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TEST OF ENERGY EFFICIENCY IN CONVENTIONAL SMALL-SCALE MAIZE PRODUCTION IN NIGER STATE, NIGERIA AND ITS IMPLICATION ON SUSTAINABLE AGRO-ECOLOGY: APPLICATION OF STOCHASTIC FRONTIER APPROACH

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ABSTRACT

The research conducts an in-depth investigation on agro-ecology management through efficient energy optimization in maize production in Niger State, Nigeria. The study employed multi-stage sampling technique to elicit information from 120 respondents through administration of pre-tested questionnaire and interview schedule. Data were collected during the 2014 cropping season. Stochastic energy frontier function which incorporates the neoclassical test of efficiencies was used to estimate energy efficiency. Results show that total inputs energy used in maize production was 2227.81 MJha^{-1}, with 85.2% of input energy contributed by agrochemical input or coming from biological energy with energy ratio of 4.5 in the production systems. Furthermore, results shows that average farmers' operate at rational stage (RTS=0.72) of energy inputs utilization which was further collaborated by the mean energy efficiency score of 0.78. The mean efficiency score of 0.78 implies that average farmers are beneath the energy frontier and therefore require energy saving of 22 percent to be on frontier. However, the estimated gamma coefficient (0.54) and the generalized likelihood test result indicate presence of energy inefficiency effects in maize production. Therefore, reduction in agrochemical consumption and improvement in agro management practices are important for energy saving and decreasing the environmental risk problems in the area. Also policies that prevent global warming, soil and water pollution should be enacted thereby creating environmental friendly ecosystem.

Keywords: Agro-ecology management; energy-efficiency; stochastic frontier; Maize; Niger state; Nigeria

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1.0 INTRODUCTION

The age old necessities of life are food, clothing and shelter. The 20th and 21st has century dramatized and devised a fourth one known as energy. Energy starvation of the technological complex that maintains modern society may soon be a crucial problem as feeding the world's hungry. Therefore, energy starvation could well precipitate more widespread food starvation. Solutions for energy crisis are strongly dependent on the technology of how energy is utilized. However, to make a physical change in the world, it is necessary to use four resources: energy, space, matter and time. How well a tasked is been performed can be measured in terms of the amount of fuel consumed, the mass of material used, the space occupied, labour hour required to accomplish a task and the ingenuity with which these resources are utilized. Squandering of irreplaceable energy sources, wastes of materials, or large expenditures of space and time should not be tolerated if the necessities of life are to be provided for all. Technology addresses itself to the efficient utilization of these four ingredients of physical change. The era of cheap energy is now coming to an end and the populace will necessarily become energy conservation conscious because of the rising cost for energy and the dire consequences of placing additional stresses on our biosphere, already showing serious strain signs. The introduction of high yielding varieties of major crops in sixties paved the way for important technological changes that led to unprecedented rise in the crop yield and land productivity in many parts of the country. These new production technologies made use of large quantity of inputs such as fertilizers, chemicals, plant protections, diesels, farm machineries, fuel, electricity, etc. The application of these inputs demands more and more use of energy in the form of human, animal and machinery. With improved rural transportation system, the rural unskilled labour has become more mobile thereby making agricultural labour supply elastic. Therefore, since the energy scenario of crop production has changed with the introduction of modern inputs, it become imperative to study the energy utilization patterns analytically and suggest what is likely to happen in the future on energy front. Furthermore, there are growing trends in the application of two hybrid neo-classical competing approaches for measurement of energy efficiency; parametric stochastic frontier model and nonparametric data envelopment analysis (DEA), with little or no documentary evidence of its application in Nigeria were it has been widely used in agricultural production. Examples of studies conducted in other countries which made used of these two hybrid neo-classical approaches are Iran (Hossein *et al.*, 2013; Avval *et al.*, 2012; Rahelel *et al.*, 2012; Morteze *et al.*, 2012; Omid *et al.*, 2011; Pishgar-Komleh *et al.,*2011; Banaeian *et al*., 2011; Mohammadi and Omid, 2010), Pakistan (Nassiri and Singh, 2009; Zhou *et al.*, 2008; Malana and Malano, 2006), and India (Chauhan *et al*., 2006). The main advantage of Cobb-Douglas over DEA is its ability to allow measurement error; and the advantage of Data envelopment analysis (DEA) is that it does not require any prior assumptions on the underlying functional relationships between inputs and outputs. Nowadays, stochastic frontier technique and data envelopment analysis (DEA) technique has gained great popularity and application in energy and environmental (E and E) modeling. It is an established fact worldwide that agricultural production is positively correlated with energy input (Taherigaravand *et al*., 2010), as such efficient energy utilization will help to achieve increased productivity and contributes to the economy, profitability and competitiveness of agriculture sustainability in rural areas (Lorzadeh *et al*., 2012). Moreover, in order to meet the ever increasing demand for food production, energy use in agriculture production has become more intensive which even brought some important human health and environment issues forcing humans to make more efficient use of inputs to maintain a sustainable agriculture production (Marai, 2012). Therefore, this research ought to benchmark energy efficiency in maize production in Niger state, Nigeria by application of stochastic energy frontier technique with a view to derive policy implications for proper policy recommendations thereby exerting positive effect on managing the agro-ecosystems and agro-ecology in order to ensure sustainability in agriculture.

2.0 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Energy efficiency is the ability of a firm to produce a given level of output with minimum energy inputs under a given technology. In one sense, the efficiency of a firm is its success in producing as large an amount of output as possible from given sets of energy-inputs. Maximum efficiency of a firm is attained when it becomes impossible to reshuffle a given energy resource combination without decreasing the total output. Since the seminal work of Farrell in 1957, several empirical studies have been conducted on farm efficiency. These studies have employed several measures of efficiency. These measures have been classified broadly into three namely: deterministic parametric estimation, nonparametric mathematical linear programming and the stochastic parametric estimation. There are two non-parametric measures of efficiency. The first, evaluates efficiency based on the neoclassical theories of consistency, restriction of production form, recoverability and extrapolation without maintaining any hypothesis of functional form; and the second, decomposed efficiency into technical and allocative. Several approaches, which fall under the two broad groups of parametric and non-parametric methods, have been used in empirical studies of energy efficiency, e.g Omid *et al.*(2011); Pishgar-Komleh *et al.*(2011); and Mohammadi and Omid (2010). These include the production functions, programming techniques and recently, the efficiency frontier and data envelopment analysis (DEA). The frontier is concerned with the concept of maximality in which the function sets a limit to the range of possible observations. Thus, it is possible to observe points below the energy frontier for firms producing less than the maximum possible output but no point can lie above the energy frontier, given the technology available. The frontier represents an efficient technology and deviation from the frontier is regarded as inefficient. Literature emphasizes two broad approaches to imposed energy frontier estimation and energy efficiency measurement: The non-parametric programming approach, and the statistical approach. The programming approach requires the construction of a free disposal convex hull in the energy input-output space from a given sample of observations of energy inputs and outputs. The convex hull (generated from a subset of the given sample) serves as an estimate of the energy frontier, depicting the maximum possible output. Energy efficiency of an economic unit is thus measured as the ratio of the actual output to the maximum output possible on the convex hull corresponding to the given set of energy inputs. The statistical approach of energy frontier estimation can be sub-divided into two, namely, the neutral shift frontiers and the non-neutral shift frontiers. The former approach measures the maximum possible output and then energy efficiencies by specifying a composed error formulation to the conventional production function. The non-neutral approach uses a varying coefficients production function formulation. The main feature of the stochastic energy frontier is that the disturbance term is composed of two parts, a symmetric and a one-sided component. The symmetric (normal) component, Vi captures the random effects due to the measurement error, statistical noise and other non symmetric influences outside the control of the firm. It is assumed to have a normal distribution. The one-sided (non-positive) component, Ui with $Ui \geq 0$, captures energy inefficiency relative to the stochastic frontier. This is the randomness under the control of the firm. Its distribution is assumed to be half normal, truncated or exponential. The random errors, Vi are assumed to be independently and identically distributed as $N(0, \sigma^2)$ random variables, independent of Uis. The Uis are also assumed to be independently and identically distributed as, for example, exponential, half normal, truncated normal and gamma.

The stochastic frontier function is typically specified as:

$Yi=f(Xij; ß) + (Vi-Ui)$ (i = 1, 2, n) …………………….. (1)

Yi = Output of the ith firm;

Xij = Vector of actual jth energy-inputs used by the ith firm;

ß = Vector of energy coefficients to be estimated;

Vi = Random variability in the production that cannot be influenced by the firm and;

Ui = Deviation from maximum potential output attributable to energy inefficiency.

The model is such that the possible production Yi, is bounded above by the stochastic energy quantity, f (Xi; ß) exp (Vi), that is when Ui = 0 hence, the term stochastic frontier. Given suitable distributional assumptions for the error terms, direct estimates of the parameters can be obtained by either the Maximum Likelihood Method (MLM) or the Corrected Ordinary Least Squares Method (COLS). However, the MLM estimator has been found to be asymptotically more efficient than the COLS thus, the MLM has been preferred in empirical analysis. In the context of the stochastic frontier energy function, the energy efficiency of an individual firm is defined as the ratio of the observed output to the corresponding frontier output, conditional on the levels of energy inputs used by the firm. Thus, the energy efficiency of firm is:

Ei = exp (-Ui) ………………………… (2)
Ei = Yi/Yi* …………………………… (3)
=f(Xi; ß) exp (Vi - Ui) /f(Xi; ß) exp (Vi) exp (-Ui).
Ei = energy efficiency of farmer i;
Yi = observed output; and,
Yi* = frontier output.

The energy efficiency of a firm ranges from 0 to 1. Maximum efficiency in production records a value of 1.0. Lower values represent less than maximum efficiency in production. Energy score of a farmer that is less than one indicates that the farmer is using more energy than required from different sources

3.0 METHODOLOGY

3.1 Study Area: This study was based on the farm level data on small scale maize farmers in Niger State, Nigeria. Niger State is located in the Guinea Savannah zone of Nigeria and lies between latitudes 8°20'N and 11°30'N of equator and longitude 3°30'E and 7°20’E of the Greenwich Meridian .The land area is about 76,363 square kilometre with varying physical features like hills, lowland and rivers. The state enjoys luxuriant vegetation with vast Northern Guinea savannah found in the North while the fringe in mostly southern guinea savannah. The people are predominantly peasant farmers cultivating mainly food crops such as yam, maize, rice, millet etcetera for family consumption, market and cash. Farming activities are usually carried out using hand tools and other simple implements (Sadiq, 2014).

3.2 Sampling Technique: The study employed multi-stage sampling technique. Data mainly from primary sources were collected from one out of the three Agricultural zones, namely, Kuta zone which was purposively selected given its conspicuous importance in maize crop production. The second stage involved purposive selection of three LGAs, namely, Shiroro, Bosso and Paikoro LGAs, respectively based on the preponderance of small-scale maize farmers’ in the areas. The third stage involved random selection of four villages from each LGA. The final stage involved simple random selection of 10 farmers from each of the villages, thus a total of 120 respondents. Data was collected with the aid of pre-tested questionnaire in which input-output data of the farmers defined within production content was obtained. Both energy index models and stochastic energy frontier model were used to analyze the data collected.

Table 1.1: Energy sources grouped under different categories of energy

Category energy	Sources of energy
Direct Energy	Human, Animal, Fuel wood, Agricultural waste, Petrol, Diesel, Kerosene, Electricity, etc
Indirect Energy	Seeds, Farm yard manure, Chemicals, Fertilizer, Machinery, etc
Renewable Energy	Human, Animal, Fuel wood, Agricultural wastes, Seeds, Farm yard manure, etc
Non-Renewable	Petrol, Diesel, Electricity, Chemicals, Fertilizers, Machinery, etc

Commercial Energy	Petrol, Diesel, Electricity, Chemicals, Fertilizers, Machinery, Seeds, etc
Non-Commercial Energy	Human, Animal, Fuel wood, Agricultural wastes, Farm yard manure, etc
Biological Energy	Diesel, Pesticides, Fertilizers, Machinery, Electricity, etc
Industrial Energy	Human, Seeds and H_2O for Irrigation

Table 1.2: Equivalents for various sources of energy

Particulars	**Units**	**Equivalent energy, MJ**	**Remarks**
Adult man	Man-hour	1.96	
Women	Woman-hour	1.57	
Child	Child-hour	0.98	
Nitrogen	Kg	60.60	
P_2O_5	Kg	11.1	
K_2O	Kg	6.7	
Herbicides	Litre	120	
Improved seed	Kg	15.2	Processed
Maize product	Kg (Dry mass)	14.7	The main output is grain

3.2.1 Model specification

1. Energy standard equations: Standard equations were used to determine the following energy model index:

Energy ratio = output energy ($MJha^{-1}$)/Total input energy ($MJha^{-1}$) (1)

Energy productivity = Grain yield ($kgha^{-1}$)/ Total input energy ($MJha^{-1}$) (2)

Net energy = Total output energy ($MJha^{-1}$) – Total input energy ($MJha^{-1}$) (3)

Specific energy = Total input energy ($MJha^{-1}$)/ Grain yield ($kgha^{-1}$) (4)

2. The Stochastic Frontier Production Function: The model was specified as follows:

ln Yi = lnßo + Σ ßj lnXij + (Vi – Ui) (5)

Where,

Yi = maize output (MJ) from farm i;

Xi = Vector of energy inputs used.

X_1 = nitrogen (MJ);

X_2 = P_2O_5 (MJ);

X_3 = K_2O (MJ);

X_4 = family labour (MJ);

X_5 = hired labour (MJ);

X_6 = improved seed (MJ); and

X_7 = herbicides (MJ).

Vi = random variability in the production that cannot be influenced by the farmer;

Ui= deviation from maximum potential output attributable to energy inefficiency.

ßo = intercept;

ß$_{1-6}$ = vector of technology parameters to be estimated;

i = 1, 2, 3, n farms; and,

j = 1, 2, 3, m energy inputs.

The inefficiency model is:

$Ui = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \ldots\ldots + \delta n Zn$ (6)

Where, Ui = energy inefficiency effect of the ith farm;

Z_1 = education (years);

Z_2 = farming experience (years);

Z_3 = extension contact (yes=1, otherwise=0);

Z_4 = soil texture (sandy loamy=1, otherwise=0);

Z_5 = plant protection practices (yes = 1, otherwise =0);

δ_0 = Intercept

δ_{1-8} = variable vector parameters to be estimated.

The ß and δ coefficients are un-known parameters to be estimated along with the variance parameters σ^2 and γ. The sigma (σ^2) and gamma (γ) coefficients are the diagnostic statistics that indicate the correctness of the assumptions made on the distribution form of the error term and the relevance of the use of the stochastic energy frontier function.

4.0 RESULTS AND DISCUSSION

4.1 Source-wise energy consumption and energy balance: Amount of energy inputs and output in maize production are given in Table 2. Based on the evaluation, average human labour required in the study area was 145.68 manhours/ha. Moreover, maize production used 2.67kgha^{-1} of seeds, 23.62 kgha^{-1} of nitrogen, 11.81 kgha^{-1} of P_2O_5, 11.81kgha^{-1} of K_2O and 2.17 litre/ha of herbicides. Furthermore, the total energy consumption during the production period of maize was found to be 2227 MJha^{-1}. In some related studies in Iran, Lorzadeh *et al*. (2011) reported total energy input of 29307.74MJha^{-1} for maize. The yield value of maze was 683.54kgha^{-1}; accordingly, the total output energy was calculated as 10048.04MJ ha^{-1}. It is evident that, the largest part of total energy input was provided by non-renewable energy (85.4%), and renewable energy contributes minimal quantum (14.6%). The distribution of total inorganic fertilizer energy input is as follows: 64% nitrogen, 5.9% phosphate and 3.6% potassium. Similar studies have also reported that inorganic fertilizer were the most intensive energy inputs used in agricultural production (Avval *et al*., 20112; Mobtaker *et al*., 2010). Excessive use of chemical fertilizers energy input in agriculture may create serious environmental consequences such as nitrogen loading in the environment and receiving water, poor water quality, carbon emissions and contamination of the food chain. Integrating a legume into the crop rotation, application of composts, chopped residues or other soil amendments may increases soil fertility in the medium term and so reduces the need for chemical fertilizer energy inputs. Moreover, applying a better management technique, employing the conservation tillage methods or technological upgrade to substitute inorganic fertilizer energy with organic fertilizer energy resources may be the pathways to minimize the usage and thus reduce its environmental footprints.

Table 2: Source-wise energy consumption in maize production

Variables	**Quantity units ha^{-1}**	**Total energy equivalents (MJha^{-1})**	**% of Total energy**
a. Inputs			
Direct energy			
Family labour	84.88 manhours	166.37	7.5
Hired labour	60.80 manhours	119.17	5.5
Sub-total		**285.54**	
Indirect energy			
Seeds	2.67	40.58	1.8
Nitrogen	23.62	1431.07	64

Phosphorus (P_2O_5)	11.81	131.09	5.9
Potassium (K_2O)	11.81	79.13	3.6
Herbicides	2.17	260.40	11.7
Sub-total		**1942.27**	
Total input energy (MJha^{-1})		**2227.81**	**100**
b. Output			
Maize	683.54	10048.04	
Total energy output (MJha^{-1})		**10048.04**	

Source: Field survey, 2014

4.2 Shares of energy inputs for maize production: The energy indices including energy ratio, energy productivity, specific energy and net energy gain were presented in Table 3. Energy ratio in maize production was 4.5; implying that output energy of maize obtained was 4.5 times greater than total input energy. Also, specific energy was 3.26MJkg^{-1}. Energy ratio and specific energy are integrative indices indicating the potential environmental impacts associated with the production of crops and these parameters can be used to determine the optimum intensity of land and crop management from an environmental point of view. The energy productivity of maize production was 0.31kgMJ^{-1}. This means that 0.31kg of output was obtained per energy unit (MJ). Furthermore, the results revealed the input energy classification used for maize production according to direct, indirect, renewable and non-renewable energy forms. It is evident that, the ratios of direct and indirect energy forms are far apart, also the ratios of renewable and non-renewable energy forms are highly different from each other. The ratio of non-renewable energy is very high (85.4%), indicating that maize production in the region depends mainly on fossil fuels. These results may be due to the fact that renewable energy forms such as human labour and seed are passive in production, while non-renewable energy forms especially fertilizer and chemical plays intensive role in production. Several researchers have reported ratio of direct energy higher than that of indirect energy, and the rate of non-renewable much greater than that of renewable in production of different agricultural crops (Avval *et al*., 20112; Mobtaker *et al*., 2010). Use of non-renewable energy sources to boost agricultural productions in developing countries with low levels of technological knowledge not only results in environmental degradation, but also confronts us with the dilemma of a rapid rate of depletion of energetic resources; while renewable energy sources can be used indefinitely with minimal environmental impacts associated with their production and use. Development of renewable energy usage technologies such as integrated pest management technique and utilization of alternative sources of energy such as organic fertilizers (compost, manure, etc.) may be the pathways to substitute the non-renewable energy forms with renewable resources and thus reduce their environmental footprints.

Table 3: Yield and energy requirement in different form for maize production

Items	**Unit**	**Quantity**
Yield	Kgha^{-1}	683.54
Total input energy	MJha^{-1}	2227.81
Output energy	MJha^{-1}	10048.04
Energy ratio		4.5
Specific energy	MJkg^{-1}	3.26
Energy productivity	KgMJ^{-1}	0.31
Net energy	MJha^{-1}	7820.23
Agro-chemical energy ratio	%	85

Industrial energy	$MJha^{-1}$	326.12 (14.6)
Biological energy	$MJha^{-1}$	1901.69 (85.4)
Renewable energy	$MJha^{-1}$	326.12 (14.6)
Non-renewable energy	$MJha^{-1}$	1901.69 (85.4)
Commercial energy	$MJha^{-1}$	1942.27 (87.2)
Non-commercial energy	$MJha^{-1}$	285.54 (12.8)

4.2 Energy efficiency and associated inefficiency factors: Maximum Likelihood Estimates of the stochastic frontier energy function and the inefficiency are presented in Table 4. All parameters estimate conforms to the *aprior* expectation and were all statistically significant with exception of hired labour and herbicides, thus meaning that these energy-resources were significantly different from zero and were important in maize production. The non-significant of herbicides and paid labour might be due to low usage of these resources. The elasticity coefficients of energy yield from nitrogen, P_2O_5, K_2O, family labour and seeds were all significant at 1 percent probability level and depict inelastic relationship between MJ input and maize output. Therefore, energy inputs with positive MJ coefficients imply an increase in maize output, while negative coefficient MJ implies a decrease in maize output. Except phosphorus MJ which was in the irrational energy production stage III (deminishing) which might be due to the plant physiological requirement, all the significant inputs MJ were within the rational energy production stage II which is referred to as economic stratum in production theory. However, a unit MJ increase in nitrogen energy, K_2O energy, family labour enery and seeds energy will lead to an increase in maize output by 0.23, 0.38, 0.08 and 0.031 respectively; while a unit MJ increase in P_2O_5 energy will result in a decrease in maize output by -0.08. Hired labour and herbicides were not significant; as such they need no further discussions. However, the estimated return to scale (RTS) which is the sum value of all energy elasticity coefficients was 0.72; and this implies decreasing returns to scale. This suggests that maize farmers in the study area can increase their output by judicious utilization of all energy-resource used in the production; a unit decrease in the quantities of the productive energy resources would lead to less than proportionate increase in output of maize, *ceteris paribus*. Furthermore, measure of technical efficiency of energy resources used such as Average Energy Product (AEP), Marginal Energy Product (MEP) which shows sensitivity energy input analysis were derived. The values of the MEP show that the farmers were more efficient in the use of K_2O energy than the other resources. This suggests that if additional MJ were available, it would lead to an increase in maize yield by 48.77 among the farmers. This implies that the farmers were more technically energy efficient in the use of K_2O. Of all the energy resources used, P_2O_5 had the least MEP (-6.13MJ), thus, shows inefficiency in the use of available P_2O_5.

The estimated coefficient in the explanatory variables in the model were presented in the lower part of Table 4, in the sense that energy inefficiency effects are of interest and have important implication. The sources of inefficiency were examined by using the estimate δ coefficients associated with the variables. The inefficiency variables specified were education, farming experience, extension contact, soil type and plant protection practices. The co-efficient of all the variables were negative and significant at various percent probability levels. The sign of the estimated coefficient in the model have important implication on the energy efficiency in maize production. The coefficient of education and extension contact were estimated to be negative and significant at 10 percent and 5 percent levels respectively. This indicates that farmers with formal education tend to be more energy efficient, given that formal education is imperative for better understand and adoption of new technology which subsequently make it possible to move close to the frontier. Furthermore, educated farmers coupled with extension contact are expected to be more receptive to improved farming techniques and therefore tends to have higher level of energy efficiency than farmers with non-formal education. Also, farmers with non-formal education would be less receptive to improved farming techniques and in some cases even laggards. The predicted coefficient of farming experience had the expected negative sign and was significant at 1percent, implying that being an experienced farmer was important to significantly cause a farmer to attain higher levels of efficiency if he can rearrange his energy-inputs to obtain higher output levels with a given technology. However, farmers tend to be more active, acquire more skills and training as they spend more years in production which culminates in increase efficiency. The estimated coefficient of soil texture was negative and significant at 1 percent. This implies that sandy loamy soil texture plays an important role in mineralization process thereby increasing energy efficiency. The predicted coefficient of plant protection practices was negative and significant at 1 percent, implying that this variable decrease energy inefficiency or increase energy efficiency. This means that farmers that adopt appropriate plant protection practices such as weed control, insect-pest control, application of recommended agro-chemical dosages are likely to be more energy efficient than those who subvert the process either as a result of credit paucity. The diagnostic statistics for σ^2 and γ are 0.47 and 0.54 respectively, and are significant at 1 percent level respectively. The sigma squared σ^2 indicates the goodness of fit and correctness of the distributional form assumed for the composite error term while the gamma γ indicates that the systematic influences that are un-explained by the energy function are the dominant sources of random errors. Therefore, inefficiency effects make significant contribution to the energy inefficiencies of maize farmers. The estimated gamma parameter (γ) of 0.54 indicates that about 54% of the variation in the value of farm output of maize farmers was due to their differences in energy efficiencies. However, the result of generalized likelihood ratio test which is defined by the chi-square distribution reveals that the hypothesis which specifies that the inefficiency effects were absent from the model was strongly rejected (coefficient of β = 0), thus, proving that traditional response function (OLS) is not an adequate representation of the data given that the magnitudes of the explanatory variables incorporated into the inefficiency model were not equal to zero. In other words the null hypothesis which specifies that inefficiency effects in the stochastic frontier energy function are non-stochastic is rejected, since the χ^2cal value (15.23) is greater than χ^2 critical (14.68) at 0.05 probability level, hence the null hypothesis of no energy inefficiency in maize production was rejected and the alternative accepted.

Table 4: Maximum-likelihood estimates of parameters of the Cobb-Douglas stochastic energy frontier function and energy inefficiency in maize production in Niger state, Nigeria.

Variable	Parameters	Coefficients	MEP
General model			
Constant	β_0	0.93(2.98)***	
Nitrogen	β_1	0.23(7.67)***	1.63
P_2O_5	β_2	-0.08(3.81)***	-6.13
K_2O	β_3	0.38(24.0)***	48.77
Family labour	β_4	0.08(14.9)***	4.91
Hired labour	β_5	0.014(1.17)^{NS}	1.2
Seed	β_6	0.031(20.7)***	7.68
Herbicides	β_7	0.063(1.37)^{NS}	2.45
Return to scale		**0.72**	
Inefficiency model			
Constant	δ_0	0.31(3.41)***	
Education level	δ_1	-0.64(1.78)*	

Experience	δ_2	-0.21(2.88)***	
Extension contact	δ_3	-0.13(2.15)**	
Soil type	δ_4	-0.44(3.65)***	
Plant protection practices	δ_5	-0.09(7.58)***	
Diagnostic statistic			
Sigma-square $\sigma^2 = \sigma^2 v + \sigma^2 u$		0.47(3.92)***	
Gamma $\gamma = \sigma^2 u/\sigma^2 v + \sigma^2 u$		0.54(4.91)***	
Log likelihood function (llf)		11.23	
LR test		15.23	

Source: Computer print-out of FRONTIER 4.1

Note: ***, **, * Implies significance at 0.01, 0.05 and 0.10 probability levels respectively.

NS: Non-significant; ( ): t-values

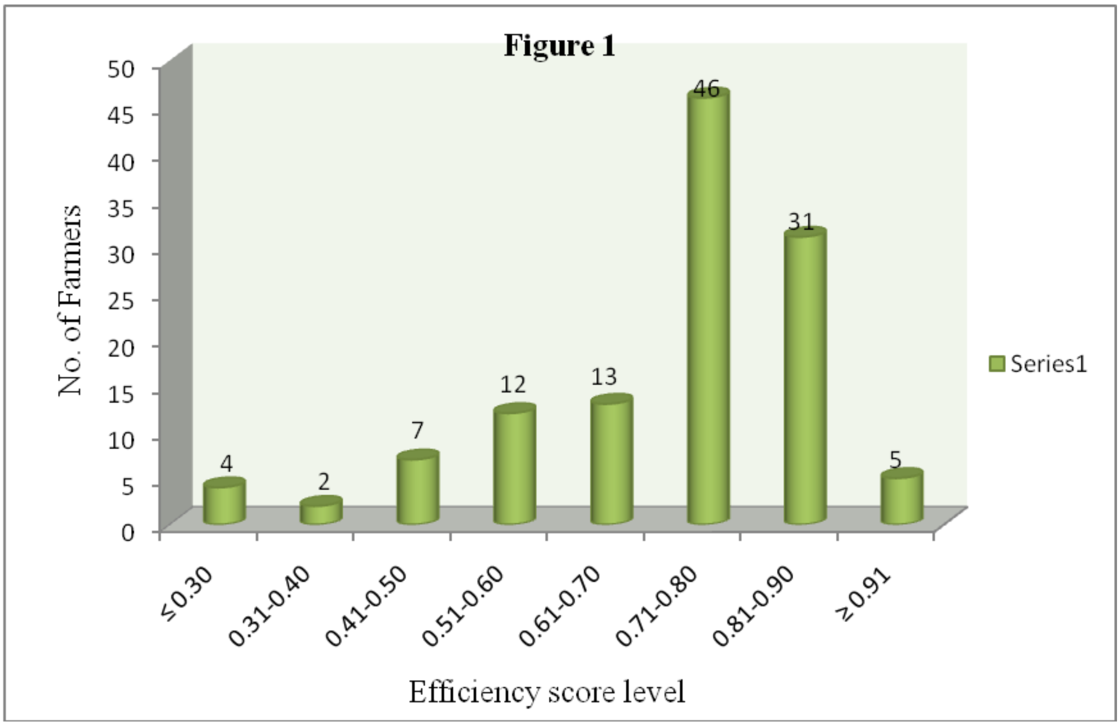
4.3 Individual farm energy efficiency scores. The frequency distribution of predictive individual farm level energy efficiency score for each respondent was also estimated and was shown in Table 5 and depicted in figure 1. The result of the frequency distribution of energy efficiency estimates shows that the estimates ranged from 0.10 to 0.94. Energy score of a farmer that is less than one indicates that the farmer is using more energy than required from different sources. The wide variation in the energy efficiency implies that all the farmers were not fully aware of the right energy techniques or did not apply them properly. The distribution seemed to be skewed toward the frontier given that the mean efficiency was 0.78. The minimum energy efficiency score was 0.10, which indicated high level of inefficiency (waste) in energy resource allocation, while the maximum energy efficiency score was 0.94, implying that the most efficient farmer operated closer to the frontier with minimal energy wastage. Even with the mean of 0.78, 68.4% of the farmers are frontier farmers since their efficiency scores were above the mean. This implies that an average farmer need energy saving of 22% scores (1– [0.78/1.00]*100) to be on the frontier. However, the most efficient farmer needs energy saving score of 6% (1– [0.94/1.00]*100) to be on the frontier, while the average farmer needs energy saving score of 17% (1 – [0.78/0.94]*100) to attain the status of the most energy efficient farmer. Furthermore, the least efficient farmer needs energy saving score of 89.4% (1– [0.10/0.94]*100) to attain the status of the most energy efficient farmer and 90% energy saving score (1– [0.0.10/1.00]*100) to be on the frontier. From the results obtained, although farmers were generally relatively efficient, they still have room to increase energy efficiency in their production activities since 22% efficiency gap from the optimum (100%) remains yet to be attained by all farmers. An energy efficiency score of less than one for a farmer indicates that, at present conditions, he is using more energy than required. Therefore, it is desired to suggest realistic levels of energy to be used from each source for every inefficient farmer in order to avert/avoid wastage of energy. As such in setting realistic input levels, total energy input could be reduced while, maintaining the current production level and also assuming no other constraining factors.

Table 5: Deciles frequency distribution of energy efficiencies

Efficiency level	**Frequency**	**Relative efficiency (%)**
≤ 0.30	4	3.3
0.31-0.40	2	1.7
0.41-0.50	7	5.8
0.51-0.60	12	10
0.61-0.70	13	10.8
0.71-0.80	46	38.3

0.81-0.90	31	25.8
≥ 0.91	5	4.3
Total	**120**	**100**
Minimum	**0.10**	
Maximum	**0.94**	
Mean	**0.78**	

Source: Computed from MLE Results



5.0 CONCLUSION AND RECOMMENDATIONS

The research investigated agro-ecology management through efficient energy utilization in maize production in Niger State, Nigeria using stochastic frontier energy function. These techniques helped to identify the impact of energy use from different inputs on output, measure efficiency scores of farmers, segregate efficient farmers from inefficient farmers and find the wasteful uses of energy by inefficient farmers. In the use of P_2O_5, there is higher potential for increasing output by decreasing its application dosage, given that it is inconsistent; indicating that the use of this input was high, resulting in energy dissipation as well as imposing negative effects on environment and human health. The results of energy frontier application further indicated that there were substantial energy inefficiencies for farmers; such that, a potential of almost 22% increased energy efficiency is required for farmers to operate efficiently. Moreover, the results revealed that maize production in the study area showed a high sensitivity to non-renewable energy sources which may results in both environmental deterioration, rapid rate of depletion of these energetic resources, thus, causing environmental challenges such as global warming, soil and water pollution which in turn affects human health. This trend indicates that environmental challenges will worsen in the near future if there is absence of managerial consideration in excessive non-renewable energy application pattern in these agro-ecosystems.. Therefore, policies should emphasize on development of new technologies to substitute fossil fuels with renewable energy sources aiming efficient use of energy and lowering the environmental footprints, i.e, development of renewable energy usage technologies such as conservation tillage methods, utilization of alternative sources of energy such as organic fertilizers are suggested to reduce the environmental footprints of energy inputs and to obtain sustainable food production systems. However, the research inferred that improvement in energy use efficiency among the farmers is the responsibility of the individual farmers, government and research institutions.

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