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Energy efficiency and use of a parametric method for poultry production in Kwara State, Nigeria

T Adekanye[1], A Saleh[2], A Okunola[1], I Osavbie[1] and K Jegede[1]

[1]Department of Agricultural and Biosystems Engineering, Landmark University, Omu Aran, Kwara State, Nigeria.
[2]Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.
E-mail: adekanye.timothy@lmu.edu.ng

Abstract. Analysis of input-output was done to investigate energy utilization pattern and efficiency in selected poultry farms in Kwara State, Nigeria. The poultry farms used for the study were grouped into three as group I (small), II (medium) and III (large) respectively based on number of birds. Energy used in chemicals, chicks, electricity feed, fuel, labour, and wood shaving as inputs and eggs, poultry meat and litter as outputs were determined. The result has shown that that diesel and feed accounted for the biggest proportion of all energy inputs in the farms. Energy consumption of the farms was found to be 28006.41, 26450.19 and 21894.39 MJ (1000 bird)$^{-1}$, respectively. The energy output was 179766.54, 193670.10 and 223307.50 MJ, respectively (1000 bird)$^{-1}$. Impacts of renewable and indirect sources of energy were greater than that of nonrenewable and direct energy. The rate of return to the scale was estimated at -0.04, suggesting that a 1% rise in each of the power inputs would result in a 0.04% reduction in the production. R^2 was found to be 0.81 for the estimated model. Therefore, energy inputs (independent variables) can capture about 81% of layer yield variations in the poultry farms.

1. Introduction

Poultry production was not considered to be an important industry until it occupies a significant place among the livestock enterprises. Nowadays, poultry industry presents diverse business opportunities to the unemployed youths. Many people had ventured into hatchery business, broiler production, egg production, and sales of poultry drugs and equipment [1]. Poultry meat and eggs are good sources of protein for man and animals. Poultry accounts for about 15% of the annual protein consumption in Nigeria with about 1.3 kg per head consumed annually. About 36.5% of the total proteins required by Nigerians are obtained from poultry products [2]. Developing countries are encouraging farmers to venture into poultry production system in order to increase the supply of animal protein [3]. The livestock sector contributes approximately 10% of the agricultural GDP of Nigerian. According to Ojo [4], cited by [5], poultry products' contribution to livestock share of GDP increased from 26% in 1995 to 27% in 1999 with egg production alone accounting for about 13% during the period. Despite the poultry industry's importance for the domestic economy, poultry farms face difficulties that are antithetical to the industry's development. Generally speaking, poultry production is being faced with low capital base, inefficient management, issues with illness and parasites, housing and marketing, and so on [6].

Recently, poultry industry in Nigeria has become a commercialized subsector of Nigerian agricultural production. There are many benefits in poultry production than other livestock. There is quick return of investments because production cycle is short [6]. Poultry products (eggs, broiler and layers) are relatively affordable compared to other proteins in animals. Poultry birds transform food into protein in meat and eggs which are good sources of protein required by man. Return on investment in poultry is high even though unit cost of production is low. Another advantage of poultry meat is that it is acceptable to all religions in Nigeria [7].

Climate change and rising in energy prices have made energy savings in animal production to be a necessity. To determine the potential savings, energy consumption and distribution in the system are required. Feed is the biggest energy input in poultry production [8]. This high input could be reduced by savings in crop and feed production chains. The use of energy in the agricultural industry is increasing in terms of demographic growth and requirements for a decent standard of living [9]. Understanding of energy input in a system's unit operations is a necessity for investigating high energy consuming areas [10]. Energy analysis of a production system is useful in comparing costs of energy inputs in a particular existing production system with a new production system. In addition, energy analysis allows farmers to compare their energy efficiency with that of a competitor or other plant in the same company. Hence, energy analysis is a very useful tool for planning ahead, assessing energy consumption pattern for a specific product or service, predicting energy requirements in such a production system, and planning for expansion.

Energy and agriculture are closely linked together. Agriculture utilizes energy and supplies the same as bio-energy [9]. In agriculture, energy use is classified as direct (DE), indirect (IDE), renewable (RE) and non-renewable (NRE) forms. Direct energy involves manpower, diesel and electricity in poultry production. Food, equipment, poultry litters, disinfectants, medicines, and chicks were included as indirect energies. Chick, feed, litter and human labor are covered by renewable energy, while non-renewable energy contains diesel fuels, disinfectants, energy and machines [11].

Sustainable agriculture depends on efficiency of energy usage in agricultural production [9]. Agricultural production can be improved if energy needed is available and it is used effectively [12]. This is because agricultural output (crop, animal, poultry products) and food supplies are connected directly to inputs of energy during production.

Many research works have been carried out on energy use pattern in crop and livestock production in different parts of the world. Heidari et al [13], investigated energy efficiency of broiler production. Results of their study revealed that output energy in broiler production in Yazd Province, Iran, were 186,885.87 and 27,461.21 MJ (1000 birds)$^{-1}$ respectively. Rajaniemi and Ahokas [14] found that, if the energy equivalents of all production inputs were considered, the energy equivalent of broiler feed would be a key factor in broiler production. Rajaniemi and Ahokas [15] studied direct energy consumption in a broiler house in Finland and reported that heating energy was the highest direct energy input in the broiler house. Najafi et al [16] assessed the energy efficiency of chicken production in different farm sizes in Iran and concluded that large farms had a higher productivity rate than small and medium-sized farms. Oladimeji et al [17], researched on energy use and economic analysis of melon production technologies in Kwara state, Nigeria. However, there have been no studies related with emphasis on energy analysis in poultry production farms in Nigeria. The aim of this study was to determine energy use pattern in poultry farms in the North Central part of Nigeria. The study also compares energy inputs for egg, meat and litter production.

2 Materials and Methods

2.1 Study area and data collection

Kwara State, with a population of about 3.5 million people [18] and land area of about 36,825 km^2 is located between latitudes 7°45 N and 9°30 N and longitudes 2°30 E and 6°25 E [17]. Data were collected from poultry farmers through a face to face questionnaire administered in between 2017 and 2018. Poultry farms used in this study were selected randomly from the registered poultry farmers in Irepodun and Offa local government area, Kwara State, Nigeria. Equation (1) was used to determine size of each group of farms;

$$n = \frac{(\sum N_h S_h)}{N^2 D^2 + \sum N_h S^2{}_h} \qquad [17] \qquad (1)$$

Where n is the sample size, N is the number of poultry farms in target population, N_h is the number of population in Group I (43 farms), II (23 farms), and III (14 farms), S_h is the standard deviation in the groups, S^2h is the variance of the three groups, d is the precision, z is the reliability of coefficient, $D^2 = d^2/z^2$. Permissible error in the sample size was defined to be 5% for 95% confidence.

Inputs used in poultry farms included chicks, chemicals, disinfectants, fuel, feed, human labour, electricity, machinery, medications, while the outputs were chicken, broilers and poultry wastes. Energy equivalent of inputs (chicks, disinfectants, electricity, feed materials, fuels, labor, and medications) was calculated by multiplying their total consumption for 1000 birds by their equivalent energy shown in Table 1. The production power equivalent (egg, meat and poultry) (Mcal U^{-1}) were calculated by multiplying the output amount by equivalent energy.

Table 1. Energy coefficients of inputs in poultry production

Items	**Energy coefficients (Mcal U^{-1})**	**References**
Input		
Labour	0.54	[19]
Machinery (h)	64.8	[19]
Diesel (l)	47.8	[19]
Electricity (kWh)	5.65	[16]
Feed (kg)	12.98	[20]
Medicine (kg)	3.26	[20]
Disinfectants (kg)	0.1	[21]
Chick (kg)	2.47	[21]
Output		
Bird (kg)	10.33	[13]
Egg (g)	7.28	[1]
Poultry meat (kg)	2.47	[17]
Poultry litter (kg)	0.07	[22]

Energy use ratio, energy productivity, specific energy and net energy were determined by using Eqs (2) – (5);

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$$\text{Energy use ratio} = \frac{Output\ energy\ (Mcal\ 1000\ birds{-}1)}{Input\ energy\ (Mcal\ 1000birds{-}1)} \quad (2)$$

$$\text{Energy productivity} = \frac{Poultry\ meat/egg\ (kg\ 1000birds{-}1)}{Input\ energy\ (Mcal\ 1000birds{-}1)} \quad (3)$$

$$\text{Specific energy} = \frac{Input\ energy\ (Mcal\ 1000birds{-}1)}{Poultry\ meat\ (kg\ 1000birds{-}1)} \quad (4)$$

Net energy gain = Output energy (Mcal 1000 birds^{-1}) – Input energy (Mcal 1000 birds^{-1}) (5)

Cobb-Douglas function was used to model the impact of energy equivalents of inputs used in poultry production farms. Cobb - Douglas production function is expressed in general form as;

$$Y = f(x)\exp(u) \qquad [23] \qquad (6)$$

Eq. (6) can be linearized and expressed as Eq (7):

$$\ln Y_i = a + \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \qquad i = 1,2,3....n \quad (7)$$

Where Y_i indicates the output of the i[th] farm, X_{ij} the input vector used in the production process, a, constant term, α_j represents the input coefficient estimated from the model and e_i is the error term.

Assuming that when the energy input is zero, the poultry production is also zero, then Eq. (7) modified to Eq. (8):

$$\ln Y_i = \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \qquad i = 1,2,3....n \quad (8)$$

If a yield is a function of energy input, Eq. (8) becomes Eq. (9):

$$\text{Ln } Y_i = \alpha_i + \ln X_1 + \alpha_2 lnX_2 + \alpha lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + e_{ai} \quad (9)$$

Where;

X_1 = chick energy, X_2 = human labour energy, X_3 = electricity energy inputs, X_4 = machinery energy, X_5 = diesel fuel energy, X_6 = feed energy, X_7 = disinfectant energy inputs, X_8 = medicine energy inputs

Cobb – Douglas function (Equation 10 - 11) was also applied to assess the impact of direct, indirect, renewable and non-renewable energy in the poultry farms;

$$\ln Y_i = \beta_1 \ln DE + \beta_2 \ln IDE + e_i \qquad (10)$$

$$\ln Y_i = \gamma_1 \ln RE + \gamma_2 \ln NREz + e_i \qquad (11)$$

Where;

Y_i = yield of the i[th] farm, DE = direct energy inputs, IDE = indirect energy inputs, RE = renewable energy inputs, NRE = non-renewable energy inputs, β_1 and γ_1 = coefficients of variables and e_i is the error term.

The least square method was used to evaluate the Eqs (9), (10) and (11). Basic data on energy inputs and returns of poultry was entered and simulated using R software in Excel spread sheet.

Differences in poultry output with energy input differences were predicted with the return to scale by adding coefficients for each regression equation. Sensitivity of energy inputs used in the poultry production was calculated by using marginal physical productivity (MPP). MPP estimates the difference in yield (egg, meat and litter) with one input if other inputs are constant. MPP was calculated by using Equation (12);

$$\text{MPP} = \frac{GM(Y)}{GM(Xij)} \times aij \quad [21] \qquad (12)$$

Where;

MPP_{xj} is marginal physical productivity for j[th] input, a_{ij} is regression coefficient of the input, GM (Y) is geometric mean of poultry yield and GM (X_{ij}) is geometric mean of energy consumed.

MPP is positive when production increases in relation to increased input. This suggests that if the fixed resource is not fully used, the use of the variable inputs should be boosted. A negative MPP value shows, however, that further use of inputs has negative impacts on production.

3. Results and Discussion

3.1. Energy inputs and outputs

Table 2 provides the average energy usage in three classes of poultry farm sizes and their energy equivalents. Results indicated that, diesel fuel energy usage with an average energy equivalent of 12157.97 Mcal (1000 birds)$^{-1}$ had the highest significant share of 47.8% of the energy inputs. After diesel fuel, feed was the second most consumed energy input with an energy equivalent of 48,742.04 Mcal (1000 birds)$^{-1}$. This represents 34.35% of poultry production's overall energy input. Electricity with the amount of energy equivalent to 4123.46 Mcal (1000 birds)$^{-1}$ was the third most consuming energy source, accounting for 16.20 per cent of total poultry power consumed. Shares of human labour, machinery, medications and disinfectants in total energy usage were 0.3, 1.05, 0.06 and 0.004%, respectively as presented in Figure 1. Average total energy inputs and output were 25450.33 and 198914.7 Mcal (1000 birds)$^{-1}$ respectively. These results were in agreement with the studies of Saeed et al [11] and Amid et al [20] that diesel fuel and feed ranked the first and second energy inputs for broiler production.

In Table 2, energy inputs required for the production of poultry were also disclosed in the three poultry farm size groups. Farms I, II or III had total energy inputs of 28006.41, 26450.19 and 21894.39 Mcal (1000 birds)$^{-1}$, respectively. The average total energy input of different poultry farms differs. There was noticeable reduction in the total input of energy with increasing farm size. This has to do with increased management in the large farms. In this regard, it is of great importance to scientifically design broiler farm structures and manage the broilers' nutrition, based on environmental conditions and the birds' growth.

Table 2. Energy inputs required for the production poultry

Items	Small farms	Medium farms	Large farms	Total (Average)	(%)

Inputs					
Labor	123.63	54.65	49.23	75.83	0.3
Machinery	311.52	273.47	216.41	267.13	1.05
Diesel fuel	13740.11	11866.83	10866.98	12157.97	47.77
Electricity	4024.16	4758.49	3587.75	4123.46	16.20
Feed	9713.46	9417.16	7095.49	8742.04	34.35
Medicines	24.16	11.35	10.75	15.42	0.06
Disinfectants	1.71	0.68	0.53	0.97	0.04
Chick	67.66	67.56	67.25	67.49	0.27
Total input	28006.41	26450.19	21894.39	25450.33	100
Outputs					
Egg	172930.21	187421.5	217286.2	192546	96.80
Poultry meat	6670.96	6075.34	5859.04	6201.78	3.12
Poultry litter	165.37	173.24	162.32	166.98	0.08
Total output	179766.54	193670.10	223307.50	198914.70	100

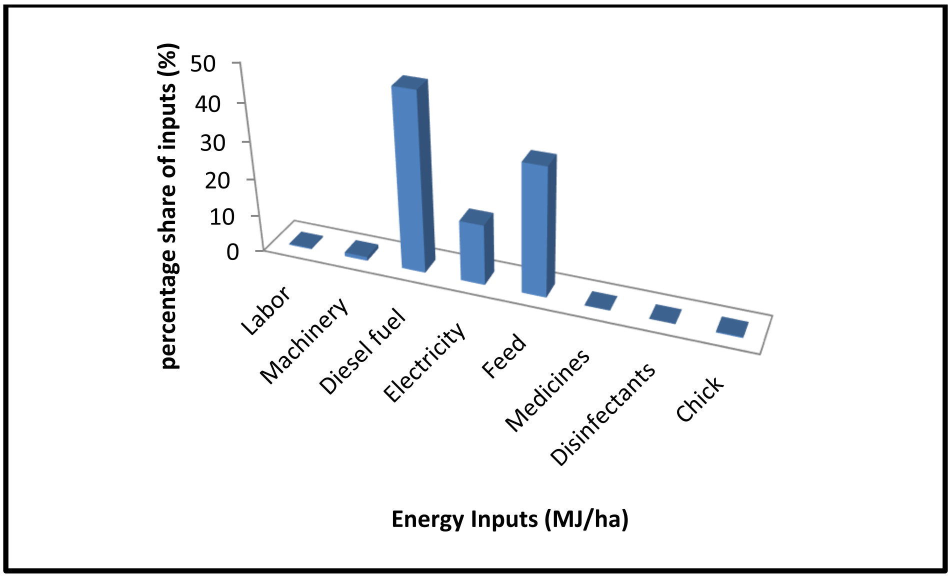

Figure 1. Share of energy inputs in the surveyed farms

Table 3 presents the energy indices of the surveyed farms. Energy ratios were estimated to be 6.42, 7.32 and 10.20 for group I, group II and group III farms. The mean energy ratio was found to be 7.98. Energy productivity was calculated to be 6.175, 7.086 and 9.924 kg Mcal^{-1} for group I, II and II farms respectively, indicating the higher productivity of large-sized farms. Specific energy for the respective farms was revealed to be 0.162, 0.141, and 0.132 Mcal kg^{-1}. These indicate that the energy needed to produce 1 kg of poultry meat in group III farms is lower than those of group I and II farms. Net energy gain for the surveyed farms was 151760.1, 167219.9 and 201413.1 kg (1000 birds)$^{-1}$, respectively, showing an ascending trend with the farm size. This finding implies that large-sized farms have more optimum energy advantage.

Table 3 also showed the amount of different energy forms used for poultry production in this study. The amount of direct (DE) and indirect energies (IDE) were 17887.90, 16679.97 and 201413.1 Mcal (1000 birds)$^{-1}$, respectively. Average quantities of renewable (RE) and non-renewable energy (NRE) consumed were 8885.36 and 16548.57 Mcal (1000 birds)$^{-1}$ as presented in Figure 2.

Table 3. Energy indices for poultry production in the surveyed farms

Indicators	Unit	Group I farms	Group II farms	Group III farms	Average

Energy ratio	%	6.419	7.322	10.199	7.98
Energy productivity	kg Mcal -1	6.175	7.086	9.924	2.67
Specific energy	Mcal kg -1	0.162	0.141	0.132	0.15
Net energy gain	Mcal 1000 birds-1	151760.1	167219.9	201413.1	173464.4
Direct energy	Mcal 1000 birds-1	17887.90	16679.97	14503.96	16357.27
Indirect Energy	Mcal 1000 birds-1	10092.64	9758.19	7379.15	9076.66
Renewable Energy	Mcal 1000 birds-1	9904.75	9539.37	7211.97	8885.36
Non-renewable Energy	Mcal 1000 birds-1	18075.79	16898.79	14671.14	16548.57

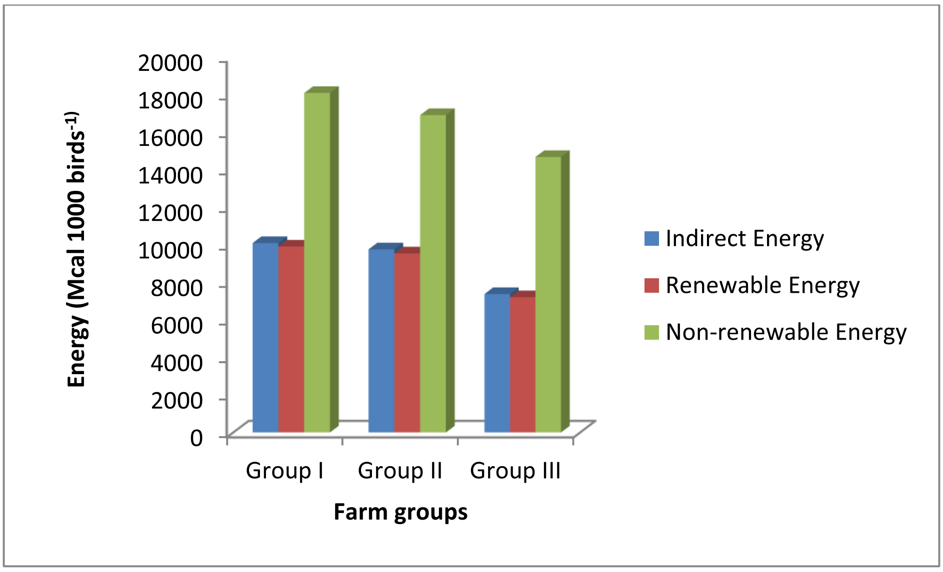

Figure 2. Share of direct, renewable and non-renewable energy forms

3.2. Modeling energy inputs in poultry production

Table 4 shows results of the estimation model in terms of equivalents energy inputs in poultry production in the surveyed farms. Impacts of diesel fuel and that of electricity were significant at 5% confidence level, showing regression coefficients of 0.074 and -0.235, respectively. From the Table, energy inputs of labor, chick, diesel fuel, machinery, disinfectants, and medications had positive impacts on the production, while electricity and feed had a negative effect. Results of sensitivity analysis showed that 1 Mcal increase in energy inputs of labor, chick, diesel fuel, machinery, disinfectants, and medications resulted to 2.52, 0.05, 0.02, 1.77, 5.43 and 2.16 kg increase in yield. However, 1 Mcal increase in electricity and feed would reduce the yield by 0.235 and 0.140 kg. Return to scale rate was estimated at - 0.04 which indicates that 1% increase in the energy equivalents caused a 0.04% loss in the production yield. R^2 was found to be 1.86 for the estimated model. Therefore, energy inputs (independent variables) can capture about 79% of layer yield variations in the poultry farms.

Table 4. Model for estimating impact of energy inputs on poultry production

	Coefficient	t-ratio	P-Value	MPP
$Model = \alpha_i + \ln X_1 + \alpha_2 lnX_2 + \alpha lnX_3 + \alpha_4 lnX_4 + \alpha_5 lnX_5 + \alpha_6 lnX_6 + \alpha_7 lnX_7 + \alpha_8 lnX_8 + e_i$				
	0.014	0.23 ns	0.514	0.05
	0.058	1.21 ns	0.353	2.52
	0.074	2.48 *	0.021	0.05
	-0.235	-4.51	0.011	0.02
	0.346	2.21 ns	0.053	1.77
	-0.140	-0.64	0.285	0.05
	0.003	0.14 ns	0.863	5.43
	0.007	0.13 ns	0.468	2.16
R^2	0.81			
R^2_{Adj}	0.72			
Durbin Watson	1.86			
Return to scale	-0.04			

Note: *significant at 5% probability level, ns = non-significant

4. Conclusions

This research examined the energy utilization and application of a poultry parametric technique in poultry farms. Results showed that diesel fuel was the most important energy input in the farms surveyed followed by feed. The average power expenditure on farms was 28006.41, 26450.19, 21894.39 MJ (1000 birds)$^{-1}$, respectively. Impacts of renewable and indirect sources of energy were greater than that of nonrenewable and direct energy Impacts of renewable and indirect sources of energy were greater than that of nonrenewable and direct energy. Return on the scale rate was -0.04 and R^2 for the predicted model was 0.81. Large farm holdings have been shown to be more energy efficient than small and medium farm holdings. This might arise from enhanced input handling in large farms in comparison with small and medium-sized farms.

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