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Abstract: The Nigerian government plans to produce bioethanol from its staple food crops to increase transport fuel supply, reduce imported motors fuels, create jobs and diversify its oil-dependent economy. However, the conflicts between the benefits of biofuels and the potential impacts on food security requires analysis to quantify fuel, food, economy and employment metrics to inform policy decision making. Drawing upon a bespoke partial equilibrium model, the Nigerian Energy-Food Model (NEFM), populated using secondary data, indicates that cassava is the 'optimal' feedstock for profitable ethanol production in all six geo-political zones of Nigeria. Results show that Nigeria has the potential to produce sufficient feedstock and food crops to meet the current domestic ethanol and crop consumption demands, without affecting domestic food security in the short-run, due to availability of vast fertile uncultivated arable land and unemployed labour, providing positive energy, economic and employment benefits in the short term. Nevertheless, future expansion of the bioethanol programme to double current national ethanol and food consumption demands, would result in significant impacts on national land-use change, negatively impacting on domestic food production and increasing food prices. It is recommended that Nigeria's future biofuels' policy requires a carefully-articulated land-use policy to ensure that land allocation to bioethanol feedstock production is tempered by the need to allocate arable land to food production, in order to avoid consequential adverse impacts on its food security.

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Analysis of the Inherent Energy-Food Dilemma of the Nigerian Biofuels Policy using Partial Equilibrium Model: The Nigerian Energy-Food Model (NEFM).

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Abstract

The Nigerian government plans to produce bioethanol from its staple food crops to increase transport fuel supply, reduce imported motors fuels, create jobs and diversify its oil-dependent economy. However, the conflicts between the benefits of biofuels and the potential impacts on food security requires analysis to quantify fuel, food, economy and employment metrics to inform policy decision making.

Drawing upon a bespoke partial equilibrium model, the Nigerian Energy-Food Model (NEFM), populated using secondary data, indicates that cassava is the 'optimal' feedstock for profitable ethanol production in all six geo-political zones of Nigeria. Results show that Nigeria has the potential to produce sufficient feedstock and food crops to meet the current domestic ethanol and crop consumption demands, without affecting domestic food security in the short-run, due to availability of vast fertile uncultivated arable land and unemployed labour, providing positive energy, economic and employment benefits in the short term. Nevertheless, future expansion of the bioethanol programme to double current national ethanol and food consumption demands, would result in significant impacts on national land-use change, negatively impacting on domestic food production and increasing food prices. It is recommended that Nigeria's future biofuels' policy requires a carefully-articulated land-use policy to ensure that land allocation to bioethanol feedstock production is tempered by the need to allocate arable land to food production, in order to avoid consequential adverse impacts on its food security.

Keywords: Energy-Food Dilemma, Biofuels, Partial Equilibrium Model, Nigeria, Policy Analysis.

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Abbreviations and Nomenclature

ADP - Agricultural Development Programme
CAPRI – Common Agricultural Policy Regionalised Impact Modelling System
CGE – Computable General Equilibrium Model
CGEs – Computable General Equilibrium Models
CIF – Charges, Insurance and Freight
CPI – Consumer Price Indicator
DDGS - Distillers' dried grains with soluble
DR – Democratic Republic
FAOSTAT – FAO Statistical Database
FOA – Food and Agriculture Organisation of the United Nations
FOB – Free on Board
GAMS – General Algebraic Modelling System
GDP – Gross Domestic Products
GHG – Greenhouse Gas
GM – Gross Margin
Ha – Hectare
ICS-Nigeria - Information and Communication Support for Agricultural Growth in Nigeria
IITA - International Institute of Tropical Agriculture
IMF – International Monetary Fund
IMPACT – International Model for Policy Analysis of Agricultural Commodities and Trade
L/Li - Litres
MARKAL – MARKet ALLocation Model
MP – Mathematical Programming
MT – Metric tonnes
NBS – National (Nigerian) Bureau of Statistics
NC - North-Central Geo-political zone of Nigeria
NE - North-East Geo-political zone of Nigeria
NW - North-West Geo-political zone of Nigeria
NEFM – Nigerian Energy-Food Model
PEM – Partial Equilibrium Model
PEMs – Partial Equilibrium Models
PMP – Positive Mathematical Programming
POLES – Prospective Energy Outlook on Long-term Energy Systems
PRIMES – Price-Induced Market Equilibrium System
PV – Photovoltaics
RAUMIS – Regionalized Agricultural and Environmental Information System
RHS – Right Hand Side
RPP - Refined petroleum products
SE - South-East Geo-political zone of Nigeria
SS - South-South Geo-political zone of Nigeria
SW - South-West Geo-political zone of Nigeria
TASM - Turkish Agricultural Sector Model
WATSIM – World Agricultural Trade Simulation System
WB – The World Bank

1 Introduction

The use of biofuels, particularly bioethanol and biodiesel, as alternative renewable motor fuel sources has continued to receive significant attention. For example, global biofuels production, grew by 2% from 2015 to 2016 reaching 135 billion litres [1]. Biofuels' potential contributions include: global/domestic energy security; rural economic development; employment creation; diversification of economic activity; buffering of volatility in oil and gas prices; and reduction of anthropogenic greenhouse gas (GHG) emissions. In 2016, the global renewable energy sector employed 9.8 million people, with solar photovoltaic (PV) and biofuels providing the largest number of jobs [1]. In Europe, the bioeconomy (including biofuel and bioenergy) employs about 22 million people and contributes about €2.4 billion per annum [2].

Nevertheless, the recent increase in biofuel production has been accompanied with growing concerns about the associated impacts on national and global food security, from potential competition in the use of limited/fixed production resources such as land, family labour, and water. International debates about the net-energy and GHG reduction contributions of biofuels remain [for details see: 3, 4-9]. In particular, food security debates have stimulated further investigations on the impacts of producing and/or expanding biofuel production, with contrasting findings and viewpoints emerging. Several authors [10-16] suggest that biofuels have been the principal cause of global food crises as witnessed during the global economic crises in 2008, and/or having the potential to lead to future global food shortages and food price rises. By contrast, authors in favour of biofuels [17-19] argue that other factors such as drought in major grain producing areas (e.g. Argentina, Australia, Ukraine, Japan), adverse export policies, increasing energy demand from emerging economies (e.g. China and India), speculative trading and hoarding, and growing demand for meat and milk in developing countries have been, or will be, the main driving factors of global food crises. These issues raise more nuanced perspectives, [3, 14, 20-25], including recognising the contrasting levels of resource endowment for the production of biofuels across different countries, in particular, in relation to African countries where large areas of uncultivated arable land exist, providing the potential for biofuels production with minimal impact on food security. Based upon these observations it is argued that biofuels' impact analysis studies are necessary as a pre-condition to potential introduction and/or expansion of biofuels programmes in order to negate associated fuel-food conflicts.

Within the African context, the Nigerian government aims to produce biofuels, in line with developing nations such as Brazil, China, India, Malaysia, and Philippines. In Nigeria, availability of crop production resources: substantial uncultivated arable land, unemployed labour, and suitable climatic and soil conditions, at the national and regional levels, exist. Relying on the review of implemented biofuel programmes in other developing countries, previous studies [26, 27] have predicted that the potential benefits of biofuels' investments to the Nigerian economy include job creation, diversification of national economy, and revitalisation of the agricultural sector. Others [28-32] investigated the progress of biofuels' investments and development in Nigeria, with Ohimain [28] reporting that over $3.86 billion has been invested for the construction of 19 bioethanol refineries between 2007 and 2010. Abila [29] highlighted the drivers, incentives and enablers of biofuels development and adoption in Nigeria, while Ishola et al. [30] critically evaluated the advantages and disadvantages of biofuels development and production in Nigeria. Further, given the ethical and food security implications of using food crops as feedstocks for ethanol production, [33, 34] assessed the Nigerian potential for cellulosic ethanol production from agricultural residues, however did not examine optimal feedstock (energy crop/residues combination) combinations. Most recently, Okoro et al. [35] applied a partial equilibrium model to study the impacts of bioenergy policies on land-use change in Nigeria, focusing on using carbon price to prevent deforestation and greenhouse gas emissions, while Ben-Iwo et al. [36] assessed the biomass resources (including agricultural, forest, urban and other wastes) available in Nigeria for biofuel production, without attempt to identify the 'best' resource (optimal feedstock) or resource combination that can be used. Such approaches require the application of resource allocation models, that contain as arguments the constraints of the available national resource endowments, national food and ethanol demands, per hectare crop production inputs' requirements and the current market information. These model approaches are necessary to analyse the technical feasibility of actualising proposed biofuels production policies, and assist in identifying the potential impacts and/or trade-offs of implementing such policies. In addition, information about the per hectare profitability analysis of each crop enterprise is needed to provide evidence of the relative merits of private investors and farmers to invest in the cultivation of feedstocks versus alternative land uses or land abandonment. Moreover, such approaches must account for the impact of biofuel production on food security, job creation and rural development. This study aims to fill these gaps.

This research focuses on the development and application of a constrained partial equilibrium model – the Nigerian Energy-Food Model (NEFM) for the production of staple food crops and bioethanol feedstocks (including their conversion into bioethanol) across the six administrative regions (geo-political zones) of Nigeria, in order to assess the impact of bioethanol production on Nigerian energy and food securities. Our paper analyses the crop production and resource use trade-offs, and recommends policy strategies that can help resolve the inherent energy-food dilemma in the Nigerian biofuel policy.

2 Material and Methods

2.1 Choice of Mathematical Programming (MP) Approach for Analyzing the Nigerian Energy-Food Dilemma.

Historically, mathematical programming (MP) models have been widely used in agricultural and economic policy analyses. These approaches can be constructed and implemented with limited data, unlike econometric models, and can be established to reflect the multi-input and -output agricultural relationships. Within MP approaches, complementarities (between maize grain and maize flour production) and substitution relationships (between maize and rice production) and the linkages (between crop and livestock production via feed demand and supply) can be adequately specified, represented and modelled [37, 38]. Sectoral modelling using MP approaches facilitates the analysis of different policy instruments such as trade and/or change in trade policies, change in input and output demands and supplies, environmental impact policies, quota systems, input subsidies, domestic agricultural price and intervention policies, and technology improvement measures [see 38, for a list of other application references]. These advantages are present because the constraint structure of MP models is very suitable in characterizing resource, environmental and policy constraints [39]. Moreover, structurally, MP models typically exhibit Leontief production technology characteristics which intrinsically appeals in input determination during farm production modelling [40].

The majority of sector models are either MP models, which optimise a specific sectoral goal function, or partial equilibrium models (PEMs) [41]. PEMs are preferred to computable general equilibrium (CGE) models when special interest and attention are required on a particular sector of an economy, rather than requiring an assessment of all the sectors of that economy. Moreover, PEMs provide an ability to include more sector-specific structural simulations in a model, than would be possible in a multi-sectoral economy-wide (CGE) model. Other key advantages of PEMs include: less data, labour and time requirements compared to CGE models; structural flexibility which helps in accommodating specific environmental conditions and constraints; permission of an analysis at a detailed level reducing aggregation bias; relatively simple structures, thus making modelling straightforward and results easily interpreted. Examples of PEMs employed for energy sector analysis in the past include POLES, PRIMES, and MARKAL while those used for agricultural sector analysis include WATSIM, IMPACT, CAPRI, and RAUMIS [42]. Nonetheless, PEM is also criticized for being poor in covering dynamics of economic decisions, because of its simplifying assumption that major interactions and feedbacks between a particular sector and the whole economy are negligible; negligence of the macroeconomic consistency; and over simplified behaviour of an economic agent [41, 43, 44]. Conversely, CGE models are praised for overcoming some of these shortcomings of PEMs. Nevertheless, CGE models have been previously criticised due to their structural complexity and attendant large data requirement make modelling cumbersome and time consuming, introducing aggregation bias, rigidity, less transparency, implementation difficulties and often producing results that cannot easily be explained (or interpreted) because of their complex structure [41, 43, 44]. Given the main objective of this study is to analyse the technical feasibility of implementing the proposed Nigerian biofuels production policy and identify its potential impacts and/or trade-offs to the Nigerian energy and food securities, an optimised PEM approach is preferred to a CGE modelling approach. This choice is based upon the detailed requirements for modelling the directly affected sectors (agriculture and energy) to ensure that all the necessary sector-specific structural details are reflected in the constructed model, in order to replicate these sectors, and be capable of quantifying the potential impacts of the proposed biofuels policy to these sectors.

2.2 The Nigerian Energy-Food Model (NEFM) – Model Description

The model is regionalised into the existing six geo-political zones of Nigeria[1]: North-West (NW), North-East (NE), North-Central (NC), South-West (SW), South-South (SS) and South-East (SE) to ensure conformity with the existing structural units and facilitate quicker adoption and/or implementation of achieved results. NEFM is a primal positive mathematical programming (PMP) model, adapted from Howitt [39] and calibrated according to Heckelei and Britz [45] recommendations by including prior information (observed behaviours) at the model specification stage in order to ensure that the Calibration run calibrates to the base-year crop production and resource use data. The resultant first order condition values (shadow prices) of the model are accepted without applying Howitt's [46] phase one PMP calibration approach (i.e. without including calibration constraints and using the shadow prices generated from such calibration constraints to calibrate the cost function in the objective function). The Calibration run's results from models specified using this PMP approach are thus consistent with microeconomic theory while accommodating the inherent heterogeneity in the quality of land and livestock [39, p. 329]. In this study, base-year crop allocation, crop demand elasticities[2] for twenty one different crops covered in the model and the base-year crop resource use data were utilised in the model specification. In particular, the model is inspired and influenced by notable previous studies highlighted above and consequently shares similar structural characteristics with other sector models [especially the non-linear partial

[1] See Appendix G for the detailed description of the geo-political zones of Nigeria.

[2] Price elasticities of demand utilized in the NEFM, part of the model's input data, were adapted from Le-Si et al. (1982) as it was not possible to estimate these due to unavailable time-series data. Hazell and Norton (1986, p. 276) report 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.

equilibrium model as described by 37, pp.156 & 166, 38, 39, and 45] - capturing the essential features of a sector model such as description of producers' economic behaviour (i.e. farmers' profit maximization), region specific production technology sets, resource endowment availability, market environment specification, and specification of the policy goals and instruments. NEFM is a static quadratic PEM with domestic price responsive demand functions such that an integral over the inverse domestic demand curve (i.e. the area under the inverse demand curve) becomes a quadratic inverse domestic demand equation representing the sum of consumers' and producers' surplus as in other non-linear sector models (e.g. Turkish Agricultural Sector Model–TASM). Other structural features of the model include factor supply functions with exogenous prices for inputs with effectively elastic supply characteristics such as fertilizer, herbicides, seeds and hired labour, and inelastic factor supply functions with endogenous prices for inputs with fixed or limited supply characteristics such as land, family labour and tractors as recommended by Hazell and Norton [37, p. 201]. Inter-regional trade necessary to ensure regional and national commodity re-distribution and balances as well as the intra-and-inter regional commodity transportation cost parameters are also included in the model. In addition, the NEFM has a fixed exogenous domestic ethanol demand function - representing the estimated current national/regional ethanol market demand [28, p. 7162] as well as an endogenous ethanol supply function. The maximization of the objective function in the NEFM is the sum of consumers' and producers' surplus plus the gross margin from ethanol production, plus the net trade revenues from both crop and ethanol production. It is well-established that the maximization of the sum of consumers' and producers' surplus is able to simulate a competitive (equilibrium) market system [cited in 37, pp. 87 - 102, 38, p. 276, 47, 48, Ch. 13, pp. 1 – 34, 49, pp. 87 - 102]. NEFM differs from other 'traditional' sectoral bio-economic models due to the presence of ethanol production and marketing activities, namely the implicit feedstock supply, feedstock conversion into bioethanol using published feedstock conversion factors[3], and bioethanol trading in the domestic and world markets. The energy crops considered as feedstock for ethanol production are maize, cassava, potatoes, rice, sorghum, millet, wheat, sugarcane, and their residues[4] (straws from maize, rice, sorghum, millet, wheat; peels from cassava and potatoes; and bagasse from sugarcane). Importantly, the NEFM is implemented such that the national/regional food consumption demand is first met through domestic supply (production) and/or external supply (imports) before the feedstock demand from the biofuel industry is satisfied. This is implemented through the addition of a constraint requiring the domestic food consumption demand to be at least equal to the base-year domestic food consumption demand. Base-year domestic food consumption demand is defined as the three-year average quantity of domestic crops produced minus the average quantity exported plus the average quantity imported. The three-year average is taken from the 'most recent years' (2008 -2010) Nigerian crop production as at the research time, export and import data available from NBS [50] and FAO [51]. The model's input data are presented in Appendix E while the GAMS codes written for its implementation are provided as extra information called NEFM-Codes (available at request). In summary, the algebraic structure of the constrained non-linear sectoral optimization problem (NEFM), assuming only one production technology, multiple products and regions, can be described as follows:

[3] Grain-to-ethanol and residue-to-ethanol conversion estimates have been published in several literature, see Dick (2014, Ch.3) for details.

[4] Only 30% residue collection is considered to ensure maintenance of soil fertility, prevention of soil erosion and other economic and cultural uses such as animal bedding and roofing sheets in remote areas as done in northern part of Nigeria.

$$Max\ Z = \sum(\alpha_{j,i} - \frac{1}{2}\beta_{j,i}Q_{j,i})Q_{j,i} - \sum C_{j,i}(S_{j,i}) + \sum P^{e}_{j,i}E_{j,i} - \sum P^{m}_{j,i}M_{j,i} + \sum GM_{ET,i} + \sum P^{e}_{ET,i}E_{ET,i} - \sum P^{m}_{ET,i}M_{ET,i} \quad \dots\dots (1)$$

such that

$$Q_{j,i} + E_{j,i} + FDST_{j,i} - (S_{j,i} + M_{j,i}) \leq 0, \quad \forall\, j, i \quad [\pi_{j,i}] \dots\dots (2)$$

$$ETP_{FDST,i} + M_{ET,i} - (E_{ET,i} + ETD_{i}) \leq 0, \quad \forall\, ET, i \quad [\pi_{ET,i}] \dots\dots (3)$$

$$\sum a_{k,j,i}X_{j,i} = \sum (a_{k,j,i}/y_{j,i})S_{j,i} \leq b_{k,i,} \quad \forall\, k, i \quad [\lambda_{k,i}] \dots\dots (4)$$

$$E_{j,i} \leq \overline{e_{j,\iota}}, \quad \forall\, j, i \ \ which\ are\ exportable \dots\dots (5)$$

$$Q_{j,i,}S_{j,i,}ETP_{FDST,i}\ ETD_{i} \geq 0, \quad \forall\, j, i. \dots\dots (6)$$

where

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

i = the six administrative/economic regions in Nigeria (NW, NE, NC, SW, SS & SE);

$\alpha_{j,i}$ = demand intercept for each product (crop produce) in each region, in currency units;

$\beta_{j,i}$ = slope or gradient of the demand curve for each product in each region;

$Q_{j,i}$ = average quantity demanded (sold) in the domestic market for each product in each region, in MT;

$S_{j,i}$ = average quantity of each product supplied (produced & transported) domestically in each region, in MT;

$\sum C_{j,i}$ = total input cost (total unit cost) of producing and transporting each product domestically in each region, in currency units;

$P^{e}_{j,i}$ = regional real export price of each product after adjusting for export (FOB-free on board) cost, in currency units;

$E_{j,i}$ = average quantity of each product exported (demanded/sold externally) from each region, in MT;

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

$P^{m}_{j,i}$ = regional real import price of each product after adjusting for import (CIF-charges, insurance and freight) cost, in currency units;

$M_{j,i}$ = average quantity of each product imported (supplied/bought externally) into each region, in MT;

$X_{j,i}$ = the level of jth production activity such as hectare of maize grown in each region. If n denotes the number of possible activities, then $j = 1$ to n;

$y_{j,i}$ = per hectare average yield of each product in each region, in MT;

$a_{k,j,i}$ = 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 each region, 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;
$b_{k,i}$ = amount of the k[th] resource available or resource endowments (RHS) in each region;
$\pi_{j,i}$ = shadow price of each product at the commodity (market) balance constraint in each region, in currency units, which is the same as the product price of each product;
$\pi_{ET,i}$ = shadow price of ethanol at the ethanol demand-supply balance constraint in each region, in currency units, which is the same as the product price of ethanol in each region;
$\lambda_{k,i}$ = marginal opportunity cost of resource k, or the market valuation of resource k in each region, 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;
$FDST_{j,i}$ = average quantity of each feedstock (energy crop) demanded for ethanol production in each region, in MT;
$ETP_{FDST,i}$ = average quantity of ethanol produced from all feedstocks in each region, in litres;
ETD_i = average quantity of ethanol demanded for domestic use in each region, in litres;
$\sum GM_{ET,i}$ = the total gross margin from the domestic sale of ethanol produced from all feedstocks in each region, in currency unit;
$P^e_{ET,i}$ = real export price of ethanol exported from each region after adjusting for export cost, in currency units;
$E_{ET,i}$ = average quantity of ethanol exported (demanded) from each region, in litres;
$P^m_{j,i}$ = real import price of ethanol imported into each region after adjusting for import cost, in currency units;
$M_{ET,i}$ = average quantity of ethanol imported (supplied) into each region, in litres;
Equations (2), (3), (4) and (5) are the national commodity or market balance, resource use balance and export quota balance constraints, respectively; while equation (6) is the set of non-negative constraints.

2.3 Data Aspects of the NEFM

2.3.1 Data Type

The analytical model is implemented using secondary data, covering the available historic Nigerian and regional physical and economic farm production data relating to crop type, yields, prices, inputs' requirements (e.g. labour, fertilizer, pesticide, seed, cash capital) in addition to Nigerian food consumption, ethanol demand, and trade (commodity import and export) data.

2.3.2 Data Challenges and Mitigation Measures Employed

The challenge of incomplete or lack of reliable data in developing nations is well-known and has been recognised by other studies [see for example, 37, p. 126]. This study is not an exception. For instance, the crop production data in terms of types of crops grown, area harvested, quantities produced and input resources utilized such as fertilizer, pesticide, labour, cash capital, and seeds were not comprehensively available from a single database/source. To overcome this challenge, different data sources were used in sourcing the study data. In most cases, NBS (National Bureau of Statistics) and FAOSTAT (statistical database of the Food and Agriculture Organisation of the United Nations-FAO) were complementarily used to assemble the needed crop production data as neither was comprehensive. For example, NBS (2008, 2010) reported Nigerian and regional 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. Also data on the quantity of pesticides applied for the base-year crop production and the cash capital utilised for the farm operations were neither available from NBS nor FAO. To overcome this data limitation, recommended per hectare pesticide application rate from crop production manuals from research institutes (such as IITA -International Institute of Tropical Agriculture, FAO and ICS -Nigeria -Information and Communication Support for Agricultural Growth in Nigeria) was implemented as the model's pesticide input-output coefficient and the model endogenously determine the quantity of pesticide required to achieve the production levels of the selected crop enterprises. This is necessary to create and simulate the optimum crop production environment in the model. Similarly, the per unit cost of all the production inputs required to undertake all the pre-harvest/sales farm operations (including the borrowing cost of the cash capital) was implemented as a cost in the model and summed up after the production process to arrive at the total cash capital required. Further, the base-year seed rate calculated from the NBS's reported quantity of seeds/seedlings utilised and the total harvested area over a period of time fell short of the recommended seed rate for optimum crop production and harvest. Hence, the recommended seed rates for optimum crop production from crop production manuals of the above named research institutes were used to mitigate this limitation and create the enabling optimum crop production environment in the model. There was a discrepancy between the FAO and NBS data with respect to some crop production data available in the two databases. Therefore to overcome this dichotomy, NBS data (where available) is presumed to be more reliable (being a direct national database) and therefore preferred to FAO data. Nonetheless, FAO data are used where NBS data are not available. In general, the different data sources utilised are indicated in the model's input data (Appendix E). Further, due to the mixed-cropping system practiced in many regions of Nigeria, NBS reported an aggregated annual labour employment data utilised for all the crops produced in Nigeria over a time period, instead of the annual labour employed in the cultivation of each crop. To implement the labour technical coefficient in the model, the base-year average per hectare annual labour employed under mixed-cropping system was assumed as the per hectare annual labour required to cultivate each of the crops considered in the Calibration (Base) model. This is necessary to ensure that the Calibration model replicates the existing crop production data at the base-year. However, using per hectare annual labour specification in the model instead of the seasonal (monthly) specification has the tendency of over-estimating the total labour employment in the model. To overcome the labour over-estimation challenge, the Nigerian Cropping Calendar from Abia ADP-Agricultural Development Programme (Appendix F) was used to implement a seasonal (monthly) labour demand in the Baseline/Simulation model instead of the annual labour demand from the NBS data. The implementation of seasonal labour demand has the advantage of making the Baseline/Simulation model more efficient in labour allocation, providing for more off-farm job opportunities, than the Base model with the base-year annual labour allocation.

2.3.3 Method of Data Collection, and Data Integrity

Data collection was mainly undertaken through internet screening of recognized national and international official websites and databases such as NBS, IITA, FAOSTAT, IMF, World Bank; 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 and ministries (e.g. Ministry of Agriculture), and a pioneer biofuel company in Nigeria (Global Biofuels Ltd). The essence of the personal research visits to these organisations was to collect additional up-to-date data that were 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. The visit to the biofuel company was intended to ascertain the status or stage of biofuel production in Nigeria – being the pioneer company, and to collect ethanol production data (costs). However, data on ethanol production cost was not available as the company has not started producing ethanol as at the field trip in 2012.

2.3.4 Data Processing

To apply the raw data from the databases into the 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.

2.4 Calibration of the NEFM (Preliminary Results from the Base Model)

The NEFM was calibrated using the PMP calibration approach advanced by Heckelei and Britz (2005), as noted earlier. In addition, verification tests as proposed by Hazell and Norton [37, ch.11, p.270] were employed in order to confirm that the Base model's results are consistent with the base-year crop production data. Base model (Calibration run) is the Food-Only Production Model. The Calibration run reproduces the base-year (NBS) crop production data both in terms of regional output and individual crop (cropping pattern) bases (see Appendices C.1 and C.2). In addition, the prescribed regional cultivated land use results suggest that the model is consistent with the base-year data (see Appendix D). 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) as there is no slack (unused) land; hence, the displayed shadow price of land in Table 1. Comparatively, the resultant shadow price of land in the SE (see Table 1) is slightly lower than the actual land rent (US$131) in the only state in the region (Abia State) for which land rent data are available. This difference could be due to demands for other land uses in the state/region (e.g. construction of new houses, roads, etc.) which are not accounted for in the model as this region has the smallest land mass in Nigeria. In summary, the results indicate that the Base model is consistent in structure and in the representation of the base-year crop production data (including market information). Therefore, the Calibration run can serve as the benchmark against which the Ethanol-and- Food Production Model (NEFM)-Baseline and/or Simulation models can be evaluated.

Table 1, Regional Land Shadow Prices from the Base Model (Calibration Run of the NEFM)

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

Source: Researchers' Base Model results

Key: NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

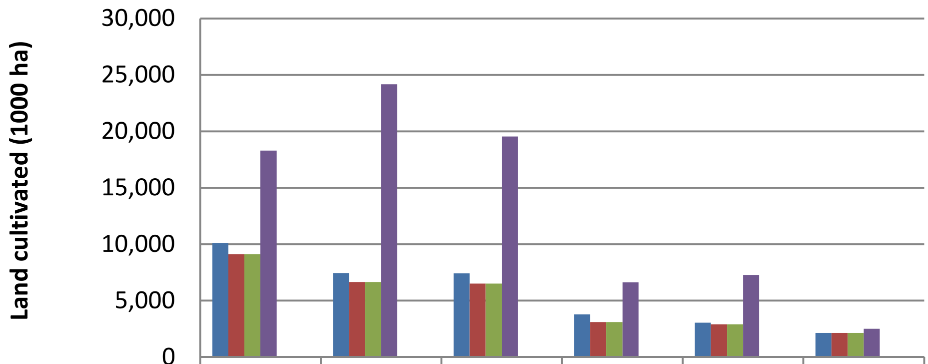
3 Results and Discussions

The key results from the NEFM (Baseline) are presented and discussed below.

3.1 Regional Resource Allocation: Land Use Level

The land use result from the NEFM (Figure 1) shows that more arable land will be cultivated in all the regions under a biofuel policy, compared to the base-year, implying an impact on land use as reported in other studies [e.g. 11, 13, 52]. Note that 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. However, Figure 1 also indicates that the available uncultivated arable land in each region would not be exhausted if the Nigerian ethanol production policy is implemented only to meet the current ethanol market demand in Nigeria. Substantial uncultivated land will still be available in all the regions, except in the SE where almost all available arable land is already utilised. The corresponding cropping pattern (Appendix H.1) shows that meeting the current ethanol demand would not displace food crops from arable land as all current cash and food crops in Nigeria were included in the model without any being displaced in the optimal solution. This signifies no reduction in domestic food production and supply. Therefore the land-use impact of the bioethanol programme might be relatively insignificant since there is currently a surplus of uncultivated arable land in each region available to meet the combination of current domestic food consumption, export and the ethanol feedstock demands. Extending this analysis, the model was tested under a requirement that doubled Nigerian ethanol and food demand, given the Nigerian 2013 population and economic growth rates of 2.47% and 3.21%, respectively [53, 54], and suggested that under this “doubling of demand” scenario there will be a significant land-use impact as the available arable land in each region would be completely utilised while meeting this target. This finding implies that less of the currently available arable land should be used for the production of bioethanol feedstocks in the long-run in order to ensure sufficient supply of land to meet domestic food demand, and moderate food pricing; in the absence of such a policy arable land scarcity will negative impact on food production potential and increase food prices. Therefore future expansion (e.g. doubling) of the current national ethanol demand, as a result of growing population and economy, would adversely impact on land-use, domestic food supply (production) and consequently food prices. This result corroborates previous research findings that the land-use impact of bioethanol is more severe and significant in areas where available arable land is limited [3, 11, 55, 56]. Nonetheless, in the short-run, the land-use impact (in the Nigerian case) may rather be viewed as a positive one instead of negative since the ‘unprofitable’ hectares of fertile arable land currently lying fallow will be put into productive use through meeting the current ethanol demand. However, the implementation of an ‘aggressive’ bioethanol expansion programme would not be advisable as our results show that this would lead to displacement of some food/cash crops, and consequently reduce domestic food supply and increase domestic food prices.

Figure 1, Optimal Land Use from the Nigerian Energy-Food 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

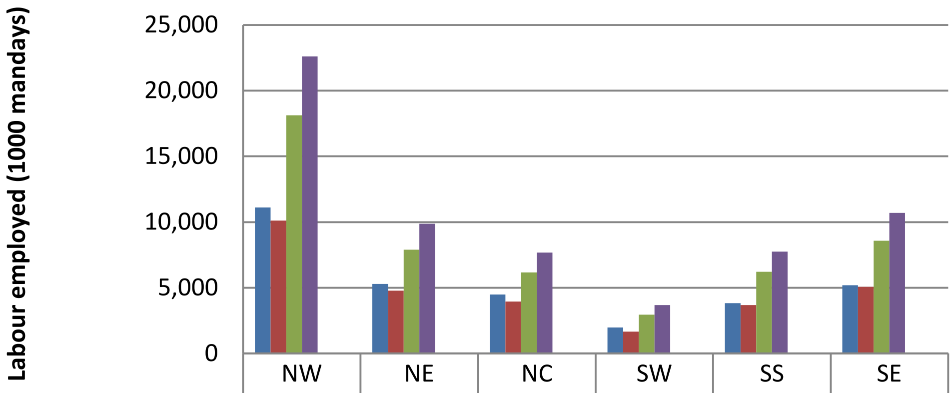
Source: S0 land and NLP Baseyr land results are respectively from researchers' Baseline and Calibration (Base) models while NBS Baseyr and Available Land data are from National (Nigerian) Bureau of Statistics (NBS).

Key: S0 land = quantity of land cultivated in the Baseline model, NLP Baseyr land = quantity of land cultivated in the Calibration (Base) model, and NBS Baseyr land = observed quantity of land cultivated at the base-year from National Bureau of Statistics (NBS). Also NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

3.2 Regional Resource Allocation: Labour Employment

Figure 2 refers only to the labour requirement to meet the production of the ethanol feedstock and the base-year's catch and cash crops required to satisfy the current domestic food consumption and export demands. The number and cost of labour employed in the ethanol refinery to process the feedstocks into ethanol are already factored into the per litre variable cost of producing ethanol [57]. Similar to the land use impact, Figure 2 shows that the production of bioethanol will require additional labour to cultivate ethanol feedstocks. Employment creation (increase in crop farming labour force) is a positive and desirable outcome of the bioethanol programme since it will help reduce the unemployment rate in Nigeria. It could by extension help to improve the food security challenge in the nation since employment income would additionally enhance food access. The NEFM is more efficient in labour allocation and utilization due to the implementation of crops' seasonal (monthly) labour demand in the model as against the base-year annual labour requirement derived from the NBS (observed) data. As a result, the regional off-farm labour employment opportunity is revealed as shown in Appendix A. Ethanol production is expected to create off-farm jobs in the rural areas when it comes on stream, especially if the refinery is sited in the rural areas where the feedstocks are produced. Further, the associated shadow prices for hired and family labour employment are presented in Appendix B. The shadow price for family labour is lower than that of the hired labour, but greater than zero, and thus supporting existing arguments that the opportunity cost of a family labour (i.e. the amount that a family labour is willing to receive in order to continue supporting and participating in a family farm work) is greater than zero but less than that of a hired labour.

Figure 2, Regional Optimal Labour Employment from the Nigerian Energy-Food 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

Source: S0 labour and NLP Baseyr labour are respective results from researchers' Baseline and Calibration (Base) models while NBS Baseyr and Available Labour data are from National Bureau of Statistics (NBS).

Key: S0 labur = number of labour employed in the Baseline model, NLP Baseyr labour = number of labour employed in the Calibration (Base) model and NBS Baseyr labour = number of labour employed at the base-year from National Bureau of Statistics (NBS). Also NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

3.3 Regional Ethanol Production from the Nigerian 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 gross margin (GM) by the corresponding reduced cost in Table 2e, at least on the current cost and conversion data. Specifically, Figure 3a shows the total volume of ethanol produced in each region. From Figure 3a, the northern part of Nigeria has greater potential for ethanol production than the southern part due to the availability of more arable land for food and feedstock production. Figure 3b 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 2a), but are excluded because of their ethanol conversion characteristics (Table 2b). Conversely, potatoes, sugarcane and wheat (in the NW and NE) are shown to be approximately competitive in their conversion characteristics, but are excluded 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. Columns with 'N/A' in Table 2a imply that such feedstocks are not produced (supplied) from those regions. On the other hand, Table 2b 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 (Table 2a) make it unprofitable to produce/supply ethanol from sugarcane in any of the regions. As indicated in Table 2a, the reduced cost of supplying 1 MT of each energy crop that could be selected as a feedstock for ethanol production is zero. Similarly, 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 ('best') feedstock for ethanol production in any region, that feedstock must have zero reduced cost values in Tables 2a and 2b; 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 an 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 [48, Ch.17, p. 22, Ch.18, p.5, 58, Ch.9, p.22]. 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) [50] which is substantially lower than that of Brazil (75 MT/ha) [5], and 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 [11, 59, 60]. From a management practice and practical view point (based on corresponding 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 [59, 60]. These reasons are consistent with Nigeria's status as the largest cassava producer and exporter in the world [61]. 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 via cassava production that from other feedstocks.

Further, Table 2d reveals the opportunity costs of producing one litre of ethanol from any of the feedstocks (factoring in the implicit feedstock cost per litre), i.e. the per litre GM of processing ethanol from each grain feedstock. From Table 2d, cassava, sugarcane and potatoes have exactly the same opportunity costs per litre of ethanol produced in all the regions. Also these 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 2d, 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 preferred feedstock for ethanol production due to their feedstock supply reduced costs.

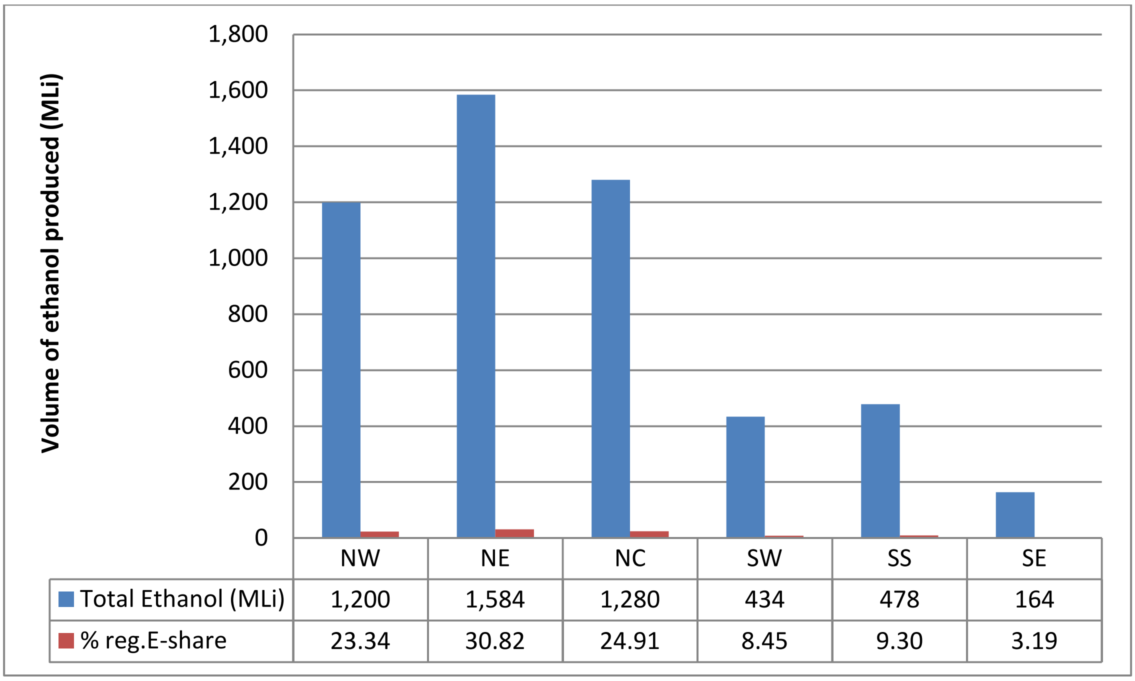
The estimated aggregate feedstock cost per litre of ethanol produced is US$0.13; implying that the feedstock cost accounts for 54% of the per litre cost of producing ethanol from cassava feedstock (US$0.24), with the rest resulting from the ethanol processing/refining cost. This result conforms with findings of previous studies [57, 62, 63], which suggest that feedstock cost accounts for more than half of the total ethanol production cost. It also implies that an average GM of US$0.33 is made per litre of ethanol demanded 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 2c), implying the real market price of 1 litre of ethanol sold, are approximately equal to US$0.33 for each region.

In summary, the potential viable and 'best' feedstock that can be used for ethanol production in each region is identified as cassava, followed by sugarcane, among others. In addition, a total GM of US$2,364M on a national scale, excluding the potential co-products'[5] revenues, could be achieved from the ethanol produced and supplied to satisfy the current ethanol market demand in Nigeria. From the study estimates[6], the by- and co-products produced alongside the ethanol could yield a total revenue of US$360M or US$354M (including or excluding potential carbon credits revenue, respectively), of which only distillers' dried grains with soluble (DDGS) would account for US$347M, i.e. 96% or 98% of the total achievable co-products revenue respectively. Hence, a total GM of US$2,725M (including co-products revenue) could be realised from the sale of the ethanol produced and the associated co-products. Further, the total quantity of ethanol produced (5.14 billion litres) would substitute about 514 million litres of gasoline under 10 percent ethanol blending with 90% gasoline, while the entire production system could yield a total GM of US$45.71 billion,– equivalent to approximately 8% of the 2014 Nigerian GDP at 2010 current basic prices (US$B585).

[5] Bye/co-products include: DDGS, carbon credits obtainable from the bioethanol project as a clean development mechanism project, 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.

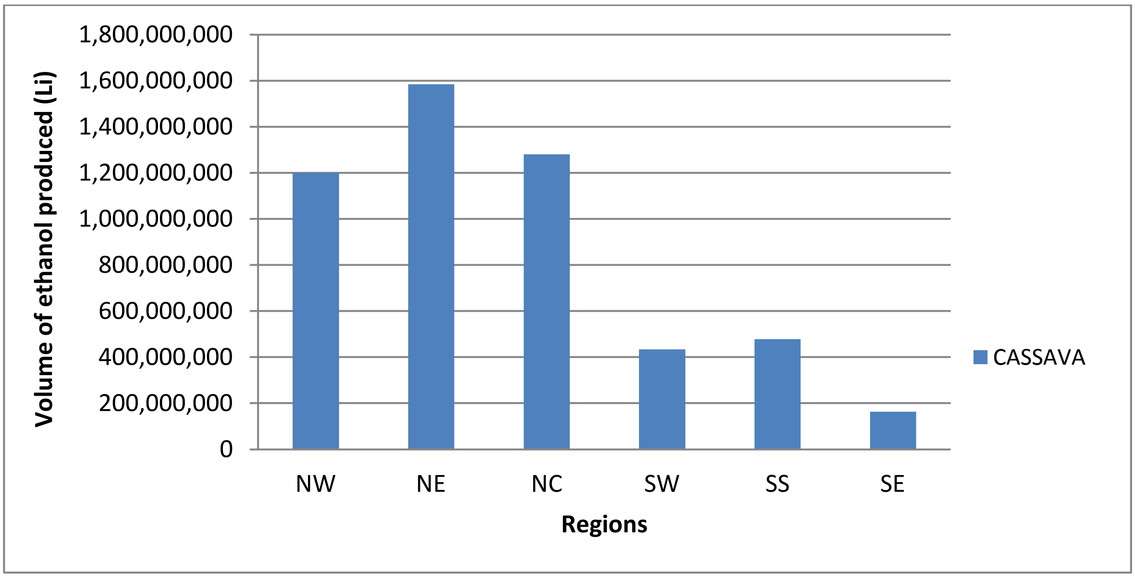
[6] Method of bye/co-products revenue estimation is documented in pages 134 – 139, 64. Dick, N.A., *Analysis of Biofuel Potential in Nigeria*. 2014, Newcastle University, England: Newcastle Upon Tyne, England. p. 1 - 232.

Figure 3a, Ethanol Production by Region from the Nigerian Energy-Food Model



Source: Researchers' Baseline Model (NEFM) results.
Key: MLi = Million litres, reg. E-share = Regional ethanol share. Also NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

Figure 3b, Ethanol Production by Feedstock from the Nigerian Energy-Food Model



Source: Researchers' Baseline Model (NEFM) results.
Key: NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones; Li = Litres.

Table 2a, Reduced Costs for the Feedstock Supply Variables from the NEFM

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

Source: Researchers' Baseline Model (NEFM) results.
Key: NWRC = North-West reduced cost, NE = North-East reduced cost, NC = North-Central reduced cost, SW = South-West reduced cost, SS = South-South reduced cost, and SE = South-East reduced cost.
N/A: Not applicable

Table 2b, Reduced Costs for the Ethanol Production Variables from the NEFM

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

Source: Researchers' Baseline Model (NEFM) results.
Key: NWRC = North-West reduced cost, NE = North-East reduced cost, NC = North-Central reduced cost, SW = South-West reduced cost, SS = South-South reduced cost, and SE = South-East reduced cost.
N/A = Not applicable.

Table 2c, Shadow Prices on the Regional Ethanol Demand-Supply Balance from the NEFM

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

Source: NEFM results.
Key: NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

Table 2d, Ethanol Production Shadow Price for Grain Feedstock from the NEFM

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

Source: NEFM results.
Key: NWSP = North-West shadow price, NE = North-East shadow price, NC = North-Central shadow price, SW = South-West shadow price, SS = South-South shadow price, and SE = South-East shadow price.
N/A: Not applicable.

Table 2e, Reduced Costs for the Cellulosic Ethanol Production from the NEFM

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

Source: NEFM results.
Key: NWRC = North-West reduced cost, NE = North-East reduced cost, NC = North-Central reduced cost, SW = South-West reduced cost, SS = South-South reduced cost, and SE = South-East reduced cost.
N/A: Not applicable

3.4 The Nigerian Ethanol Policy Impacts on the Domestic Food Supply and Food Prices

In the short run, the production of ethanol feedstocks and their conversion into ethanol to meet the current national ethanol demand of 5.14BL does not show any significant negative impact on the production cost of the energy and other crops, due to the availability of sufficient unutilised arable land and labour in Nigeria. Also the optimal cropping plan and the optimal crop production output results (Appendices H.1 and H.2) reveal that the crops cultivated at the base-year need not be displaced nor reduced in terms of output if the ethanol feedstock is produced alongside currently cultivated crops. In addition, domestic food/commodity prices (shadow prices at the demand-supply balance) remained unchanged from the base-year real market prices, thus implying that food prices need not rise above the base-year real prices if ethanol is produced using local staple food crops as feedstocks as implemented in the NEFM to meet the current national ethanol demand. However, if the current national ethanol and food demands double due to increased economic and population growth in the long run, the domestic food supply would be adversely affected (significantly reduced) due to competition and change in land-use arising from the displacement of food crops by energy crops (ethanol feedstock). This would drive up food prices. Therefore significant future expansion of bioethanol production in Nigeria beyond the current ethanol demand would have significant negative impacts on land-use, domestic food production/supply and food prices (i.e. domestic food security). This finding conforms with earlier findings from other studies [3, 11, 55, 56].

4 Conclusions and Policy Implications

From the NEFM results above, 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 in the short-run without impacting adversely on its land-use change, domestic food supply and food prices. Nevertheless, future efforts to double the current ethanol and crop consumption demands in the long-run, due to population and economic growth, would adversely impact on its land-use change, domestic food supply and food prices. Further, ethanol production analysis suggests that cassava and sugarcane are respectively the ‘best’ and 'second best' feedstocks for profitable ethanol production in all the six geo-political zones of Nigeria. In conclusion, it has been demonstrated that the NEFM can be used to assess the potential impacts of the Nigerian biofuels and/or agricultural policies. The results generated are of considerable use to the Nigerian agricultural and biofuels policymakers and planners. The NEFM has the potential to be adapted to analyse the biofuel production potential of other developing countries (e.g. sub-Saharan African countries such as South Africa, Congo DR, Cameroon and Tanzania) which share similar characteristics, in terms of crop production resources and energy insecurity challenges, with Nigeria.

Building on the findings presented above, Nigerian bioenergy and food policies must be aligned to ensure that future allocation of arable land is not devoted to the production of bioethanol feedstocks at the expense of future food and cash crops. This policy direction is required in order to avoid the adverse impacts of bioethanol production expansion on the national/regional land-use change, domestic food production/supply and food prices. However, in the short term, the domestic production of bioethanol has potential economic benefits for Nigeria. 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 refined petroleum products (RPP) demand) at 10% ethanol blending, and save approximately US$36B per annum at US$70.33 per litre of the imported RPP. The contribution to the national income (a total gross margin of US$2,725M), and employment creation (both on-farm and off-farm jobs) suggest that the envisioned bioethanol policy will make positive impacts to the Nigerian economy and in reducing the un-employment and/or under-employment challenges in the short to medium term. Therefore the energy security and socio-economic policy implications of this study imply that Nigeria can pursue only a 'moderate' biofuels production policy and not the 'aggressive' one.

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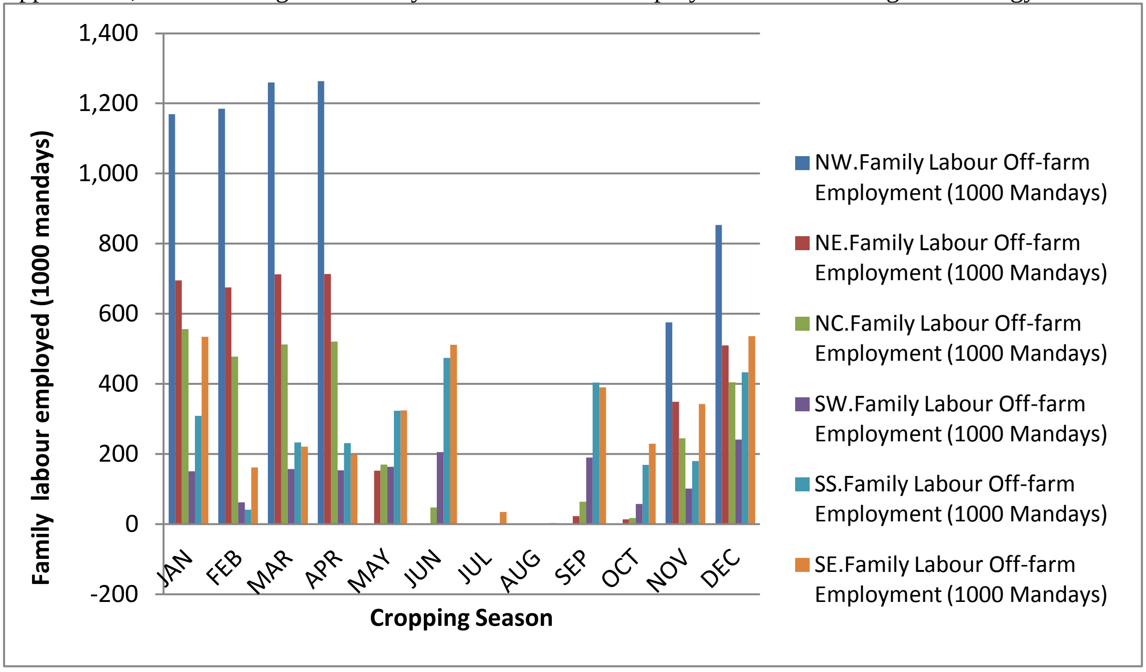
   http://www1.eere.energy.gov/biomass/feedstock_databases.html

   http://www.afdc.energy.gov/biomass/progs/search1.cgi.

Appendices

Appendix A: *Off-farm Labour Employment of the Nigerian Energy-Food Model*

Appendix A, Potential Regional Family Labour Off-farm Employment from the Nigerian Energy-Food Model



Key: NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

Appendix B: *Labour Employment Shadow Price of the Nigerian Energy-Food Model*

Appendix B.1, Shadow Prices for the Hired Labour Employment from the Nigerian Energy-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						

Key: NWSP = North-West shadow price, NE = North-East shadow price, NC = North-Central shadow price, SW = South-West shadow price, SS = South-South shadow price, and SE = South-East shadow price.

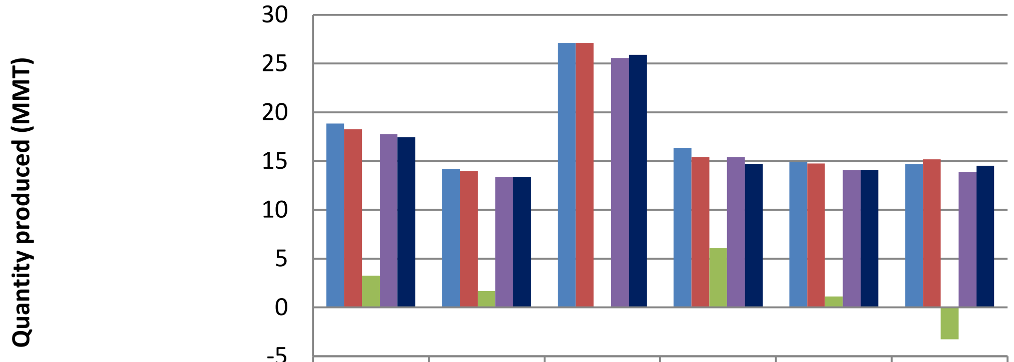
Appendix B.2, Shadow Prices for the Family Labour Employment from the Nigerian Energy-Food Model

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						

Key: NWSP = North-West shadow price, NE = North-East shadow price, NC = North-Central shadow price, SW = South-West shadow price, SS = South-South shadow price, and SE = South-East shadow price.

Appendix C, Comparison of the Calibration Run's crop production results with the input data

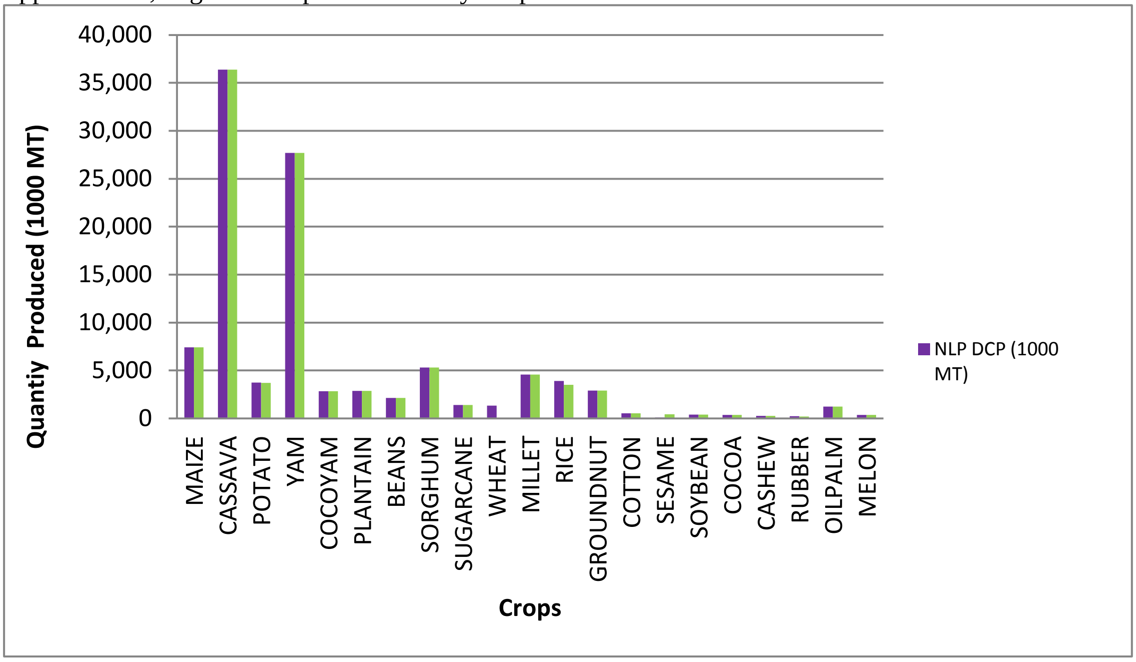
Appendix C.1, Nigerian Crop Production by Region.



	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

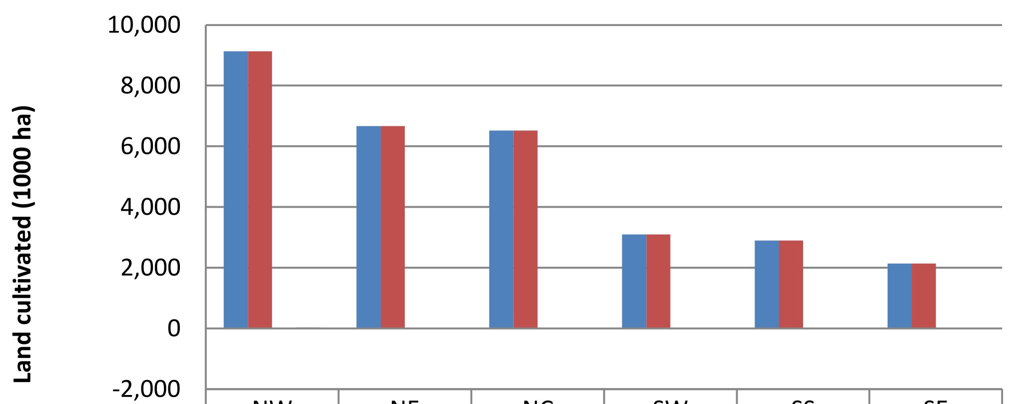
Key: NLP – indicates data generated from the NEFM, while NBS represents obtained base-year data. PAD and MAPD stand for Percentage Absolute Deviation and Mean Absolute Percentage Deviation, respectively. Hazell and Norton [37, pp. 271 - 272] propose these specific evaluation criteria as acceptable and/or unacceptable PAD range: ≤ 5% - Exceptional, ≤ 10% - Good, ≥ 15% - may require improvement. In general, Appendices 3.1 and 3.2 show that the 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. MMT = Million metric tonnes; NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

Appendix C.2, Nigerian Crop Production by Crop.



Key: NLP DCP = Domestic crop production from the Baseline model (NEFM), MT = Metric tonnes.

Appendix D, 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

Source: NLP land are results from researchers' Calibration (Base) models while NBS are data from National (Nigerian) Bureau of Statistics (NBS).

Key: NLP land = quantity of land cultivated in the Calibration (Base) model; NBS land = observed quantity of land cultivated at the base-year from NBS; MAPD = Mean Absolute Percentage Deviation; Reg. % share = Regional percentage share of the total cultivated land. Also NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

Appendix E, Model's (NEFM) Input Data Tables

Appendix E.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

Source: Estimated from the quantity of crops produced and area harvested from NBS -Nigerian Farm Survey Data, 2008 - 2010, and FAOSTAT - Nigerian Crop Production Data, 2008 - 2010 . * - Imply data sourced from FAOSTAT.

Appendix E.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

Source: Estimated from the Nigerian Farm Survey Data (NBS, 2010).

Appendix E.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	1252617	1103896	1338450	11616	10002	9753
YAM	1921043	2240173	8873227	4774353	4458733	5415357
COCOYAM	7207	13872	236627	1133270	580023	867673
PLANTAIN	175003	201646	749982	579208	609546	560948
BEANS	871877	788493	452317	14408	977	3257
SORGHUM	2621190	1681370	983467	24947		
SUGARCANE	1134887	110173	89247	20547	46840	3143
WHEAT	23182	17461	3997	26		
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

Source: Extracted from the Nigerian Farm Survey Data (NBS, 2010b).

Appendix E.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

Source: Adapted from Le-Si, Scandizzo [66].

Appendix E.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

Source: Assumed to be the same with the domestic farmgate prices from the Nigerian Farm Survey Data (NBS, 2010), due incomprehensive and unreliable export prices from NBS Commodity Trade Data (2010) which is 200% higher than the farmgate prices, thus influencing the model negatively to export all produced crops.

Appendix E.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

Source: Assumed to be 10% higher than the domestic farmgate prices (considering existing discouraging import policies with high import duties) due incomprehensive and unreliable import prices from NBS Commodity Trade Data (2010) which is over 200% higher than the farmgate prices. It does not seem logical for such imported commodities with higher prices to compete favourably with the locally produced ones and/or be sold in the local market where the cheaper ones are.

Appendix E.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						

Source: Nigerian Agricultural Trade Data [67].

Appendix E.8, TABLE IMD (C, R) AVEREAGE REGIONAL IMPORT SUPPLY (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						

Source: Nigerian Agricultural Trade Data [67].

Appendix E.9, TABLE RE (B, R) AVAILABLE AVERAGE REGIONAL 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)	12634	7803	6085	3655	5096	4726

Source: Estimated from Nigerian Land Use Data (FAOSTAT, 2014b; NBS, 2010b), and Nigerian Population Census Data [68].

Appendix E.10, TABLE BR (B, R) AVERAGE REGIONAL BASE-YEAR 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)	12634	7803	6085	3655	5096	4726

Source: Extracted from the Nigerian Farm Survey Data (NBS, 2010b).

Appendix E.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

Source: Estimated from the Nigerian Farm Survey Data (NBS, 2010b).

Appendix E.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

Source: Estimated from the Nigerian Farm Survey Data (NBS, 2010b).

Appendix E.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

Source: Estimated from the Nigerian Farm Survey Data (NBS, 2010b).

Appendix E.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

Source: Estimated from the Nigerian Farm Survey Data (NBS, 2010b).

Appendix E.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

Source: Estimated from the Nigerian Farm Survey Data (NBS, 2010b).

Appendix E.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

Source: Estimated from the Nigerian Farm Survey Data (NBS, 2010b).

Appendix E.17, TABLE RC (B, R) AVERAGE REGIONAL PER UNIT RESOURCE COSTS (US$)

	NW	**NE**	**NC**	**SW**	**SS**	**SE**
*	(US$)	(US$)	(US$)	(US$)	(US$)	(US$)
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

Source: Extracted and estimated from the Nigerian Farm Survey Data (NBS, 2010b), and CBN [69].

Appendix E.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

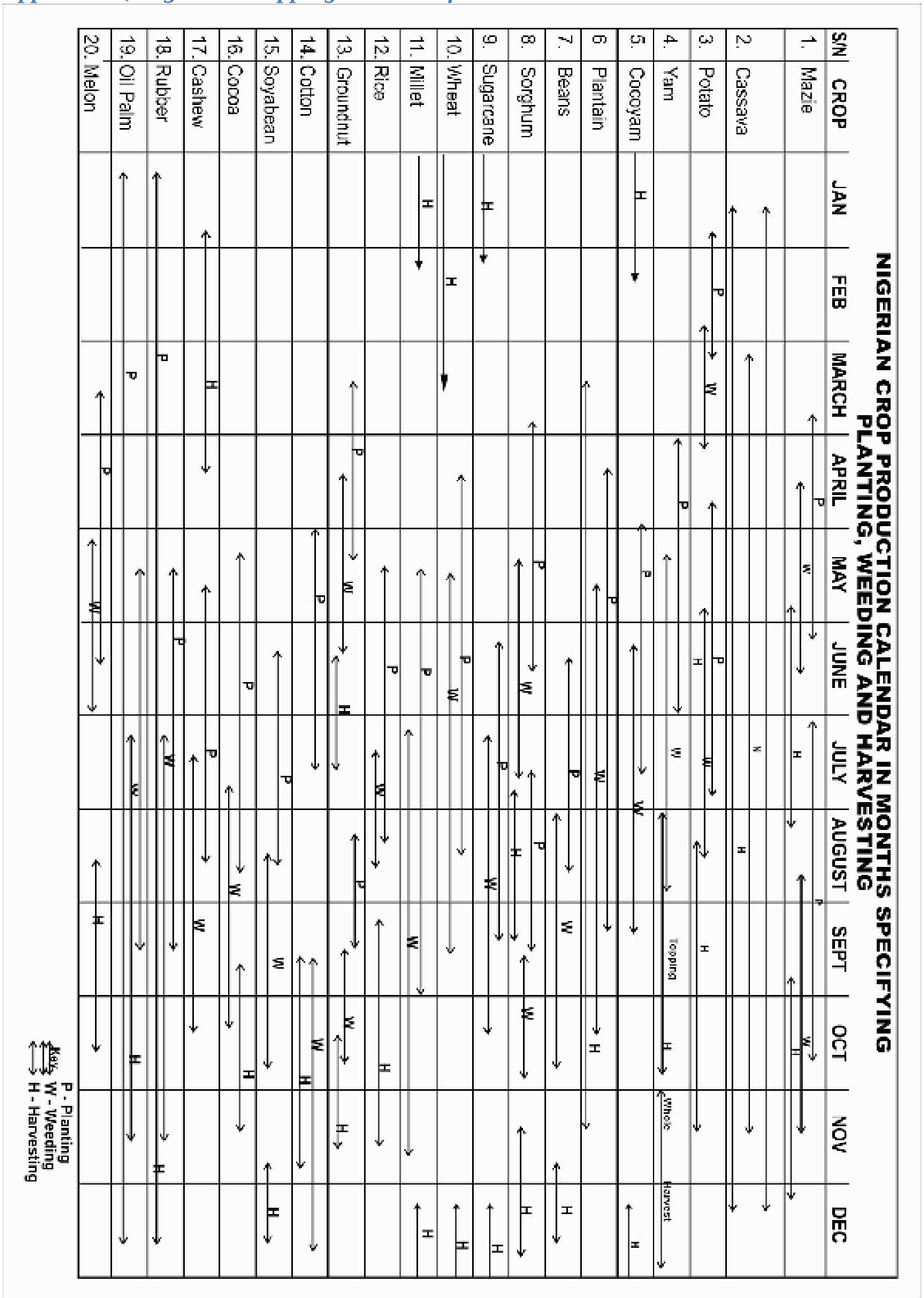
Source: Extracted from published ethanol technical efficiencies from Johnson et al. (2009, p.4) , Mitchell [3, pp. 10, 17], [71], Lal [72, p. 578], Kim and Dale [73, p. 363], EERE [74], and Shapouri and Gallagher [57, p. 4]–for ethanol cost of production.

Appendix E.19, Table RegTransC (R,R) 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

Source: Inter-regional transportation fare from Nigeria Road Transport Workers in 2012.

Appendix F, Nigerian Cropping Calendar from Abia State ADP



Source: Abia ADP (Agricultural Development Programme) Agency.

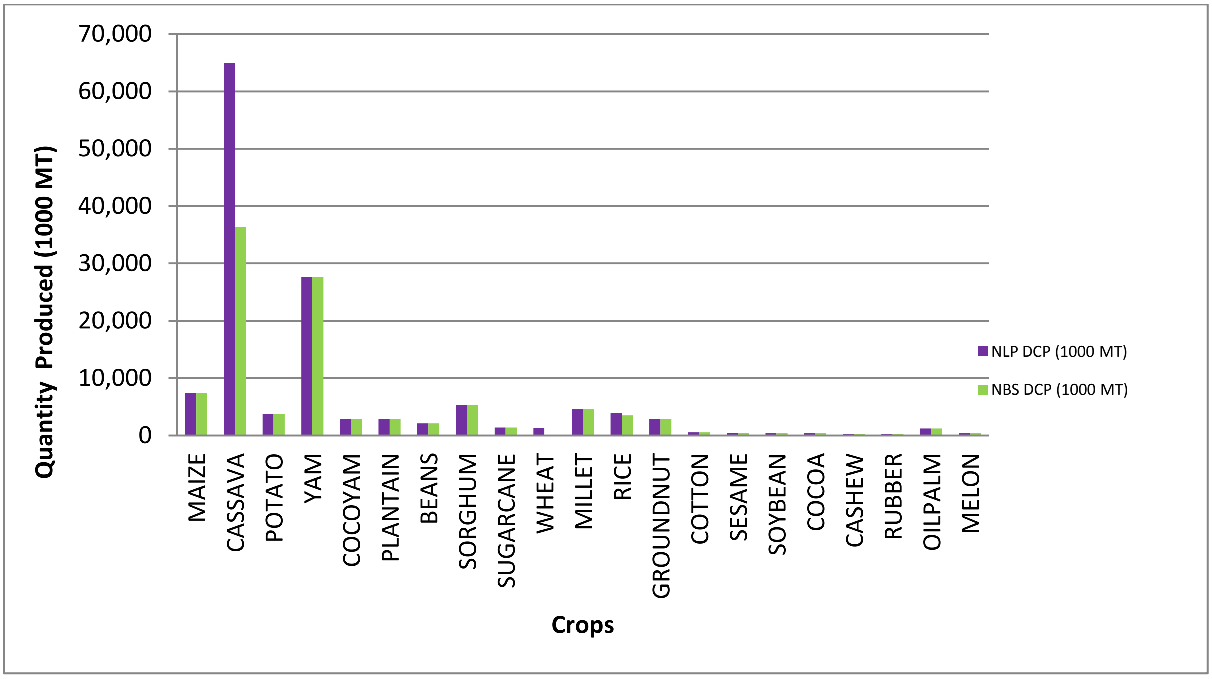
Appendix G.1, Map of Nigeria showing the Six (6) Geo-Political Zones (Administrative Regions) of Nigeria and their Member States.

Source: Nigerian Muse, accessed on 04/09/2017 from: http://www.nigerianmuse.com/20100527092749zg/sections/pictures-maps-cartoons/maps-of-various-states-and-their-local-governments-in-nigeria/

Appendix G.2, Tabular Representation of the Six Geo-Political Zones with their States

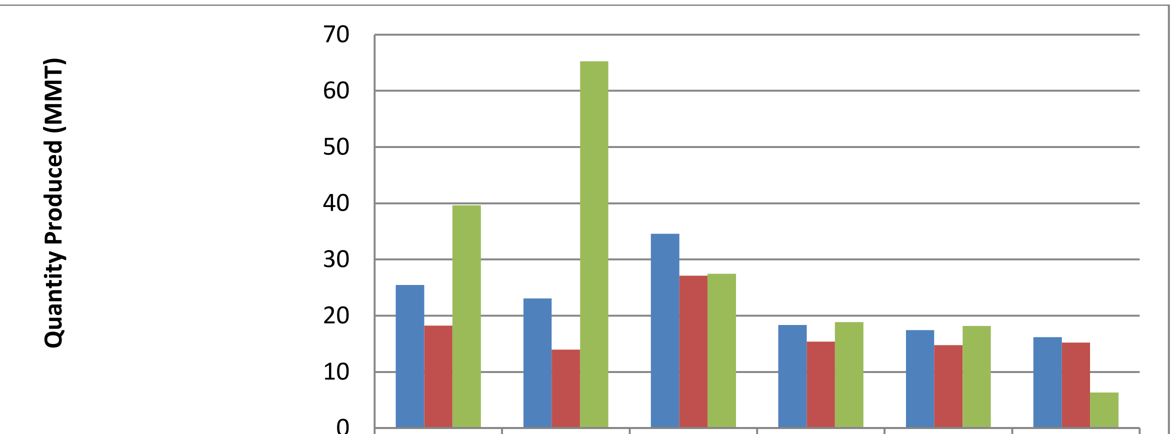
Geo-Political Regions	**North East**	**North West**	**North Central**	**South West**	**South South**	**South East**
	Adamawa	Jigawa	Benue	Ekiti	Akwa Ibom	Abia
	Bauchi	Kaduna	Kogi	Ogun	Bayelsa	Anambra
Member States	Borno	Kano	Kwara	Ondo	Cross River	Ebonyi
	Gombe	Katsina	Plateau	Osun	Delta	Enugu
	Taraba	Kebbi	Nasarawa	Oyo	Edo	Imo
	Yobe	Sokoto	Niger	Lagos	Rivers	
		Zamfara	FCT			

Appendix H.1, Comparison of the Baseline (S0) Domestic Crop Production Plan (Cropping Pattern) from the NEFM with that of the Base-year (Input) Data



Key: NLP DCP = Domestic crop production from the Baseline model (NEFM); NBS DCP = Domestic crop production data at the base-year from NBS; MT = Metric tonnes.

Appendix H.2, Comparison of the Baseline (S0) Regional Crop Production Outputs from the NEFM with that of the Base-year (Input) Data.



	NW	NE	NC	SW	SS	SE
NLP Regional Crop Production (MMT)	25	23	35	18	17	16
NBS Regional Crop Production (MMT)	18	14	27	15	15	15
% Deviation (PAD or MAPD)	39.6	65.3	27.5	18.9	18.2	6.3

Key: % Deviation (PAD or MAPD) = the percentage increase in crop production from the Base-year crop production output; MMT = Million metric tonnes; NLP = Regional crop production results from NEFM; and NBS = Regional crop production data from Nigerian National Bureau of Statistics (NBS). Also NW = North-West, NE = North-East, NC = North-Central, SW = South-West, SS = South-South, and SE = South-East, geo-political zones.

HIGHLIGHTS

- A bespoke Nigerian Energy-Food Model has been developed for current and future use.
- Nigeria can meet current food/ethanol demands without affecting its food security.
- Doubling current ethanol/food demands adversely affects land-use and food security.
- Cassava is the ‘optimal’ feedstock for profitable ethanol production in Nigeria.
- Implementing a carefully-articulated land-use policy is recommended.
- Potential socio-economic benefits to the Nigerian economy are significant.