Heliyon 8 (2022) e10053

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Analysis of energy consumption in poultry management for table egg production in Nigeria

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ARTICLE INFO

Keywords:
Egg production
Energy analysis
Poultry management
Energy consumption

ABSTRACT

Energy audit and mass flow studies of commercial agricultural systems are increasingly becoming of utmost importance, due to high operation costs and dependence on energy. This research was designed to study energy input, output and efficiency for daily table egg production from commercially managed poultry birds. Three commercially operated poultry farms in Ibadan, Nigeria were visited for assessment of management procedures, data collection, equipment observation and personnel interview. The energy required for each management procedure was calculated from standard methods. Each farm housed average of 25,000 actively laying birds and had average daily egg production of 21,250 egg pieces. This amounted to 1169 kg egg and 3000 kg faecal materials production per day from the average energy input of 122,461.12 MJ/day. The highest energy consumption was biological energy which resulted from daily feed consumption of 3000 kg at the rate of 120 g per bird per day. This made up 83.81% of the total energy consumed. These resulted in an energy consumption ratio of 1.05, energy productivity of 0.034 kg/MJ, specific energy of 29.29 MJ/kg and net energy of 6,569.09 MJ/day, respectively. Faecal materials constituted the bulk of the output from the system. Making use of the faecal material in its treated form for the production of feed components would reduce energy costs, increase farmers' net income and also encourage environmentally efficient processes.

1. Introduction

1.1. Importance of egg in human diet

The regular production of poultry eggs, primarily for human consumption among other uses is of utmost importance in any nation's food production and economic sector. Poultry egg production takes a major position in animal husbandry, on a global scale (Pelletier et al., 2013). Poultry egg consumption is one of the major sources of proteins in Nigeria, due to the rising cost of other sources of animal proteins (Ayanwale and Ajetomobi, 2021). Nutritionally, consuming an egg provides major nutrients such as protein, fats, vitamins and minerals in the human diet. Egg also contains some levels of carbohydrates, essential amino acids, vitamins A, D, E, B1 and B2 as well as minerals including Ca, Fe, K, Zn, Cu, Mg, I, Se and P (Binuomote et al., 2008; Molnár and Szollosi, 2020). Poultry egg consumption is essential in maintaining optimal health conditions such as improvement in the function of the brain and immune systems, reduction in health risk challenges and also the correction of eye defects, resulting from old age (Molnár and Szollosi, 2020). With the importance of egg consumption to the human diet, inputs into the production of such must be optimized and well managed. Such inputs include energy, finance, laying birds, daily feed consumed, water; for cleaning and bird consumption, and poultry medications among other things.

1.2. Energy requirements for agricultural systems

Energy use in agricultural production is germane to the success of any agricultural venture. Energy input needs in food production increase with the population as food demand increases (Jekayinfa et al., 2013a). The success of any large scale agricultural production largely depends on how efficient energy is used for all unit operations (Jekayinfa and Bamgboye, 2007).

Sources of energy can be renewable or non-renewable (Kosemani and Bamgboye, 2020). According to Kosemani and Bamgboye (2020), some non-renewable energy may be indirectly involved in agricultural production through the use of inputs such as pesticides, fertilizers, herbicides, machinery and fossil fuels. These indirect energies were expended

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https://doi.org/10.1016/j.heliyon.2022.e10053
Received 21 March 2022; Received in revised form 23 April 2022; Accepted 19 July 2022

from the production of the aforementioned inputs (Yilmaz et al., 2005). These energies are used outside the farm gate to produce, process, package, manufacture and transport farm inputs (Kosemani and Bamgboye, 2021). Renewable energy may include biological, solar and wind sources. Direct forms of energy employed in agricultural production can be harnessed from human labour, animal power, fuel and electricity (Kosemani and Bamgboye, 2020).

According to Jekayinfa and Olajide (2007), budgeting, forecast and energy requirement planning for production systems are enabled by the knowledge of energy consumption. Energy analysis is germane to monitoring the continuous increase in energy prices, dwindling natural resources for energy production, standards of energy consumption and minimization of greenhouse gases emission (Bawaneh et al., 2019). The knowledge of energy consumption for each unit operation constituting an agricultural system is germane to detecting energy consuming areas of such systems (Jekayinfa, 2008). Energy analysis assesses energy efficiencies and the impact of agricultural activities on the environment (Namdari et al., 2011) because the use of energy with improved efficiency reduces environmental pollution and destruction of natural resources to the barest minimum (Ogunlade et al., 2020).

The energy requirements of many systems, especially agricultural-related systems have been well analysed or estimated in the recent past. These had enabled improvements and enhanced policy making on such systems for optimization, waste minimization and inputs maximization. Jekayinfa and Bamgboye (2007) developed equations for estimating the required energy for seven main operations during the processing of palm kernels into oil in small, medium and large scale mills. This study reported decreased energy requirements as the mills' size increased. Estimated energy requirements were 352 MJ, 232 MJ and 177 MJ per 1000 kg of palm kernel for small, medium and large scale mills, respectively. Sandouqa and Al-Hamamre (2019) accounted for the energy input, output and greenhouse emissions associated with biodiesel production systems. An energy requirement of 29.1 MJ/L of biodiesel and greenhouse gas emission of 2.28 kg-CO_2 eq/*L biodiesel* were estimated. Jekayinfa et al. (2013b) estimated the energy consumption for mango production as 15,015.16 MJ/ha. One kilogram of mango required 0.7 MJ energy for production. Fossil fuels constituted the bulk (56 %) of the energy usage. Manual energy for cultural practices made up 33% of energy input while machinery and chemicals made up the remaining 8% of energy input into the system. In return, mango gave the energy of 57, 067 MJ/ha Salami et al. (2010) also estimated the total energy needs for strawberry production in Iran as 36822.9 MJ/ha. Approximately, about 74.5 % of total energy inputs in strawberry production were sourced from non–renewable sources and the balance from renewable sources. Nabavi-Pelesaraei et al. (2016a) determined the efficiencies and inefficiencies in the production units of watermelon in Iran. A total of 34, 228.21 MJ/ha of optimal energy was estimated for the production of watermelon in Iran. Furthermore, Nabavi-Pelesaraei et al. (2016b) estimated an average energy requirement of 25,582.50 MJ/ha for the production of oranges in orchards of North Iran. The foregoing reviews revealed that no study had been carried out to quantify the energy expended for continual and sustained daily poultry management for egg production in Nigeria. This study was thus designed to investigate the energy use and energy requirement for the daily production of edible poultry eggs. The scope of this research is limited to the daily routine management of matured laying birds producing edible eggs for human consumption. This aim was achieved by auditing energy use for feed mixing (maize milling and particle size reduction as well as mixing) and egg production (birds feeding, wetting during sunny days, lighting stimulation for egg production as well as egg harvesting). This study provides a firm basis for identifying existing options for saving energy in commercial poultry system management and operations for daily table egg production.

2. Materials and methods

2.1. Farms for the study

The study was conducted in Oyo State, Nigeria (7.25° N and 4.08° E), using three commercial farms as case studies. These farms also operated 2000 kg feed mixers, for finished feed production within their farm gates. Oyo state has a tropical savannah climate with two main seasons which

Table 1. Energy -mass input and output for table egg production.

No.	Energy Input	Energy Equivalent and Quantities	References
1.	Human Labour (MJ)	0.27	(Kosemani and Bamgboye, 2020)
2.	Biological Input		
	i. Maize (MJ)	14.70	(Kosemani and Bamgboye, 2021)
	ii. Wheat Bran (MJ)	13.26	(Amaefule et al., 2009)
	iii. Rice Bran (MJ)	15.00	(Li et al., 2018)
	iv. Layer Mash Concentrates (MJ)	23.21	(Mousavi-Avval et al., 2011; Tillman, 2019; Hossain et al., 2022)
	v. Feed Metabolizable Energy (MJ)	11.09	(Ding et al., 2016)
	vi. Average Body Mass of Laying Birds (kg) (MJ)	1.65	
3.	Chemical Pharmaceuticals (MJ)	120.00	(Shahan et al., 2008)
	i. Mass of Pharmaceuticals per Production Cycle (kg)	12.6	
4.	Machinery (MJ)	62.70	(Shahan et al., 2008; Mousavi-Avval et al., 2011)
5.	Low Heating Value of Diesel Fuel (MJ/kg)	42.6	(Bamgboye and Jekayinfa, 2006)
	Energy Outputs		
1.	Mass of Feed Output per time (kg)	2000	
2.	Egg Harvested (kg/day)	1,169	
3.	Mass of Faecal Material (kg/day)	3000	(Williams et al., 1999)
4.	Gross Energy content per Egg (kJ/Egg)	334.72	(Sibbald, 1979)
5.	Energy Contents of Egg (kJ/kg)	6,088	
6.	Energy Content of Poultry waste (kJ/kg)	13,882	(Quiroga et al., 2010)
7.	Average Nitrogen Intake of Birds (g/bird/day)	3.00	(Barzegar et al., 2019)
8.	Average Nitrogen Excreted by Birds (g/bird/day)	1.70	(Barzegar et al., 2019)
9.	Average Energy Retained as Protein (kJ/kg)	54.86	(Barzegar et al., 2019)
10.	Heat Produced by Bird (kcal/kg$BW^{0.75}$/day)	129.60	(Barzegar et al., 2019)

BW is Birds live body weight (kg).

Table 2. Unit operations of Feed Milling and Egg production.

No.	Operations	Explanation
1.	Scaling and arrangement of raw material	This is the manual measurement and arrangement of the appropriate quantities of feed components (rice bran, maize and wheat offal) mixed into the feed using a 1000 kg capacity scale.
2.	The Milling Process	This process was used to reduce the maize seeds' sizes into smaller particles, which can easily be picked up by birds. A hammer mill driven by an electric motor is used in this process. The hammer mill was fed manually and crushed maize was transported from the hammer mill sieve to the mixer through a screw conveyor, also driven by an electric motor.
3.	Mixer Loading	This process involved the turning of pre-measured materials (rice bran, wheat offal and concentrate) into the mixer. This was done manually.
4.	Mixing	This process involved the mixture of all feed components into a homogeneous mixture. The mixers have 2000 kg capacities at once and were driven by electric motors.
5.	Overturning	Overturning is the offloading of some premixed feed and then turning them back immediately into the mixer to ensure proper and homogeneous mixing of all feed components. These processes were done manually.
6.	Offloading	This is the collection of the finished feed into bags without adequate measurements. Manual energy was employed for this process.
7.	Bagging and Scaling of finished feed	This involved the bagging of offloaded finished feed into 25 kg capacity bags using a 50 kg capacity scale. This process also involved the use of manual energy.
8.	Transportation	The movement of finished feed from the feed mill section to pen houses. This was done by a haulage truck of 2000 kg capacity. The truck was always loaded and offloaded manually.
9.	Feed serving	This is the distribution of finished feed to birds in appropriate proportions. This was done manually to ensure each bird in battery cages got an equal share of feed.
10.	Feed readjustment	Served feeds were readjusted immediately to ensure even distribution of feeds to all birds for equal access. This enhances optimal bird productivity and also prevents bird mortality to certain extents.
11.	Water application	Water is applied to birds' bodies manually, by sprinkling a substantial quantity of water on birds on sunny days. This process is capable of reducing the build-up of ammonia and heat of respiration within the pen houses. This was also meant to prevent the effect of heat stress on caged birds.
12.	Feed Arrangement	This activity placed feeds needed the next day at strategic locations for easy access in the morning. The processes are done manually and it ensured the birds are not fed late for regular and unhindered egg production.
13.	Eggs Harvesting/Loading/Transportation/Offloading and Storage	These processes ensured the arrangement of eggs into egg crates, loading them into vehicles, transporting them to storehouses and offloading them from the vehicles for storage in storehouses. These processes involved manual and thermal energy.
14.	Daily cleaning routines	These routines involved sweeping the floor of pen houses and cleaning pen materials such as water tanks, nipple lines, feeder lines, nets and roof trusses (to get rid of cobwebs) are done regularly to ensure cleanliness and good housekeeping within farm premises.
15.	Pens lighting	Lighting was provided through 15 Watts energy saver bulbs. This elongates the daytime period for the birds; thus increasing the period of access to feeds. The bulbs were powered by a diesel generator.
16.	Waste Management	This process involved the cleaning of poultry droppings underneath the battery cages. These were done manually.
17.	Water Pumping	This activity ensures sufficient water is pumped into overhead tanks in pen houses and other storage tanks on the farm site. These made water available for drinking, cleaning and for waste management purposes. This was done utilizing submersible water pumps powered by a 1.5 HP rated electric motor powered by a diesel generator.

are dry and rainy. The rainy season spans from March to October annually while annual dryness is always experienced between November and February. The average annual rainfall is about 1700 mm. Annual averages of temperature and relative humidity were 30 °C and 72%, respectively.

The commercial poultry farms studied in Ibadan had continuous growing capacities. The farms manage about twenty-five thousand (25,000) heads of birds across three pen houses. The farm operates on full-scale production of edible table eggs, thus producing about seven hundred and eight crates of eggs daily (21,250 pieces of eggs, each weighing 55 g on the average), that is; about 85% of stocked birds produce on daily basis. Farms operated feed mills also produced 3 tonnes (3,000 kg) of finished feeds daily from raw materials. This implies each bird consumes an average of 120 g per day. Details of energy and mass input and output of investigated poultry farms are shown in Table 1. Energy use for daily egg and feed production was studied according to management systems employed on each farm. Energy use data including manual labour, machinery used for power generation and feed production were obtained by use of questionnaires, a direct visit to farms during operations as well as interviews with farm owners, managers and pen workers.

2.2. Energy estimation procedures

2.2.1. Energy forms in the system

Energy from poultry egg and feed production systems were broadly grouped as direct and indirect energies. The direct energies involve human labour, thermal or chemical energy from fuel (diesel) combustion and also electrical energy. Indirect energy comprises energy involved in feed, concentrates and drug production as well as energy input to water pumping and live birds' production.

2.2.1.1. Electrical energy. The use of electrical energy in most processing and production systems is in many cases achieved by the use of electric motors (Fadare et al., 2009). Mathematically, electrical energy was calculated from Eq. (1).

$$Ep = 3.6\ \{\eta Pt\ kWh\}\ MJ \tag{1}$$

where E_p is the electrical energy consumed in kWh, P is the rated power of the motor in kW, t is the hours of operations in hours and ŋ is the efficiency or power factor of the electric motors.

2.2.1.2. Manual energy. Manual energy expended during farm operation was estimated using the method employed by (Kosemani and Bamgboye, 2020). These were estimated from Eqs. (2) and (3) which gives the energy released from a grown-up male and female respectively.

$$E_{male} = 3.6(0.075 \times N \times t)\ MJ \tag{2}$$

$$E_{female} = 3.6(0.065 \times N \times t)\ MJ \tag{3}$$

Where t is the time spent on the unit operation, N is the number of persons involved, 0.075 and 0.065 are the average powers with which a healthy male and female can work, respectively under normal working conditions.

2.2.2. Thermal energy

Thermal energy produced from diesel fuel was calculated from Eq. (4) in accordance with Kosemani and Bamgboye (2020).

$$E_t = (LHV)W\ (MJ) \tag{4}$$

Where E_t = is the thermal energy expressed in Megajoules (MJ), LHV is the low value of diesel fuel (MJ/kg) and W is the quantity of fuel used (kg/day).

2.2.2.1. Chemical energy. Chemical energy input was obtained from the quantity of drugs used to treat the birds from one period to the other. The veterinary pharmaceuticals include vaccines, stress relieves, deworming drugs and antibiotics or antiviral drugs. The sum of chemical energy input for poultry production was calculated from Eq. (5).

$$E_{chem} = Q \times E_{equiv} \tag{5}$$

where E_{chem} is the chemical energy, Q is the quantity of drugs used (kg) and E_{equiv} is the energy equivalent of the concerned drugs (MJ/kg).

2.2.2.2. Biological energy. This is the amount of energy stored in the feed ingredients (Kosemani and Bamgboye, 2020) such as maize, wheat offal, and concentrates (soybean, groundnut cake, calcium supplements, and vitamins) estimated from Eq. (6).

$$E_{bio} = Q_{bio} \times E_{equiv} \tag{6}$$

where E_{bio} is biological energy expended daily (MJ), Q_{bio} is the quantity of biological resources and E_{equiv} is the energy equivalent of each biological resource (MJ/kg).

2.2.2.3. Output energy. Eq. 7 through 18 through 18 adapted from Barzegar et al. (2019), were used for the estimation of retained energy in the body and eggs of laying birds.

$$TNR = N_{intake} - N_{excreted} \tag{7}$$

TNR is total Nitrogen retained in birds' bodies (g/bird/day), N_{intake} is the mass of nitrogen intake (g/bird/day) and $N_{excreted}$ is the mass of nitrogen excreted as faecal materials by birds (g/bird/day).

$$NR_{egg} = 1.936\% \times Egg\ mass \tag{8}$$

NR_{egg} is the mass of nitrogen retained in eggs (g/bird/day), Egg mass was taken as 55 g and 1.936 is the % nitrogen in egg.

$$NR_{body} = TNR - NR_{egg} \tag{9}$$

NR_{body} is the mass of nitrogen retained in birds' bodies (g/bird/day).

$$RE = MEI - HP \tag{10}$$

RE is retained energy (kJ/kg), MEI is Metabolizable Energy Intake (11087.6 kJ/kg) and HP is the Body Heat Production by birds (542.25 kJ/kg).

According to Barzegar et al. (2019), ingested feeds by birds are retained in the bodies and eggs of birds as protein or fat. Eqs. (11), (12), (13), (14), (15), (16), (17), and (18) were used into separate the retained energy to its various forms and sites.

$$RE_{protein} = TNR \times 6.25 \times 5.7 \tag{11}$$

$RE_{protein}$ is retained energy in protein (kJ/kg), 6.25 is the protein equivalent of 1 g nitrogen and 5.7 is the energy equivalent of 1 g protein (kJ/kg/day).

$$RE_{fat} = RE - RE_{protein} \tag{12}$$

RE_{fat} is retained energy in fat (kJ/kg)

$$RE_{egg} = -19.7 + (1.81 \times Egg\ mass) \tag{13}$$

RE_{egg} is retained energy in egg (kJ/kg) (Sibbald, 1979)

$$RE_{eggprotein} = 1.936\% \times Egg\ mass \times 6.25 \times 5.7 \tag{14}$$

$RE_{eggprotein}$ is retained energy in egg protein (kJ/kg)

$$RE_{eggfat} = RE - RE_{eggprotein} \tag{15}$$

RE_{eggfat} is retained energy in egg fat (kJ/kg)

$$RE_{body} = RE - RE_{egg} \tag{16}$$

RE_{body} is retained energy in birds' bodies (kJ/kg)

$$RE_{bodyprotein} = NR_{body} \times 6.25 \times 5.7 \tag{17}$$

$RE_{bodyprotein}$ is retained energy in birds' bodies as protein (kJ/kg)

$$RE_{bodyfat} = RE - RE_{bodyprotein} \tag{18}$$

$RE_{bodyfat}$ is retained energy in birds' bodies as fat (kJ/kg).

The quantity of eggs produced daily was transformed into energy output by multiplying the value by the energy equivalent (Q_{equiv}) in each egg using Eq. (19).

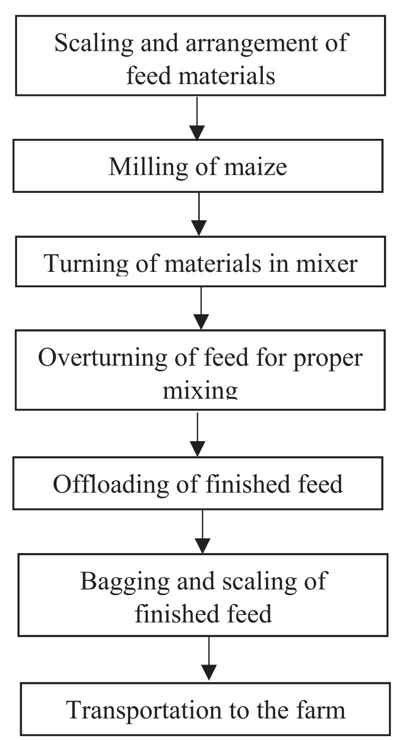

Figure 1. Flow chart of a feed mill process.

$$E_{egg} = Q_{egg} \times G_{equiv} \quad (19)$$

Where Q_{egg} is the quantity of eggs produced per day (kg) and G_{equiv} is the energy equivalent of each egg (MJ/kg).

The energy quantity of faecal materials produced each day by stocked birds was estimated from Eq. (20).

$$E_{faeces} = Q_{faeces} \times Q_{equiv} \quad (20)$$

Where Q_{faeces} is the quantity of faeces produced per day (kg) and Q_{equiv} is the energy equivalent of faeces produced (MJ/kg).

2.2.3. Energy indicators and energy forms

Energy use efficiency, specific energy, energy productivity and net energy were used to indicate the optimal use of energy or otherwise, in poultry management for table egg production. Input energies were also grouped into Renewable, non-renewable, direct and indirect energy forms. Eq. 21 through 28 through 28 were employed for estimation of the energy indicators according to Mousavi-Avval et al. (2011); Kosemani and Bamgboye (2020); Kosemani and Bamgboye (2021).

$$E_u = \frac{E_o}{E_i} \quad (21)$$

$$E_s = \frac{E_i}{Q_o} \quad (22)$$

$$E_p = \frac{Q_o}{E_i} \quad (23)$$

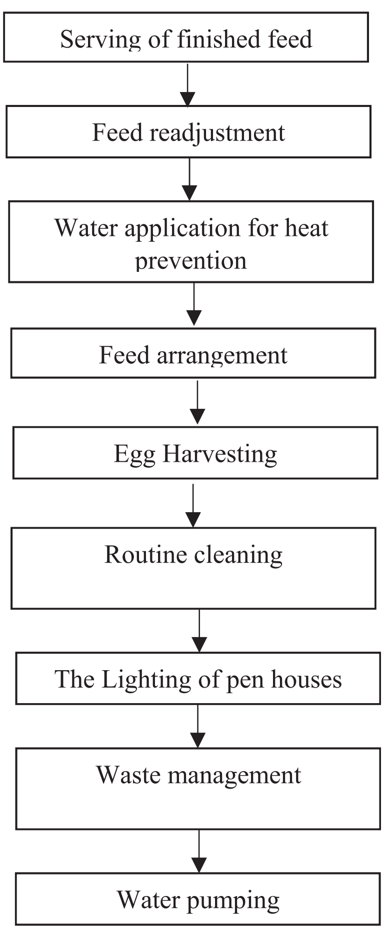

Figure 2. Flow chart of egg production processes.

$$E_n = E_o - E_i \quad (24)$$

$$E_r = E_{bio} + E_{male} + E_{female} \quad (25)$$

$$E_{nr} = E_{chem} + E_t \quad (26)$$

Table 3. Information on energy parameters for each unit operation in feed milling and daily poultry management.

Unit Operation	Required Parameters	Values	Units
Scaling	Number of persons	3	
	Duration	7200	s
Milling	Electrical Power	16.5	kW
	Efficiency	80	%
	Number of persons	2	
	Duration	2700	s
Mixer Loading	Electrical power	11	kW
	Efficiency	80	%
	Number of persons	2	
	Duration	2700	s
Mixing and Overturning	Electrical Power	5.5	kW
	Efficiency	80	%
	Number of persons	2	
	Duration	1800	s
Offloading	Electrical Powers	5.5	kW
	Efficiency	80	%
	Number of persons	3	
	Duration	1800	s
Bagging and Scaling	Number of persons	3	
	Duration	3600	s
Transportation	Number of persons	3	
	Duration	3600	s
	Fuel usage	0.003	m^3
Serving	Number of persons	9	
	Duration	5400	s
Feed Readjustment	Number of persons	9	
	Duration	10800	s
Water Application	Number of persons	9	
	Duration	1800	s
Feed Arrangement	Number of persons	9	
	Duration	900	s
Egg Harvesting/Loading /Transportation/Offloading	Number of persons	9	
	Duration	7200	s
	Fuel consumed	0.003	m^3
Routine Cleaning	Number of persons	9	
	Duration	1800	s
	Electrical Power	5.5	kW
	Efficiency	80	%
	Time of Pressure pump operation	7200	s
	Number of persons	3	
Lighting	Electrical Power	12.7	kW
	Efficiency	90	%
	Time	25200	s
	Fuel Consumed	0.015	m^3
Waste Management	Number of persons	1	
	Duration	18000	s
Water Pumping	Electrical Power	1.13	kW
	Duration	43200	s
	Efficiency	80	
	Fuel Consumed	0.015	m^3

$$E_{id} = E_{bio} + E_{chem} \quad (27)$$

$$E_d = E_{male} + E_{female} + E_t \quad (28)$$

Where E_u is energy use efficiency, E_s is specific energy (MJ/kg), E_p is energy productivity (kg/MJ), E_n is net energy (MJ/day), E_r is renewable energy, E_{nr} is non-renewable energy, E_{id} is indirect energy and E_d is direct energy. E_o is the aggregate of output energy retained, harvested as eggs, produced as materials and percentage used for body heat produced in birds on daily basis (MJ/day), E_i is total input energy as aggregates of manual, thermal, biological and chemical energies. (MJ/day), Q_0 is the quantity of egg harvested and faecal materials produced per day (kg/day).

2.2.4. Unit operations considered for energy evaluation

The unit operations considered for energy analysis are explained in Table 2. The operations were grouped into feed milling and egg production processes as shown in Figures 1 and 2.

3. Results and discussion

3.1. Energy input and output into table egg production

Table 3 highlights details of parameters used for the energy audit as obtained from studied farms. Table 4 detailed the energy input and output for onsite feeding mixing and composition on the farm while Table 5 detailed various energy inputs in each production management step or process. The bulk of energies consumed during feed mixing is from the biological components being mixed to make up a balanced and homogeneous feed mixture in adequate proportion for each bird. Feed compositions and mixing ratios on each farm visited were 50% maize, 30% concentrates, 5% rice bran and 15% wheat offal. Concentrates are mixtures of protein supplements in form of soybean, groundnut cakes, fish meals, calcium supplement in the form of limestone, premixes, toxin binder as well as varying forms of amino acids including lysine, methionine, threonine, and tryptophan.

A sum of 34,195.01 kJ/kg energy was consumed during the feed mixture and the output energy in form of homogeneously mixed feed was 34,100 kJ/kg. The difference of 95 kJ energy was made up of 2.01 kJ/kg (0.006%) manual energy, 38.00 kJ/kg (0.11%) electrical energy and 55 kJ/kg (0.16%) thermal energy. Transportation, milling and mixing processes consumed the highest amount of energy aside from feed composition mixed. The transportation process consumed 55 kJ of thermal energy, while milling and mixing processing consumed 18 and 16 kJ respectively (Table 5).

The mean energy input per kg table egg produced on farms studied is 29,279.29 kJ/kg as detailed in Table 5. The main forms of energy consumed for Table egg production on poultry farms were biological, Thermal, chemical and manual. The bulk of energy input into egg production was constituted by feed intake by laying birds. Feeds intake by

Table 4. Energy input and output in feed mixing process.

Unit Operations	Manual Energy (kJ/kg)	Electrical Energy (kJ/kg)	Biological Energy (kJ/kg)	Thermal Energy (kJ/kg)	Total Energy (kJ/kg)	% Total Energy
Scaling	0.81		-	-	0.81	0.002
Milling	0.20	18.00	14,700	-	14718.20	43.04
Mixer Loading	0.20	12.00	19,400	-	19412.20	56.77
Mixing and Overturning	0.10	4.00	-	-	4.10	0.012
Offloading	0.20	4.00	-	-	4.20	0.012
Bagging and Scaling	0.10	-	-	-	0.10	3×10^{-4}
Transportation	0.40	-	-	55.00	55.40	0.162
Total (kJ/kg)	2.01	38.00	34,100	55.00	34195.01	
% Total Input Energy	0.006	0.11	99.72	0.16	-	100.00
Output Energy (kJ/kg)	-	-	34,100	-	34,100	0.1/34195-
% Total Output Energy	-	-	100.00	-	100.00	100.00

Table 5. Energy input and output in poultry keeping and management.

Unit Operations	Manual Energy (kJ/kg)	Electrical Energy (kJ/kg)	Biological Energy (kJ/kg)	Thermal Energy (kJ/kg)	Chemical Energy (kJ/kg)	Total Energy (kJ/kg)	% Total Energy (%)
Serving	3.10	-	24,538.00		-	24,541.10	83.82
Feed Readjustment	6.270	-	-	-	-	6.27	0.02
Water Application	0.99	-	-	-	3,085.71	3,086.71	10.54
Feed Arrangement	0.52	-	-	-	-	0.52	0.002
Egg Harvesting	4.18	-	-	94.53	-	98.71	0.34
Routine Cleaning	11.81	27.27.00	-	-		39.08	0.13
Lighting	-	245.40	-	613.35	-	858.75	2.93
Waste Management	1.18	-	-	-	-	1.18	0.004
Water Pumping	-	33.3	-	613.35	-	646.98	2.21
Total Input Energy (kJ/kg)	28.05	306.30	24,538.00	1321.35	3085.51	29,279.29	
% Total Input Energy (%)	0.11	1.05	83.81	4.51	10.54	-	100.00
Output Energy (kJ/kg)							
Energy Retained in Egg (kJ/kg)	-	-	6,088	-	-	6,088	19.67
Energy Retained in the body (kJ/kg)	-	-	10,211.26	-	-	10,211.26	32.99
Energy Retained as Protein and Heat (kJ/kg)	-	-	772.37	-	-	772.37	2.50
Energy Value of Faecal Materials (kJ/kg)	-	-	-	13,882.00	-	13,882.00	44.84
Total Output Energy (kJ/kg)	-	-	17,071.63	13,882.00	-	30,953.63	-
% Total Output Energy (%)	-	-	55.15	44.85	-	-	100.00

each farm studied amounted to about 3000 kg/day for 25,000 heads of laying birds.

This translated to 120 g/bird/day since each farm housed an average of 25,000 birds with 85% of birds producing eggs per day. That is, 21,250 egg pieces (approximately 708 crates of table eggs) were produced daily. Biological energy made up 83.81% of energies consumed for daily egg production (Table 5). Biological energy amount was distantly followed by chemical energy in form of pharmaceuticals and medications, used for the treatment of diseases and symptoms in birds. These constituted 10.54% of total energy consumption. Biological and chemical energy consumption was followed by thermal energy consumption which amounted to 1321.35 kJ/kg, which is 4.51% of total energy consumed. The electrical energy consumed from lighting (extended daytime) amounted to 1.05% of total energy and manual energy employed as farm workers constituted 0.11% of the total energy use.

The main and most economic output from poultry keeping and management is table eggs. Daily table egg production on farms studied, constituted only 19.67 % of the total energy output. Each table egg has an average weight of 55 g and the total daily weight of harvested egg amounted to 1169 kg. Major energy outputs are in faecal materials, which amounted to 44.48% of the total energy output. According to Williams et al. (1999), each bird produced 120 g of faecal waste per day. The balance of energy output is stored in the body of birds as maintenance rations. Production rations of feeds are useful for laying birds for egg production while maintenance rations are used for body repair, growth, tissue replacement, fat production, respiration, digestion, weight gain and general body maintenance. Energies retained in the body were thus estimated to be 10,211.26 kJ/kg (32.99 %). This is in line with the study of Barzegar et al. (2019) which reported average Apparent Metabolic Energy (AME) value of 12,000 kJ/kg. Energy value of 772.37 kJ/kg (2.5 %) was stored in the body of laying birds as protein. Figure 3 shows the mass, energy and routine processes flow in daily poultry management for egg production.

A high amount of energy can be generated from waste materials. Poultry faecal matters should not be discarded as waste materials; since they can be employed in energy production as direct heating material (Quiroga et al., 2010). Although, using faecal material for heating requires some energy consumption for prior dewatering and drying. Poultry faecal materials are also suitable for the production of biogas and bio-digester effluents (bio-slurry); which are good sources of organic soil nutrients, for biomass or energy crop production. The bio-digestion of poultry wastes would prevent the emission of greenhouse gases into the

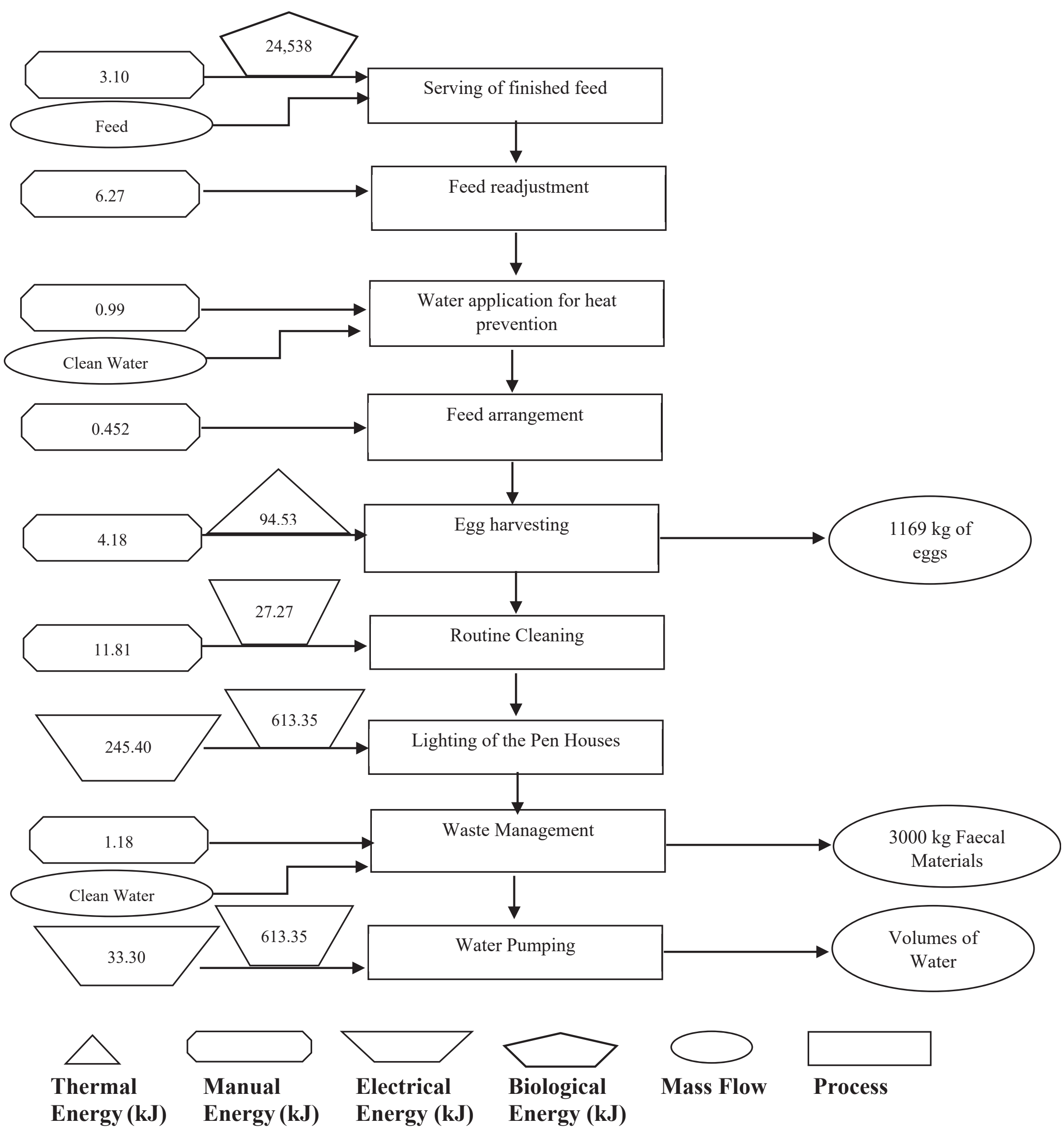

Figure 3. Energy accounting and mass flow diagram for poultry-keeping processes.

environment. Poultry waste was used for the production of bio-slurry by Sasanya and Ogedengbe (2019). The bio-digester effluents were reported to support the growth of leafy vegetables better than inorganic fertilizers. Furthermore, Sasanya (2019) pointed out that vegetables grown from bio-digester effluents can be safely consumed by humans. In the same vein, dry matters of poultry faecal material were reported by Quiroga et al. (2010) to have energy values of 13,882 kJ/kg. All of these emphasized the claim that poultry faecal materials are useful energy and organic matter sources; since they have a high potential of being ploughed into enormous economic uses. These would as well improve the eco-efficiency of the entire process as suggested by Saber et al. (2021). The organic farming system has several advantages and some of these include economic profitability as well as reduced damage to human health and the ecosystem.

3.2. Energy indicators

Energy indicators assessing optimal energy usage in its various forms are shown in Table 6. The energy use efficiency of daily table egg production was estimated as 1.05. This indicated some level of inefficiencies in poultry keeping for table egg production compared to other ventures in the agricultural sector of an economy. Kosemani and Bamgboye (2021) reported 2.46 energy use efficiency for maize production in Nigeria, Bamgboye and Kosemani (2015) estimated an energy use ratio of 7.01 for cassava production in Nigeria and an energy ratio of 7.09 was as well reported by Kosemani and Bamgboye (2020) for rice production in Nigeria. Furthermore, Mousavi-Avval et al. (2011) reported an energy use efficiency of 2.26 for the venture of soybean production in Iran. In the same vein, Canakci et al. (2005) reported energy ratios of 2.8, 4.8, 3.8, 1.5, 0.7, 1.9 and 2.0 for wheat, cotton, maize, sesame, tomato, melon and watermelon, respectively. These implied tomatoes had the least energy use efficiency from the study by Canakci et al. (2005). Nabavi-Pelesaraei et al. (2016a) and Nabavi-Pelesaraei et al. (2016b) also determined the energy use efficiency for watermelon and orange productions as 1.52 and 1.84, respectively, when the data envelopment analysis approach was used to optimized required energies. The energy productivity value for table egg production is however close to those reported by Namdari et al. (2011) as 0.99 and 0.77 for orange and mandarin production respectively.

Net and specific energies for table egg production were 6,569.09 MJ/day and 29.39 MJ/kg respectively. Jekayinfa et al. (2013b) reported net and specific energies of 5,384.84 MJ/ha and 2.00 MJ/kg respectively for mango production. Namdari et al. (2011) as well reported net energies of 625.18 and 17,651.17 MJ/ha for orange and mandarin as well as specific energies of 1.92 MJ/kg and 2.46 MJ/kg for orange and mandarin, respectively. Nabavi-Pelesaraei et al. (2016b) on the other hand reported average specific energy of 1.03 MJ/kg and a net energy gain of 21,442.5 MJ/ha for the production of oranges in North Iran. The energy productivity indicating quantities of outputs (table eggs and faecal materials) obtained per quantity of energy input is 0.03 kg/MJ. This is almost in tandem with the energy productivity reported by Yilmaz et al. (2005) for cotton production in Turkey as ranging between 0.06 and 0.2 kg/MJ. Jekayinfa et al. (2013b) and Nabavi-Pelesaraei et al. (2016b) however reported a higher energy productivity value of 1.31 and 0.97 for mango and orange production, respectively.

Comparatively, the amount of renewable energy employed in poultry management, for table egg production outweighs the non-renewable energy sources. Approximately 85% of energy inputs are from renewable sources while only about 15% makes up the non-renewable sources. This trend is encouraging since renewable or clean energy sources are usually embraced for their environmental friendliness. Non-renewable energy sources are made up of diesel fuel consumed and veterinary pharmaceuticals consumed as birds' medications. Also, indirect energy sources far exceeded direct energy sources. Indirect sources included feed materials and pharmaceuticals. Indirect energy sources constituted 94.04% of total input energy. The indirect-direct energy ratio is contrary to what was obtainable in the production of food and fruit crops. Jekayinfa et al.(2013a) reported an indirect-direct energy ratio of 0.95 and 85.92% non-renewable energy as well as 14.08% renewable energy. Ogunlade et al. (2020) also reported an indirect-direct energy ratio of 0.125 and a renewable to non-renewable energy ratio of 0.68.

Table 6. Energy indicators and energy forms in poultry management for table egg production.

Energy Indicators	Unit	Value	Percentage of Total (%)
Energy use efficiency (E_u)	-	1.05	
Specific Energy (E_s)	MJ/kg	29.39	
Energy productivity (E_p)	Kg/MJ	0.034	
Net energy (E_n)	MJ/day	6,569.09	
Renewable energy (E_r)	MJ/day	103,859.50	84.81
Non-renewable energy (E_{nr})	MJ/day	18,601.49	15.19
Indirect energy (E_{id})	MJ/day	115,162.41	94.04
Direct energy (E_d)	MJ/day	7,298.71	5.96
Total input energy	MJ/day	122,461.12	100.00
Total output energy	MJ/day	129,030.55	

4. Conclusion

The energy usage pattern in a poultry management system for daily table egg production was studied. The total input energy was 122,461.12 MJ/day; which produce 1169 kg of table egg and 3000 kg of faecal materials per day; with some amount of energy retained in the body of laying birds for bodily maintenance. These outputs amounted to 129, 030.55 MJ/day. The energy use efficiency amounted to 1.05, specific energy (29.29 MJ/kg), energy productivity (0.034 kg/MJ) and net energy was 6,569.09 MJ/day. Biological energy consumed as feed materials made up the bulk of daily energy requirements. Biological energy consumed made up 83.81% of daily total energy requirements. The amount of biological energy consumed was distantly followed by chemical energy consumed by laying birds as pharmaceutical drugs to the tune of 3.085 MJ/kg. The chemical energy made up 10.54% of the total energy input. Manual energy constituted the least energy input at a value of 0.28 MJ/day (0.11%). Daily table egg production from the management of laying birds made use of more indirect energy, making up about 94.04% of total input energy. Direct energy sources only constituted 5.96 %. Renewable energy amounted to 84.81% while non-renewable sources balanced the remaining 15.19%.

In Nigeria, efforts should be made to plough faecal materials produced from poultry management back into the system. This will encourage more energy input from renewable energy sources since these faecal matters made up the bulk of outputs from the system. These practices would be an added advantage to the farmer in form of additional income and overhead cost reduction. Further research should therefore be directed towards the reuse of poultry wastes to enhance poultry management and egg production.

Declarations

Author contribution statement

Blessing Funmbi Sasanya: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Oladayo Olaifa: Analyzed and interpreted the data; Wrote paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

Supplementary content related to this article has been published online at https://doi:10.1016/j.heliyon.2022.e10053.

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