
COTTON	365.15	378.90	375.98	372.89	N/A	N/A	373.23
SESAME	200.58	226.85	210.43	N/A	N/A	N/A	212.62
SOYBEAN	171.61	188.94	185.73	176.39	N/A	N/A	180.67
COCOA	N/A	586.56	585.46	546.05	578.89	565.75	572.54
CASHEW	224.08	225.86	230.78	198.38	231.22	218.08	221.40
RUBBER	N/A	N/A	338.16	353.27	352.27	327.00	342.68
OILPALM	580.45	606.72	634.01	635.21	639.74	626.60	620.45
MELON	168.73	168.19	167.28	166.08	158.43	145.29	162.33

Appendix 18, S4 Regional Crop Production Result (1000 MT)

	NW	NE	NC	SW	SS	SE	Nig DCP (1000 MT)
MAIZE	2,852	1,526	1,397	708	472	468	7,423
CASSAVA	2,214	11,352	16,603	9,740	10,368	8,007	58,284
POTATO	1,254	1,104	1,339	12	11	10	3,731
YAM	1,921	2,240	8,873	4,774	4,459	5,415	27,683
COCOYAM	7	14	237	1,133	580	868	2,839
PLANTAIN	176	202	750	0	0	1,751	2,879
BEANS	342	195	1,575	15	4	0	2,132
SORGHUM	2,621	1,681	1,008	0	N/A	N/A	5,311
SUGARCANE	1,135	110	89	21	47	3	1,405
WHEAT	3,084	259	262	831	N/A	N/A	4,436
MILLET	2,371	1,786	0	411	N/A	N/A	4,568
RICE	1,209	859	1,199	160	148	347	3,921
GROUNDNUT	0	859	2,024	9	8	0	2,900
COTTON	363	145	23	0.5	N/A	N/A	532
SESAME	0	18	105	N/A	N/A	N/A	123
SOYBEAN	170	31	196	0	N/A	N/A	397
COCOA	N/A	0	199	0	0	169	368
CASHEW	101	0	148	0	23	0	272
RUBBER	N/A	N/A	0.00	52	174	0	225
OILPALM	0	0	130	430	683	0	1,242
MELON	306	0	0	76	0	0	382

Appendix 19, S4 Unit Cost of Production (Input Cost) (US$)

	NWIC (US$)	NEIC (US$)	NCIC (US$)	SWIC (US$S)	SSIC (US$)	SEIC (US$)	Nig Ave. IC (US$)
MAIZE	10.38	38.52	33.04	26.78	28.17	31.27	10.38
CASSAVA	18.49	18.02	14.64	12.19	17.15	16.99	18.49
POTATO	109.75	115.40	110.98	108.10	110.38	120.00	109.75
YAM	36.55	57.11	42.63	35.58	45.83	36.44	36.55
COCOYAM	26.82	51.33	22.05	23.42	40.57	23.78	26.82
PLANTAIN	179.88	183.04	180.74	211.15	198.02	184.88	179.88
BEANS	83.11	83.11	50.27	76.16	49.29	62.43	83.11
SORGHUM	45.06	63.05	59.72	101.32	N/A	N/A	45.06
SUGARCANE	4.97	13.29	14.37	10.01	17.36	8.66	4.97
WHEAT	87.63	53.34	43.78	37.27	N/A	N/A	87.63
MILLET	53.16	54.10	70.82	33.60	N/A	N/A	53.16
RICE	24.70	51.23	31.27	36.71	11.48	34.98	24.70
GROUNDNUT	66.46	61.11	33.62	51.23	76.12	81.79	66.46
COTTON	43.53	55.98	52.96	56.65	N/A	N/A	43.53
SESAME	219.21	170.13	186.37	N/A	N/A	N/A	219.21
SOYBEAN	46.41	40.26	42.16	88.43	N/A	N/A	46.41
COCOA	N/A	301.87	269.03	310.63	297.50	284.36	895.29
CASHEW	35.22	101.92	50.37	91.97	64.18	118.86	35.22
RUBBER	N/A	N/A	106.84	69.62	105.01	95.89	498.93
OILPALM	137.90	137.90	105.06	85.26	98.39	111.53	137.90
MELON	20.96	47.23	64.08	55.99	88.83	82.26	20.96

Appendix 20, S4 Opportunity Cost of Crop Production (Individual Crop GM) (US$)

	NWOC (US$)	NEOC (US$)	NCOC (US$)	SWOC (US$S)	SSOC (US$)	SEOC (US$)	Nig Ave. OC (US$)
MAIZE	95.67	67.53	73.01	81.46	80.07	76.97	79.12
CASSAVA	55.26	55.73	59.11	63.75	58.79	58.95	58.60
POTATO	152.10	146.45	150.87	155.94	153.66	144.04	150.51
YAM	82.40	61.84	76.32	85.56	75.31	84.70	77.69
COCOYAM	73.53	49.02	78.30	79.12	61.97	78.76	70.12
PLANTAIN	129.67	126.51	128.81	100.59	113.72	126.86	121.03
BEANS	27.94	27.94	60.78	37.08	63.95	50.81	44.75
SORGHUM	62.29	44.30	47.63	8.22	N/A	N/A	40.61
SUGARCANE	99.88	91.56	90.48	97.03	89.68	98.38	94.50
WHEAT	93.92	128.21	137.77	146.47	N/A	N/A	126.59
MILLET	47.19	46.25	29.53	68.94	N/A	N/A	47.98
RICE	96.35	69.82	89.78	86.53	111.76	88.26	90.42
GROUNDNUT	48.09	53.44	80.93	65.51	40.62	34.95	53.92
COTTON	344.02	331.57	334.59	333.09	N/A	N/A	335.82
SESAME	41.44	90.52	74.28	N/A	N/A	N/A	68.75
SOYBEAN	149.54	155.69	153.79	109.71	N/A	N/A	142.18
COCOA	N/A	373.68	406.52	367.11	380.24	393.38	384.19
CASHEW	207.03	180.76	191.88	152.47	180.26	147.92	176.72
RUBBER	N/A	N/A	268.51	307.92	272.53	281.65	282.65
OILPALM	531.05	531.05	563.89	585.88	572.75	559.61	557.37
MELON	158.09	131.82	125.25	125.25	92.41	98.98	121.97

Appendix 21, S6 Regional Crop Production Result (1000 MT)

	NW	NE	NC	SW	SS	SE	Nig DCP (1000 MT)
MAIZE	2,852	1,526	1,397	708	472	468	7,423
CASSAVA	8,879	11,352	16,603	9,740	10,368	8,007	64,948
POTATO	1,254	1,104	1,339	12	11	10	3,731
YAM	1,921	2,240	8,873	4,774	4,459	5,415	27,683
COCOYAM	7	14	237	1,133	580	868	2,839
PLANTAIN	176	202	750	0	610	1,141	2,879
BEANS	413	1,248	452	15	4	0	2,132
SORGHUM	2,621	1,681	983	25	N/A	N/A	5,311
SUGARCANE	1,135	110	89	21	47	3	1,405
WHEAT	479	259	262	351	N/A	N/A	1,352
MILLET	2,371	1,891	303	3	N/A	N/A	4,568
RICE	1,209	859	1,199	160	148	347	3,921
GROUNDNUT	975	859	1,042	17	8	0	2,900
COTTON	363	145	23	0.5	N/A	N/A	532
SESAME	0	169	0	N/A	N/A	N/A	169
SOYBEAN	170	25	196	6	N/A	N/A	397
COCOA	N/A	91	0	23	48	205	368
CASHEW	42	0	148	0	82	0	272
RUBBER	N/A	N/A	0.00	52	174	0	225
OILPALM	0	0	118	712	413	0	1,242
MELON	237	0	0	145	0	0	382

Appendix 22, S6 Unit Cost of Production (Input Cost) (US$)

	NWIC (US$)	NEIC (US$)	NCIC (US$)	SWIC (US$S)	SSIC (US$)	SEIC (US$)	Nig Ave. IC (US$)
MAIZE	11.81	32.08	42.42	30.35	30.68	35.46	30.47
CASSAVA	19.21	17.09	15.81	12.59	17.56	17.78	16.67
POTATO	113.19	112.05	116.87	110.74	113.03	125.55	115.24
YAM	37.48	55.70	44.48	36.26	46.65	37.72	43.05
COCOYAM	28.60	48.21	24.53	24.63	42.47	25.77	32.37
PLANTAIN	181.43	181.08	183.84	213.34	181.10	187.07	187.97
BEANS	96.71	70.44	64.81	86.75	54.30	67.44	73.41
SORGHUM	51.93	53.19	76.81	86.77	N/A	N/A	67.17
SUGARCANE	5.39	12.24	16.45	10.67	18.31	9.48	12.09
WHEAT	46.25	45.20	55.94	42.06	N/A	N/A	47.36
MILLET	61.29	45.62	71.89	38.09	N/A	N/A	54.22
RICE	28.72	43.45	40.27	41.79	12.64	40.20	34.51
GROUNDNUT	80.90	52.01	43.37	58.02	82.87	84.29	66.91
COTTON	50.90	48.23	68.08	64.24	N/A	N/A	57.86
SESAME	172.14	145.87	172.14	N/A	N/A	N/A	163.38
SOYBEAN	52.93	34.35	53.34	74.70	N/A	N/A	53.83
COCOA	N/A	295.07	321.34	343.24	330.11	316.97	321.34
CASHEW	40.46	86.70	64.45	106.05	70.36	135.97	84.00
RUBBER	N/A	N/A	115.04	77.82	113.37	104.09	102.58
OILPALM	164.24	137.97	129.33	94.18	105.40	120.45	125.26
MELON	24.67	50.94	83.12	64.21	97.05	239.00	93.17

Appendix 23, S6 Opportunity Cost of Crop Production (Individual Crop GM) (US$)

	NWOC (US$)	NEOC (US$)	NCOC (US$)	SWOC (US$S)	SSOC (US$)	SEOC (US$)	Nig Ave. OC (US$)
MAIZE	94.24	73.97	63.63	77.89	77.56	72.78	76.68
CASSAVA	54.54	56.66	57.94	63.35	58.38	58.16	58.17
POTATO	148.66	149.80	144.98	153.30	151.01	138.49	147.71
YAM	81.47	63.25	74.47	84.88	74.49	83.42	77.00
COCOYAM	71.75	52.14	75.82	77.91	60.07	76.77	69.08
PLANTAIN	128.12	128.47	125.71	98.40	130.64	124.67	122.67
BEANS	14.34	40.61	46.24	26.49	58.94	45.80	38.74
SORGHUM	55.42	54.16	30.54	22.77	N/A	N/A	40.72
SUGARCANE	99.46	92.61	88.40	96.37	88.73	97.56	93.86
WHEAT	135.30	136.35	125.61	141.68	N/A	N/A	134.74
MILLET	39.06	54.73	28.46	64.45	N/A	N/A	46.68
RICE	92.33	77.60	80.78	81.45	110.60	83.04	87.63
GROUNDNUT	33.65	62.54	71.18	58.72	33.87	32.45	48.73
COTTON	336.65	339.32	319.47	325.50	N/A	N/A	330.24
SESAME	88.51	114.78	88.51	N/A	N/A	N/A	97.27
SOYBEAN	143.02	161.60	142.61	123.44	N/A	N/A	142.67
COCOA	N/A	380.48	354.21	334.50	347.63	360.77	355.52
CASHEW	201.79	175.52	177.80	138.39	174.08	160.94	171.42
RUBBER	N/A	N/A	260.31	299.72	264.17	273.45	274.41
OILPALM	504.71	530.98	539.62	576.96	565.74	550.69	544.79
MELON	154.38	128.11	121.54	117.03	84.19	90.76	116.00

Appendix 24, Alternative Empirical Method of Estimating and/or Verifying Product prices

Empirically, the product price from the model's solution (shadow price at the commodity balance in Table 4.2a) can also be verified using this formula:

$\pi = \alpha_{j-}\beta_j Q_j = P_j$ ——————————————————————————(63)

where α_j is the estimated demand intercept of crop j available in Appendix 25; Q_j is the quantity demanded (sold) domestically of each crop j (Table 4.2b) and β_j is the absolute (positive) value of the demand slope for each product demanded (Appendix 26). For example, the demand intercept for maize in the NW is US$507, while the absolute value of the demand slope is 0.13673 and the quantity of maize demanded in the region is 2,852 thousand metric tonnes. Substituting these values into equation (63), the domestic market price of maize in the NW will therefore be equal to US$117 (the exact input domestic market price). The price of each product can be verified or estimated using the same procedure. Hence, the principle of commodity balance shadow price being equal to the product market price in an optimal solution is upheld by results from these models.

Appendix 25, Slope of the Demand Curve at Base Year (β_j)

	NW	NE	NC	SW	SS	SE	Nig Ave.
MAIZE	-0.13673	-0.25565	-0.27922	-0.55112	-0.82586	-0.83257	-0.48019
CASSAVA	-0.19126	-0.16599	-0.04463	-0.05779	-0.05491	-0.05967	-0.09571
POTATO	-1.08797	-1.23497	-1.01862	-109.411	-128.069	-132.968	-62.2982
YAM	-0.3381	-0.28993	-0.0732	-0.13604	-0.14567	-0.11994	-0.18381
COCOYAM	-77.219	-40.118	-2.35188	-0.49107	-0.95947	-0.64139	-20.2968
PLANTAIN	-13.0285	-11.3318	-3.05082	-3.9487	-3.75315	-4.07873	-6.53195
BEANS	-0.45126	-0.49904	-0.86982	-26.9601	-350.897	-116.793	-82.745
SORGHUM	-0.15044	-0.23453	-0.40096	-15.8069			-4.1482
SUGARCANE	-0.33682	-3.46961	-4.28314	-18.6041	-8.16093	-121.622	-26.0794
WHEAT	-1.19234	-2.20433	-2.17864	-1.6254			-1.80018
MILLET	-0.13931	-0.18496	-0.80796	-122.175			-30.8267
RICE	-0.54613	-0.76842	-0.55055	-4.12299	-4.46005	-1.90225	-2.0584
GROUNDNUT	-0.42211	-0.47898	-0.39504	-45.4748	-52.825	-54.1773	-25.6289
COTTON	-3.6671	-9.16551	-56.6941	-2754.11			-705.908
SESAME	-20.9214	-50.65	-14.1898				-28.5871
SOYBEAN	-4.00234	-26.6206	-3.46535	-121.261			-38.8374
COCOA		-6752.56	-6284.62	-6475.58	-7064.55	-7788.52	-6873.16
CASHEW	-118.458	-1532.58	-38.519	-156.674	-198.025	-77.3136	-353.596
RUBBER			-872.874	-140.222	-39.6437	-959.631	-503.093
OILPALM	-931.819	-703.947	-41.3272	-13.7856	-11.7652	-13.9671	-286.102
MELON	-681.982	-60.2826	-6.38566	-29.3487	-27.7819	-27.4187	-138.867

Appendix 26, Intercept of the Demand Curve at Base Year (α_j)

	NW	NE	NC	SW	SS	SE	Nig Ave.
MAIZE	507	507	507	507	507	507	507
CASSAVA	508	508	508	508	508	508	508
POTATO	1,637	1,637	1,637	1,637	1,637	1,637	1,637
YAM	779	779	779	779	779	779	779
COCOYAM	668	668	668	668	668	668	668
PLANTAIN	2,610	2,610	2,610	2,610	2,610	2,610	2,610
BEANS	516	516	516	516	516	516	516
SORGHUM	513	513	513	513			513
SUGARCANE	498	498	498	498	498	498	498
WHEAT	764	764	764	764			764
MILLET	442	442	442	442			442
RICE	792	792	792	792	792	792	792
GROUNDNUT	537	537	537	537	537	537	537
COTTON	1,727	1,727	1,727	1,727			1,727
SESAME	1,162	1,162	1,162				1,162
SOYBEAN	885	885	885	885			885
COCOA		5,590	5,590	5,590	5,590	5,590	5,590
CASHEW	2,062	2,062	2,062	2,062	2,062	2,062	2,062
RUBBER			3,146	3,146	3,146	3,146	3,146
OILPALM	5,536	5,536	5,536	5,536	5,536	5,536	5,536
MELON	1,547	1,547	1,547	1,547	1,547	1,547	1,547