International Journal of Research in Agriculture and Forestry
Volume 4, Issue 9, 2017, PP 20-32
ISSN 2394-5907 (Print) & ISSN 2394-5915 (Online)

Global Warming Potentials of Lowland Paddy Rice Production in Kwara State of Nigeria: Lessons for Sustainable Agriculture

***Sadiq, M. S[1], Singh, I.P[1], Yakubu, G.M[2]**

[1]*Department of Agricultural Economics, SKRAU, Bikaner, India*
[2]*Department of Agricultural Economics, FUT, Minna, Nigeria*

***Corresponding Author:** Sadiq, Mohammed Sanusi, Department of Agricultural Economics, SKRAU, Bikaner-334006, India*

***Received Date:** 15-08-2017* ***Accepted Date:** 05-09-2017* ***Published Date:** 23-09-2017*

ABSTRACT

The present research empirically determines the energy balance and global warming potentials (GWP) of lowland paddy rice production in Kwara State of Nigeria using cross-sectional data obtained from 200 farmers during the 2016 cropping season via multi-stage sampling design. Information elicitation from the field was achieved using structured questionnaire complemented with interview schedule and the collected data were synthesized using Data envelopment analysis (DEA), energy index and Tornqvist index models. Findings showed that the majority of the farmers did not achieve the twin of global and local efficiencies i.e scale efficiency which was due to either non-awareness or inappropriate application of energy production techniques in the studied area, thus resulting in dissipation of excess energy inputs which have GWP that endanger the biodiversity and food security. Since the results indicated the sensitivity of paddy rice production in the studied area to non-renewable energy (fossil fuel and agrochemical inputs) and given the direct synergy between non-renewable energy inputs with GHG emissions with GWP, the study recommends among others the adoption of sustainable farming practices in order not to endanger the biodiversity and future food security of the country.

Keywords: *Energy balance; GHG emissions; GWP; Lowland; Paddy rice; Nigeria*

INTRODUCTION

Use of energy in agriculture has surged due to increased food demands by the ever growing world population (Kizilaslan, 2009). Dagistan *et al*.(2009) reported that the major setbacks to increased energy consumption were inadequate energy sources, high production costs, incorrect supply allocation, and increased national and international competition in agricultural trade.

The enormous greenhouse gases (GHG) emission, especially carbon dioxide (CO_2), produced by human activities and their influence on climate conditions has become a major ecological and political challenges. According to IPCC (2007), for over the past decades, the concentration of GHG in the atmosphere has quickly increased e.g CO_2 concentration had increased to 380ppm in 2006 compared to 280ppm in 1700. Timmermann *et al*. (1999) as cited by Mondani *et al*.(2017) reported that if the increase in the trend of GHG emission remains unchecked i.e continues, there is every possibility of huge climate changes in the future. Although predictions have been subject to arguments due to uncertainty in climate projections- most scientific organizations agree that increase in temperature has considerable negative impacts on human developments, natural and agricultural ecosystems (Fischlin and Midgeley, 2007). Nevertheless, it is believed that these occurrences can be avoided with a significant reduction in GHG emission (Meinshausen *et al*., 2009). Therefore it becomes imperative to realize GHG emissions from various actions and resources in agricultural production systems in order to identify the potential areas for emissions reductions.

The first reasonable step for GHG emission reductions in agro ecosystem is to quantify the amount of emissions from specific energy input sources in agricultural production processes and identify the most economically sensible options for possible GHG emission reduction. To achieve these purposes, creation of available information related to energy use in farm operations, their exchange to GHG equivalents and finally expressing energy use in terms of

GHG emission as kg carbon equivalent is very essential.

One of the principal requirements of sustainable agriculture is the efficient utilization of energy and to evaluate the sustainability of agriculture, its energy efficiency must be considered and major sources of energy waste must be identified and assessed. In order to achieve sustainable development, it is necessary to manage energy use and greenhouse gases (GHG) emission in all ramifications of production processes. For agricultural production to significantly increase while also minimizing its impact on future climate change, it has become important to understand the current status of energy and GHG budgets and their link with farm outputs. Energy and GHG emission analysis in agricultural production operations result in determining overuse sectors and may act as a platform to improve production processes.

While literature display very few studies (e.g Pathak and Wassmann, 2007; Yousefi *et al.*, 2014; Asgharipour *et al.*, 2016 and Sadiq *et al.*, 2017) on the topic of gas emissions global warming potentials as results of agricultural in-farm and off-farm activities, paucities of information about gas emissions in the production processes of agricultural outputs may be one of the most important reasons for this ignorance.

Till date, to the best of our knowledge, the literature review showed no research on GHG emission global warming potentials and carbon efficiency of non-renewable energy input used in paddy rice production in the studied area in particular and the country in general despite the growing cultivation of this crop. Therefore, the ultimate aim of this study was to quantify in mass energy inputs and output of lowland paddy rice production to gain a better understanding of the relationship between energy inputs and yield, GHG emission global warming potentials and carbon efficiency of lowland paddy rice production in Kwara State of Nigeria. The specific objectives were:-

- To determine the global, local and scale efficiencies of the farmers in the studied area;
- To identify the smart farmers as reference set to be emulated by the inefficient farmers in the studied area;
- To determine the Total factor productivity (TFP) of energy used in paddy rice production in the studied area;
- To determine the energy economic indices;
- To determine the optimum and energy saving target ratio of the farmers in the studied area; and,
- To estimate the GHG emissions and the global warming potentials of non-renewable energy inputs used in paddy rice production in the studied area.

RESEARCH METHODOLOGY

The coordinates of Kwara state in Nigeria are between longitudes 4^0 $20^'$ and 4^0 $25^'$ East of the Greenwich Meridian and latitudes 8^0 $30^'$ and 8^0 $50^'$ North of the equator. The population size of the state is about 2.3 million, approximately 1.69% of the total population of the country (NPC, 2006) having relied upon immigration for population growth and development. The landmass of the state is approximately 36,825 square kilometers having varying physical features like hills, lowland, rivers etc and the vegetation of the state comprises of guinea savannah in the North-East and rainforest to the South-West. The mean annual precipitation and monthly temperature ranges between 1000-1500mm and 25^0C-34^0C respectively (NBS, 2010). The major occupation of the inhabitants is agricultural activities complemented with trade, artisanal, Ayurvedic medicine etc. The study utilized cross sectional data collected from 200 farmers' *viz.* multi-stage sampling design. The stage-wise sampling procedure is as follows: The purposive selection of two Local Government Areas *viz.* Edu and Patigi due to their comparative advantage in rice production; random selection of five (5) villages from each of the selected LGAs; and, random selection of twenty (20) farmers from each of the selected village, thus, given a total sample size of 200 active rice farmers. The instrument for data collection was structured questionnaire complemented with interview schedule. For reliability test of the questionnaire, the questionnaire was pre-tested in a pilot survey made up of 25 farmers from the sampling population and the estimated Cronbach Alpha was 0.723, indicating high reliability and consistency of the questionnaire. With the aid of block extension agents, data were collected on fortnight basis during the 2016 cropping season. For analysis of the collected data, DEA technique was used to achieve objective I, II, V and VI; energy index models were used to achieve objective IV and Tornqvist index model (TFPI) was used to achieve objective III.

EMPIRICAL MODEL

Data Envelopment Analysis

The DEA is a non-parametric data analytical technique whose domain of inquiry is a set of entities, commonly called decision-making units (DMUs), which receive multiple inputs and produce multiple outputs [Hedari *et al.*(2012) as cited by Khoshnevisan *et al.*(2013)]. The CCR model which was built on the assumption of constant returns to scale (CRS) was suggested by Charnes, Cooper and Rhodes (Charnes *et al.*, 1978) and is also called global efficiency model, while BCC model which was built on variable returns to scale (VRS) was introduced by Banker, Charnes and Cooper (Banker *et al.*, 1984) and is called local efficiency model. DEA models are broadly divided into two categories on the basis of orientation: input-oriented and output-oriented. Input-oriented models have the objective of minimizing inputs while maintaining the same level of outputs, whereas output-oriented models focus on increasing outputs with the same level of inputs. In this study, an input-oriented DEA model was used to determine the efficient and inefficient DMUs.

Three different forms of efficiency are defined by DEA; technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE). TE is defined as the DMU's ability to achieve maximum output from given inputs, while pure technical efficiency is defined as the DMU's success in selecting inputs in optimal proportions while keeping the price in view (Malana and Malano, 2006).

Inappropriate operation and inadequate scale of a farm are two main reasons for the inefficiency of a DMU. CCR model includes both TE and SE, while BCC model calculates the only PTE of DMUs. In order to obtain SE the following formula was used:

$$\boldsymbol{SE} = \frac{\theta CCR}{\theta CCR} \qquad (1)$$

Where, 'θ' and $'\theta'$ are the *CCR* and *BCC* scores of a DMU, respectively. $SE = 1$ shows scale efficiency (or *CRS*) and $SE < 1$ indicates scale inefficiency. Scale inefficiency can be due to the existence of either increasing returns to scale (IRS) or decreasing returns to scale (DRS). The shortcoming of the SE score is that it does not demonstrate if a DMU is operating under IRS or DRS and this is resolvable by simply imposing a non-increasing returns to scale (NIRS) condition in the DEA model (Mousavi-Avval *et al*., 2011). IRS and DRS can be determined by comparing the efficiency scores obtained by the BCC and NIRS models; so, if the two efficiency scores are equal, then DRS apply otherwise IRS prevail (Omid *et al*., 2011).

Energy Saving Target Ratio (ESTR)

Energy saving target ratio helps to determine the inefficiency level of energy usage and it is given below:

$$\boldsymbol{ESTR\ (\%)} = \frac{Energy\ \ saving\ \ target}{Actual\ \ energy\ \ input}\ X\ 100 \qquad (2)$$

ESTR represents each inefficiency level of energy consumption with the value ranging between zero and unity. A higher ESTR implies higher energy use inefficiency and thus, a higher energy saving amount, while the reverse is the case for lower ESTR.

Coefficient of Multiple Determination (R^2)

$$\boldsymbol{R^2} = 1 - \frac{\sum_{i=1}^{n}(Pi-Ai)2}{\sum_{i=1}^{n} Ai\ 2} \qquad (3)$$

Where, $\boldsymbol{R^2}$ = coefficient of multiple determination; A_i = actual total energy input for i^{th} farmer; and, P_i = Projected required total energy input for i^{th} farmer.

Energy Measurement Indices

Energy use efficiency = *Output energy (MJha^{-1}) ÷ Input energy (MJha^{-1})* (4)

Energy productivity = *Rice yield (kgha^{-1}) ÷ Input energy (MJha^{-1})* (5)

Net energy = *Output energy (MJha^{-1}) − Input energy (MJha^{-1})* (6)

Total Factor Productivity Index

The productivity of a single-output single-input firm is almost always defined as the output-input ratio. O'Donnell (2008) generalizes this idea to the multiple-output multiple-input case by formally defining the *total factor productivity (TFP)* of a firm to be the ratio of an aggregate output to an aggregate input. Let $x_{it} = (x_{1it}, \ldots\ldots, x_{kit})'$ and $q_{it} = (q_{1it}, \ldots\ldots, q_{kit})'$ denote the input and output quantity vectors of firm *i* in period *t*. Then the TFP of the firm is:

$$TFP = \frac{Qit}{Xit} \qquad (7)$$

(Total Factor Productivity)

Where, $Q_{it} = Q(q_{it})$ is an aggregate output, $X_{it} = X(x_{it})$ is an aggregate input, and $Q(.)$ and $X(.)$ are nonnegative, non-decreasing and linearly homogeneous aggregator functions. The associated index number that measures the *TFP* of i^{th} firm in period *t* relative to the *TFP* of firm *h* in period *s* is:

$$TFP_{hs,\,it} = \frac{TFPit}{TFPhs} = \frac{Qit/Xit}{Qhs/Xhs} = \frac{Qhs,it}{Qhs,it} \qquad (8)$$

Where $Q_{hs,it}$ = Qit/Qhs is an output quantity index and $X_{hs,it}$ = Xit/Xhs, is an input quantity index.

Global Warming Potential (GWP)

Each greenhouse gas, i.e. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) has a GWP, which is the warming influence relative to that of carbon dioxide and the emissions are measured in terms of a reference gas, CO_2. The GWP of CO_2 (with a time span of 100 years) is 1, CH_4 is 21, and N_2O is 310.

The formula for determining total emissions of greenhouse gasses is given below:

Greenhouse effect = $\sum GWPix\ M_i$ (9)

M_i is the mass (in kg) of the emission gas and the score is expressed in terms of CO_2 equivalents. Also, adopted in this study is carbon efficiency ratio (CER) and is specified as follow:

CER = *[yield (kgCha^{-1})] ÷ [GWP (kgCha^{-1})]*(10)

Where *CER*= Carbon efficiency ratio

GWP = Global warming potential

The output yield should be converted to carbon equivalent: usually, the carbon content is 45% of the total yield. Moreover, since GWP is based on carbon dioxide equivalent, to determine the carbon content this amount should be multiplied by the ratio of carbon to carbon dioxide, i.e 12/44 (or ~ 0/27).

Table1a. *MJ equivalent and CO_{2eq} coefficient of farm inputs and output*

Inputs	**Unit**	**Energy equivalent (MJ unit^{-1})**	**GHG coefficient (KgCO_2eq. unit^{-1})**
Human labour	Manhour	1.96	-
Seed	Kg	14.7	-
Nitrogen	Kg	60.6	1.3
P_2O_5	Kg	11.1	0.2
K_2O	Kg	6.7	0.15
Herbicides	Litre	238	6.3
Diesel fuel	Litre	56.31	2.76
Tractor machinery	Tractor hr	93.61	0.0725

Table1b. *Gaseous emissions (g) per unit of chemical sources*

Inputs	**CO_2**	**N_2O**	**CH_4**	**Reference**
Pesticides (L)	5100	0.02	0.01	Green (1987)
Nitrogen (kg)	3100	0.03	3.70	Synder *et al.*(2009)
P_2O_5 (kg)	1000	0.02	1.80	Synder *et al.*(2009)
K_2O (kg)	700	0.01	1.0	Synder *et al.*(2009)
Diesel fuel (L)	3560	0.70	5.20	Kramer *et al.*(1999)
GWP CO_2 equivalent factor	**1**	**310**	**21**	Tzilivakis *et al.*(2005)

Table1c. *Amount of inputs-output and their energy equivalents for lowland paddy rice production*

Input	**Qty ha^{-1}**	**Equivalent MJ**	**Total energy equivalent (MJha^{-1})**	**Percentage**
Family labour (manhr)	56.31925	1.96	110.39	2.52
Human Labour (manhr)	20.16137	1.96	39.52	0.90
seeds (kg)	27.42226	14.7	403.11	9.21
Nitrogen (kg)	6.453738	60.6	391.10	8.94
P_2O_5 (kg)	6.453738	11.1	71.64	1.64
K_2O (kg)	6.453738	6.7	43.24	0.99
Urea (kg)	18.84864	60.6	1142.23	26.10
Herbicides (L)	2.101873	238	500.25	11.43
Tractor (hr)	0.331253	93.61	31.01	0.71
Diesel fuel (L)	29.18326	56.31	1643.31	37.56
Total input			**4375.80**	**100**
Paddy rice output (kg)	393.335	14.7	5782.02	
Total output energy			**5782.02**	
Net energy(MJha^{-1})			**1406.22**	

Source: *Field survey, 2016*

RESULTS AND DISCUSSION

Measuring Farmers' Efficiency

The results of the farmer's efficiency distribution scores based on the application of CCR and BCR are presented in Table 2a. The perusal of the table shows that only 10% of the farmers were scale efficient i.e globally and locally efficient, indicating potential productivity gained from achieving optimum size by DMUs. Relying on CCR and BCC assumptions exclusively, approximately 9.5% and 26% of the farmers were identified to be global and locally efficient respectively, as evident from their efficiency scores which were on the frontier surfaces. Therefore, for the average farmer to be globally and locally efficient he/her needs to increase their technical efficiency by 47% and reduce input wastage by 22.6% respectively, to attain the frontier surfaces. Also, for the least efficient farmers to be globally and locally efficient they need to adjust forward their efficiency scores by 94.30% and reduce their input wastage by 79.30% respectively, to be on the frontier surfaces. Global efficiency means that a DMU applied the given production techniques properly but is not efficient in input mix while local efficiency means that a DMU is efficient in input allocation but did not apply the production techniques appropriately. Therefore, to be scale efficient both global and local efficiencies are necessary conditions that need to be satisfied. Relying on the conglomeration of these conditions, results showed that majority (90%) of the farmers were not managerial efficient-scale inefficient in the utilization of energy in rice production in the studied area. This suggests the need for energy gain and efficiency improvement through optimization of energy input and increasing energy output because it contributes significantly to sustainable development in agriculture given that at the present time, the productivity and profitability of agriculture depend upon energy consumption. In addition, results show the disadvantageous condition of scale size as evident from the relatively low average scale efficiency score of 0.681. The implication is that if all of the inefficient farmers operated at the most productive scale size, approximately 31.9% savings of energy consumed from different productive resources used in rice production would be possible without affecting the current rice yield level of the farmers in the studied area.

Table2a. *Deciles frequency distribution of efficiency scores*

Efficiency level	**OTE**	**PTE**	**SE**
≤ 0.09	**4 (2.0)**	**-**	**2 (1.0)**
0.10-0.19	19 (9.5)	-	8 (4.0)
0.20-0.29	13 (6.5)	6 (3.0)	7 (3.5)
0.30-0.39	30 (15.0)	11 (5.5)	10 (5.0)
0.40-0.49	39 (19.5)	7 (3.5)	16 (8.0)
0.50-0.59	22 (11.0)	17 (8.5)	24 (12.0)
0.60-0.69	23 (11.5)	19 (14.5)	35 (17.5)
0.70-0.79	1.5 (7.5)	28 (14.0)	28 (14.0)
0.80-0.89	8 (4.0)	30 (15.0)	25 (12.5)
0.90-0.99	8 (4.0)	20 (10.0)	25 (12.5)
1.00	19 (9.5)	52 (26.0)	20 (10.0)
Total	**200**	**200**	**200**
Mean	**0.530**	**0.774**	**0.681**
Minimum	**0.057**	**0.207**	**0.080**
Maximum	**1.00**	**1.00**	**1.00**
Median	**0.490**	**0.814**	**0.697**
STD	**0.261**	**0.216**	**0.241**
CV	**0.491**	**0.280**	**0.354**
Skewness	**0.327**	**-0.728**	**0.528**
Kurtosis	**-0.768**	**-0.370**	**-0.479**
IQ range	**0.360**	**0.376**	**0.358**

Source: *Computed from DEA computer print-out*, **( ):** *percentage*

The results of returns to scale estimation showed that all of the technically efficient farmers (19 DMUs) (based on the CCR model) were operating at CRS, showing the optimum scale of their practices, while 172 and 8 farmers operated at IRS and DRS respectively (Table 2b). Therefore, for IRS and DRS farmers a proportionate increase in all inputs leads to a more proportionate increase or decrease in outputs respectively; and, for considerable changes in productivity, technological changes in practices are required. The information on whether a farmer operates at IRS, CRS or DRS status is particularly helpful in indicating the potential redistribution of resources between the farmers and thus, enables them to achieve higher output.

Table2b: *Return to scale of lowland paddy rice farmers*

RTS	Frequency	Percentage
Increasing Return to Scale (RTS)	172	86
Decreasing Return to Scale (DRS)	8	4
Constant Return to Scale (CRS)	20	10
Total	**200**	**100**

Source: *Computed from DEA computer print-out*

Efficient Farmers' Appearing as Peers for Inefficient Farmers

DEA approach ranked units based on their efficiency values and separate units into two sets of efficient and inefficient units given the possibility that some efficient DMUs have better performance than the other efficient ones, thus chosen them as the useful target for many inefficient DMUs. Peer is the number of times each DMU appears as a reference set for another DMU(s) and the peer summary results are shown in Table 3. The identified superior efficient farmers with highest peer counts were DMUs 100, 68, 106 and 39 with peer count of 104, 57, 56 and 55 respectively; and they can be used as criteria or reference set for inefficient farmers since their appearance as peers for the inefficient ones were more, thus, the best practice DMUs in the studied area. In other word, farmers with low and zero peer count can emulate these best practice farmers if their objective is to become scale efficient. Also, in order to cut cost and ensure ease in technology transfer, the study suggests that extension service delivery system should link up with these efficient DMUs as key communicators-spark plugs-role models to reach the larger farming population in ensuring efficient utilization of energy inputs used in the studied area.

Table3. *Benchmarking of efficient DMUs using peer count*

Farm	Frequency in referent set	Ranking
DMU100	104	1
DMU68	57	2
DMU106	56	3
DMU39	55	4

Source: *Computed from DEA computer print-out*

Inefficiency of Individual Farms

The performance assessment of comparing a particular system with key competitors showing best performance within the same group or another group performing similar functions, a process called benchmarking was conducted. Efficient DMUs can be selected by inefficient DMUs as best practice DMUs, making them a composite DMU instead of using a single DMU as a benchmark. A composite DMU is formed by multiplying the intensity vector (λ) in the inputs and outputs of the respective efficient DMUs. BCC is modeled by setting the convexity constraint and the summation of all intensity vectors in a benchmark DMU must be equal to 1.

Presented in Table 4 were the worst inefficient DMUs *viz.* DMU129 and DMU128; and, the best inefficient DMUs *viz.* DMU119 and DMU167. For instance, with respect to DMU129, the composite DMU that represent the best practice or reference composite benchmark DMU is formed by the combination of DMU11, DMU148, DMU183 and DMU100, implying that DMU129 is close to the efficient frontier segment formed by these efficient DMUs represented in the composite DMU. The selection of these efficient DMUs is made on the basis of their comparable level of inputs and output yield to DMU129. The benchmark DMU for DMU129 is expressed as 11(0.442), 148(0.074), 183(0.014) and 100(0.469); where 11, 148, 183 and 100 are the DMU numbers while the values in the brackets are the intensity vector (λ) for the respective DMUs. The higher value of the intensity vector (λ) for efficient DMU12 (0.528) implied that its inputs-output level is closer to DMU164 compared to the other DMUs.

Table4. *Performance Assessment of Farms*

Farm	PTE score (%)	Benchmarks
DMU129	20.7	11(0.442) 148(0.074) 183(0.014) 100(0.469)
DMU128	21.9	183(0.097) 100(0.533) 25(0.177) 148(0.193)
DMU164	99.7	12(0.528) 39(0.389) 100(0.006) 46(0.044) 8(0.034)
DMU119	99.9	106(0.117) 39(0.360) 78(0.041) 100(0.265) 72(0.217)

Source: *Computed from DEA computer print-out*

TFP Levels of Rice Producers' in the Studied Area

The increase in input use to a certain extent, allows the farm sector to move along the production surface. The balanced use of inputs is expected to induce an upward shift in the production function to the extent that a technological change is embodied in them. The TFP measures the extent of increase in the total output which is not accounted for by increases in the total inputs. The estimated input, output and TFP index of rice production in the studied area as at 2016 cropping season are shown in Table 5.

A perusal of Table 5 showed that only 35 (0.5%) farms achieved a robust increase in output index. Increase in output of 16 DMUs *viz.* 12, 32, 43, 51, 64, 68, 114, 134, 135, 168, 171, 173, 168, 182, 188, 189 and 198 was due to increased input use which brought inefficiencies in their use. The increase in output index coupled with an almost parallel increase in energy inputs-use index led to near stagnant total factor productivity of rice production for these DMUs. However, the output indexes were found to be higher than the indexes of inputs-use leading to positive TFP. Furthermore, the robust increase in the output of the remaining 18 DMUs *viz.* 8, 11, 26, 56, 71, 78, 96, 100, 106, 123, 146, 151, 156, 159, 175, 178, 187 and 200 was attributed to balanced use of energy inputs which induced an upward shift in the production function to the extent that technological change was embodied in them. The higher output increase triggered by technological change has resulted in high positive TFP in rice production at the period of this study.

Table5. *Estimated input, output and TFP index of rice production in the studied area*

Farm	Output	Input	TFP	Farm	Output	Input	TFP
DMU08	1.1770	0.8559	1.3751	**DMU134**	1.0667	0.9867	1.0810
DMU11	1.0433	0.7987	1.3062	**DMU135**	0.9808	0.8987	1.0913
DMU12	0.7908	0.7331	1.0787	**DMU146**	1.3830	1.2155	1.1378
DMU26	1.8391	1.4960	1.2293	**DMU151**	1.9757	1.2934	1.5275
DMU32	1.3609	1.2714	1.0704	**DMU156**	4.6100	2.6773	1.7219
DMU43	1.8440	1.7046	1.0818	**DMU159**	1.6429	1.4260	1.1521
DMU51	0.8601	0.8313	1.0346	**DMU168**	3.9514	3.5951	1.0991
DMU56	1.4958	0.8987	1.6643	**DMU171**	1.7287	1.5950	1.0838
DMU64	0.9349	0.8554	1.0929	**DMU173**	3.0733	2.8184	1.0904
DMU68	0.8053	0.7281	1.1061	**DMU178**	1.9757	1.3243	1.4919
DMU71	1.8299	0.9718	1.8830	**DMU182**	1.3830	1.3525	1.0226
DMU78	1.0814	0.8772	1.2327	**DMU187**	1.8440	1.5017	1.2279
DMU96	1.8440	1.4636	1.2599	**DMU188**	0.9458	0.8810	1.0735
DMU100	1.4713	0.7199	2.0436	**DMU189**	0.9563	0.8709	1.0980
DMU106	2.3050	1.0210	2.2577	**DMU198**	0.5517	0.4989	1.1058
DMU114	1.0095	0.9678	1.0430	**DMU200**	1.3830	1.1547	1.1977
DMU123	1.0851	0.8777	1.2362				

Source: *TFPI computer print-out*

Setting Realistic Input Levels for Inefficient Farmers

A pure technical efficiency score of less than one for a farmer means that, at present conditions, his input energy consumption value is higher than required. Therefore, it is important to suggest realistic levels of energy inputs to be used from each source for the inefficient farmer in order to avert input energy wastage in the production cycle. The summarized information for setting realistic input levels *viz.* average usage in optimum conditions ($MJha^{-1}$), possible energy savings and ESTR percentage for different input energy sources are given in Table 6. The results evidently showed that total energy input could be reduced to 2496.43$MJha^{-1}$ while maintaining the present yield level and also assuming no other constraining factors. The implication is that an average of approximately 1879.37$MJha^{-1}$ of total input energy was wasted by the inefficient farmers, thus affecting the physiochemical balance of the rice agro-ecosystem in the studied area: erosion, leaching, volatilization, cation exchange capacity inhibition, pest and diseases build up-infestation, weed build up, food toxicity, inhibition of microbial activities, nitrogen loading in the soil etc.

The results of ESTR showed that if all farmers operated efficiently, reduction in all energy inputs would have been possible without affecting their current yield level. These energy inputs had high inefficiency which owed mainly to excess use. A high percentage of agrochemical energy and fossil fuel inputs can be attributed to low awareness or inappropriate application of production techniques in harnessing these energy inputs efficiently. The increase in input energies to obtain high yields may not result in high profits due to increase in the cost of production. Therefore, it can be deduced that the farmers in the studied area have little or no knowledge that effective use of energy in agriculture is one of the conditions for sustainable agricultural production since it helps in saving financial resources, conserve fossil fuels, and reduces pollution of all kinds and increase soil fertility.

Moreover, the ESTR percentage for total energy input was 42.95%, indicating that by adopting the optimum inputs from this study, on the average, approximately 1879.37$MJha^{-1}$ from total input energy in rice production could be saved without affecting the yield level. Using these inputs information, it is possible to advise the inefficient farmers regarding the best operating practices followed by his peers in order to reduce the input energy levels to the optimum units indicated in the analysis while maintaining their present yield level. It is evident that diesel has the maximum contribution to the total saving energy by 37.58% and then followed by urea which accounted for 27.50%. The non-renewable energy inputs contributed about 86.90% to the total saving energy. This implies that non-renewable energy inputs had the highest potential in energy productivity of rice production in the studied area.

Based on these outcomes, study suggests that an improvement in the usage pattern of these inputs should be considered as priorities that would provide the significant improvement in energy productivity of rice production in the surveyed region.

Applying appropriate machinery management techniques, sustainable tillage practices and controlling input usage by performance monitoring can help in reducing the use of diesel fuel and fertilizer energy inputs thus minimize their environmental impacts. Also, integrating legume into the crop rotation, application of composts, chopped residues or other soil amendments may increase soil fertility in the medium term and so reduce the need for chemical fertilizer inputs. The use of herbicides should be replaced with cultural and biological practices in order to reduce plant toxicity and food poison which have consequences on human and microbial organisms.

Table6. *Energy saving ($MJha^{-1}$) from different sources*

Inputs	Actual Energy Used ($Mjha^{-1}$)	Optimum Energy Requirement ($Mjha^{-1}$)	Saving Energy	ESTR (%)	Saving Energy %
Family labour	110.39	65.97	44.42	40.24	2.36
Human labour	39.52	23.45	16.07	40.66	0.85
Seed	403.11	229.92	173.19	42.96	9.22
Nitrogen	391.10	223.55	167.55	42.84	8.92
P_2O_5	71.64	40.95	30.69	42.84	1.63
K_2O	43.24	24.72	18.52	42.83	0.99
Urea	1142.23	625.43	516.80	45.25	27.50
Herbicides	500.25	307.04	193.21	38.62	10.28
Tractor	31.01	18.36	12.65	40.80	0.67
Diesel fuel	1643.31	937.04	706.27	42.98	37.58
Total input energy	**4375.80**	**2496.43**	**1879.37**	**42.95**	**100**

$R^2 = 0.67$

Improvement of Energy Indices

Presented in Table 7 are energy indices of rice production in actual and optimum use. The results revealed that by optimization of energy use, both the energy ratio and energy productivity indicators can improve by 75.76 and 75.31% respectively. This implies that energy gained in the output of rice when farmers operated at the optimum level would be 75.76% higher than what was obtained at actual input use level. Also, the output of rice in kilogram per unit of energy input used would increase by 75.3% if they adopt the optimum input levels. Also, in optimum consumption of energy inputs, the net energy indicator would improve by 133.65% which translates to 3285.59MJha^{-1}. Furthermore, results showed that energy indices *viz.* specific energy; direct and indirect energies; renewable and non-renewable energies; commercial and non-commercial energies; and agrochemical energy used in actual form were more than that of the optimum level.

To sum it up, paddy rice in the studied area is a crop with relatively high requirements for non-renewable energy resources and may be due to the fact that most of these farmers have little or no knowledge on efficient utilization of input coupled with the belief that increased use of energy resources will result in increasing yield. On the average, considerable savings in energy inputs is likely to be obtained by adopting the best practices of high-performing farmers in crop production process i.e more energy-efficient cultivation systems would help in energy conservation and better resource allocation.

Table7. *Improvement of energy indices for lowland paddy rice production*

Items	Unit	Qty in Actual use (A)	Qty in optimum use (B)	Difference (%) = (B-A/A)*100
Energy ratio	-	1.32	2.32	75.76
Energy productivity	KgMJ^{-1}	0.0899	0.1576	75.31
Specific energy	MJkg^{-1}	11.13	6.35	-42.95
Net energy	MJha^{-1}	1406.22	3285.59	133.65
Direct energy	MJha^{-1}	1824.23	1044.82	-42.73
Indirect energy	MJha^{-1}	2551.57	1451.61	-43.11
Renewable energy	MJha^{-1}	553.02	319.34	-42.26
Non-renewable energy	MJha^{-1}	3822.78	2177.09	-43.05
Commercial energy	MJha^{-1}	4225.89	2407.01	-43.04
Non-commercial energy	MJha^{-1}	149.10	89.42	-40.35
Agro-chemical	%	49.10	48.94	-16
Total input energy	MJha^{-1}	4375.80	2496.43	-42.95
Total output energy	MJha^{-1}	5782.02	5782.02	-
Productivity	Kgha^{-1}	393.34	393.34	-

Source: *Computed from DEA computer print-out*

Reduction of GHG Emission

Presented in Table 7 are the GHG emissions in actual and optimum farm level. The results show that the amount of GHG emitted from the total actual input used was 131.18kgCO$_{2eq}$ha^{-1} and can be reduced by about 56.28kgCO$_{2eq}$ha^{-1} by adopting energy optimization plan. Furthermore, a perusal of the table showed that diesel which was followed far behind by urea fertilizer had the highest amount of GHG emission. The implication of this excess GHG emission which is attributed to excess inputs used caused an environmental imbalance which is not only inimical to agro-ecology but also human ecology. Relying on these findings, study suggests the adoption of sustainable farm practices in the production of paddy rice in the studied region.

Table8. *Amount of GHG emission for actual and optimum paddy rice farmers*

Inputs	Actual (KgCO$_2$ha^{-1}) (A)	Optimum (KgCO$_2$ha^{-1}) (B)	GHG reduction	Diff. [(B-A)/A]*100	% Contribution
Nitrogen	8.39	4.80	3.59	-42.79	6.37
P_2O_5	1.29	0.74	0.55	-42.64	0.97
K_2O	0.97	0.55	0.42	-43.30	0.75
Urea	24.51	13.42	11.09	-45.25	19.71
Herbicides	13.23	8.13	5.1	-38.55	9.06
Tractor	2.25	1.33	0.92	-40.89	1.64
Diesel fuel	80.54	45.93	34.61	-42.97	61.50
Total	**131.18**	**74.90**	**56.28**	**-42.90**	**100**

Source: *Computed from EMS computer print-out*

GWP of Lowland Rice Production

The amount GWP *viz.* CO_2, N_2O and CH_4 from chemical inputs for the actual and optimum units of paddy rice production per hectare in the studied area are presented in Table 8. A perusal of the table showed that the amount of GWP *viz.* CO_2, N_2O and CH_4 from the chemical inputs used in lowland rice production for actual and optimum units were 203.99, 0.0214 and 0.0.263kgha^{-1}; and, 115.52, 0.0122 and 0.149kgha^{-1}, respectively. The aggregate GWP of 216.16kgCO_2ha^{-1} for the actual units can be reduced to 122.43kgCO_2ha^{-1} if the inefficient farmers adopt the input recommendations of the optimum plan. The implication of the excess energy inputs used aimed towards increase yield at the expense of the agro-ecosystem due to little or no knowledge of the consequences of GWP of crop production has resulted in global warming potentials which pose threats to the immediate agro-ecology environment, food security and human existence, thus creating environmental imbalances. Therefore, converting inefficient units to efficient units in lowland paddy rice production would make it possible to reduce the GWP of actual units by 43.36% which total GWP equivalent is 93.73kgCO_2ha^{-1}.

With respect to CO_2 equivalents for actual unit, 94.37, 3.07 and 2.56% were produced by CO_2, N_2O and CH_4 respectively; while for the optimum unit the CO_2 equivalents of 94.38, 3.09 and 2.55% would be produced by CO_2, N_2O and CH_4 respectively. Based on gas emission and the greenhouse effect, the highest share was related to CO_2. This implies that the greenhouse gas emission of CO_2 in kilogram is larger than the emissions of N_2O and CH_4. Also, the emission of CO_2 in terms of kgCO_2 equivalents is dominant. CO_2 emission is responsible for 94.37% of the greenhouse gases that resulted from lowland paddy rice production in the studied area. However, both the contribution of N_2O GHG emission to the GWP and the reduction in GWP of the GHG emission due to oxidation of CH_4 were small. It was observed that the energy input with the highest GWP was diesel fuel, followed by urea fertilizer and then nitrogen fertilizer, while herbicides, phosphate and potassium fertilizers had the marginal amount of GWP.

Findings indicated that in the actual units each kilogram production of lowland paddy rice production in the studied area would generate GWP of 0.55kg per kg, 0.022kgm^{-1}, 0.0494kgCO_{2eq}MJ^{-1} of input energy and 0.037kgCO_{2eq}MJ^{-1} of output energy; while in the optimum unit, each kilogram production of lowland paddy rice production in the studied area would generate GWP of 0.31kg per kg, 0.012kgm^{-1}, 0.0490kgCO_{2eq}MJ^{-1} of input energy and 0.021kgCO_{2eq}MJ^{-1} of output energy.

The carbon content of the rice yield of 393.34kg each for both the actual and optimum units in the studied area was 177.27kgCha-1, while the carbon content of chemical input used were 58.95 and 33.39kgCha^{-1} respectively. Furthermore, the carbon efficiency ratios of the actual and optimum units were 3.01 and 5.31, indicating a lower ratio in actual unit when compared to the optimum unit. This implies that the actual unit had a low ratio of carbon content stored in rice yield when compared to the optimum unit. Despite dissimilarities in agro-climatic and agronomical practices, Lal (2004) reported a similar ratio of 5.3 for stored carbon content of corn in the USA. Even though the economic yield performance of forage and tuber crops are more than any other crop (Yousefi *et al.*, 2014), rice crop is also good for storing carbon and thus, can be used for carbon sequestration. Khorramdel *et al.*(2013) as cited by Yousefi *et al.*(2014) reported that carbon sequestration could be an effective way to reduce atmospheric carbon dioxide which is the most important greenhouse gas.

Table9. *GWP of non-renewable inputs used in lowland paddy rice production*

Inputs	**Actual GWP**				**Optimum GWP**			
	CO_2	**N_2O**	**CH_4**	**GWP**	**CO_2**	**N_2O**	**CH_4**	**GWP**
Nitrogen	19.995	0.000194	0.024	20.556	11.44	0.000111	0.0137	11.76
P_2O_5	6.45	0.000129	0.012	6.734	3.69	0.000074	0.0066	3.85
K_2O	4.52	0.000065	0.0065	4.671	2.58	0.000037	0.0037	2.67
Urea	58.44	0.00057	0.0698	60.075	31.99	0.00031	0.0382	32.89
Herbicides	10.71	0.000042	0.000021	10.724	6.58	0.000013	0.000013	6.59
Diesel fuel	103.88	0.0214	0.1517	113.399	59.24	0.0117	0.0865	64.67
Total GWP (CO_2 equiv.)	203.99	0.02142	0.2634	216.158	115.52	0.0122	0.1487	122.43
%	**94.37**	**3.07**	**2.56**		**94.36**	**3.09**	**2.55**	

Inputs	**Possible GWP reduction**							
	CO_2	**N_2O**	**CH_4**	**GWP**				
Nitrogen	8.56	0.000083	0.01021	8.796				
P_2O_5	2.76	0.000055	0.00497	2.881				
K_2O	1.93	0.000028	0.00276	1.999				
Urea	26.44	0.000256	0.03156	27.185				
Herbicides	4.13	0.000016	0.81E-06	4.136				
Diesel fuel	44.64	0.008778	0.06521	48.733				
Total GWP (CO_2 equiv.)	88.46	0.009216	0.11472	93.703				
%	**94.38**	**3.05**	**2.57**					

Source: *Authors' computation, 2016*

CONCLUSIONS AND RECOMMENDATIONS

Based on these findings it can be concluded that majority of the farmers in the studied area did not achieve global and local efficiencies in conglomeration i.e were not scale efficient, thus resulting in energy input dissipation in lowland paddy rice production due to wastage with consequences of agro-ecology imbalances, GHG emissions and GWP potentials which posed serious threats to the environmental. Therefore, in view of these, the following recommendations were made:

- Sustainable farming practices such as minimum tillage, zero tillage, organic fertilizers, mulching, biological controls should replace the much used non-renewable inputs-fossil fuels, inorganic fertilizers and biocides.
- In order to cut cost and enhance efficiency in technology transfer, the extension agents should use the smart farmers' i.e the efficient farmers as a reference focal point for the inefficient ones since they are most likely to have confidence in the work of their peers, ease in understanding the nitty-gritty of the production techniques etc.
- There is need to create more awareness among farmers on the consequences of climate change.
- Knowledge on efficiency in energy input utilization should be packaged into the extension service programmes because the climate change mitigation strategies should be everybody concern i.e government, non-government organizations and individual farmers should be part and parcel of the fight against climate change.
- The federal government should redeem its pledge of $150 billion dollars green bond project for climate change tackling: making finance flow consistent with a pathway towards low greenhouse gas emissions and climate resilient development.
- The government should review its fertilizer policy by banning the use of stereotype fertilizer given its non-suitability to the agro-climatic condition of the country and restricted to the use of indigenously produced agro-chemicals which should suit the agro-climatic condition of each zones in the country.
- The government and farmers should be cautious of their temptations for increased rice production for exportation using the modern farming system (inorganic) in order not to endanger the biodiversity and future food security of the country.
- Government should come up with an agricultural premium policy that will encourage farmers to reverse from the stimulated inorganic farming system to organic stimulated farming system i.e sustainable farming in order to ensure a safe environment for all.

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Citation: *M. Sadiq, I. Singh and G. Yakubu, "Global Warming Potentials of Lowland Paddy Rice Production in Kwara State of Nigeria: Lessons for Sustainable Agriculture", International Journal of Research in Agriculture and Forestry, vol. 4, no. 9, pp. 20-32, 2017.*