Energy Equip. Sys./ Vol. 5/No.4/December 2017/ 411-418

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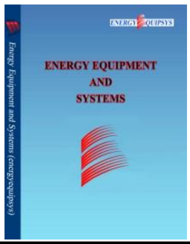

Energy flow modeling of broiler production in Guilan province of Iran

Authors

Saeed Firouzi[a]*
Mohammad Bagherzadeh[a]
Amir Hossein Bazyar[b]

[a] Department of Agronomy, Rasht Branch, Islamic Azad University, Rasht, Iran

[b] Sama Technical and Vocational training college, Rasht Branch, Islamic Azad University, Rasht, Iran

Article history:

Received : 29 May 2017
Accepted : 3 October 2017

ABSTRACT

The aim of this research was to study the energy flow and the modelling of energy use in broiler production in the Guilan Province of Iran. The data were gathered through interview with 25 broiler farm managers out of a total of 146 broiler producers in Rasht, the center of Guilan Province, Iran. The effect of broiler farm size at three levels—small (<20,000 birds), medium (20,000–30,000 birds), and large (>30,000 birds)–was evaluated, based on the energy use indices. The Cobb-Douglas model and sensitivity analysis were used to investigate the effects of energy inputs on poultry production. The results showed that the total energy input and energy ratio were 2,605.54 Mcal (1000 birds)$^{-1}$ and 0.234, respectively. Diesel fuel and feed were ranked the first and second energy inputs for broiler production with the shares of 43.92% and 36.68%, respectively, of the total energy input. The shares of renewable and non-renewable energy forms in broiler production were determined to be 37.33% and 62.67% of the total energy input, respectively. The energy ratios of small, medium, and large farms were computed as 0.232, 0.225, and 0.250, respectively. Consequently, the large-sized farms were more energy efficient than the small and medium-sized ones. Results of the Cobb-Douglas model showed that the impacts of energy inputs of labor, chick, diesel fuel, machinery, disinfectants, and medicines on broiler performance were positive, while the impacts of electricity and feed were negative.

Keywords: Agriculture, Energy Analysis, Modeling, Poultry.

1. Introduction

Given a growing population and an increasing demand for food, on the one hand, and limited resources of production inputs, on the other, the improvement of product yields has emerged as one of the main objectives of the agricultural sector, but higher production needs greater energy consumption, and productivity is proportional to energy input [1]. A growing trend of energy input in livestock production has significantly increased the environmental impact of this agro-industry [2].

In order to identify efficient approaches to energy saving, it is necessary to scrutinize the quantities of energy inputs and their allocation to the production systems. Energy measurement and input-output energy calculations are the most reliable ways to analyze energy consumption [3].

With an annual production of about 2 million tons of broiler, Iran is among the main broiler producers in the world (ranked 20[th] worldwide). In

* Corresponding author: Saeed Firouzi
Address: Department of Agronomy, Rasht Branch, Islamic Azad University, Rasht, Iran
E-mail address: firoozi@iaurasht.ac.ir

Iran, the Guilan Province possesses a relative advantage in broiler production, thanks to its favorable climatic conditions. Since energy cost accounts for a large part of the final price of broilers, saving energy inputs would cut broiler production costs and enhance the energy ratio in this agricultural industry.

1.1. Literature review

Owing to this increasing importance of energy, the energy consumption indices for broiler production have been analyzed in Iran and other parts of the world. Amid et al. [4] estimated the total energy input for broiler production to be 154,583 MJ (1000 birds)$^{-1}$ in Ardabil Province, Iran. Further, fossil fuel energy was found to have the highest share in broiler production, accounting for 61.4% of the total input energy. The indices of energy ratio, energy productivity, specific energy, and net energy gain were estimated to be 0.18, 0.02 kg MJ^{-1}, 59.56 MJ kg^{-1}, and 126,836 MJ (1000 birds)$^{-1}$, respectively. Rajaniemi and Ahokas [5] studied the direct energy consumption in a broiler house in Finland. They reported that, on average, the energy consumed by the heating system (1.3 kWh kg^{-1}) had the highest share in the consumption of direct forms of energy. Its share varied, depending on the production season, the highest one being in the cold seasons. Rajaniemi and Ahokas [3] 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. Katajajuuri et al. [6] and Hörndahl [7] have also shown that the energy consumed by the heating system contributes the most to energy input of broiler production farms. Heidari et al. [8] reported that the total input and output energy in broiler production in Yazd Province, Iran, were 186,885.87 and 27,461.21 MJ (1000 birds)$^{-1}$, respectively. Specific energy and energy ratio were found to be 71.95 MJ kg^{-1} and 0.15, respectively. Najafi et al. [9] assessed the energy efficiency of chicken production in different farm sizes and found that large farms with the capacity of 28,000 broilers per production cycle had a higher productivity rate than small and medium-sized farms. Amid and Mesri Gundoshmian [10] modeled the output energy of broiler production in Ardabil Province of Iran using ANN (MLP, RBF), and ANFIS Models. The Radial Basis Function (RBF) was reported be the best predictor for broiler energy output.

A review of the related literature showed that no study had, to date, investigated the energy consumption of broiler production in Guilan Province of Iran. Therefore, the present study aimed at examining the energy use indices and modeling of broiler production under different farm sizes in the Guilan Province, Iran.

2. Materials and method

2.1. The study region and data collection

The study was carried out in the Rasht area of Guilan Province in 2015. Guilan Province lies between latitudes 36°34' and 38°27' N and longitudes of 48°53' and 50°34' E. Rasht is at the center of Guilan Province and the leading broiler producer of the province with 146 small, medium, and large broiler farms around it. Given the limitations of the study and the precision intended in data collection, the energy consumption dataset represents 25 broiler production farms.

For more precise analysis of the energy use for broiler production, the broiler farms were divided into three groups of small (<20,000 birds), medium (20,000–30,000 birds), and large (>30,000 birds). The data were gathered by interviews with the managers of 10 small-sized, 8 medium-sized, and 7 large-sized broiler farms.

The inputs included (1) chicks, (2) labor, (3) fossil fuels, (4) electricity, (5) machinery, (6) feed, (7) medications, and (8) disinfectants, and the outputs included (1) broilers and (2) poultry wastes or litter (Fig. 1).

The energy equivalent of inputs (in Mcal U^{-1}) was calculated for fossil fuels, electricity, labor, chicks, feed ingredients, disinfectants, and medications by multiplying their total consumption for 1000 birds by their equivalent energy (Table 1). The energy equivalent of system outputs (broiler and poultry litter) was also calculated by multiplying equivalent energy by the output quantity.

The total energy input was divided into direct and indirect as well as renewable and non-renewable forms. Direct energies included energy equivalents of labor, fossil fuels, and electricity, whereas indirect energies included feed, machinery, poultry litter, disinfectants, medications, and chicks. Renewable energies were energy equivalents of feed, labor, chicks, and poultry litter, and non-renewable energies included machinery, fossil fuels, electricity, and disinfectants [11].

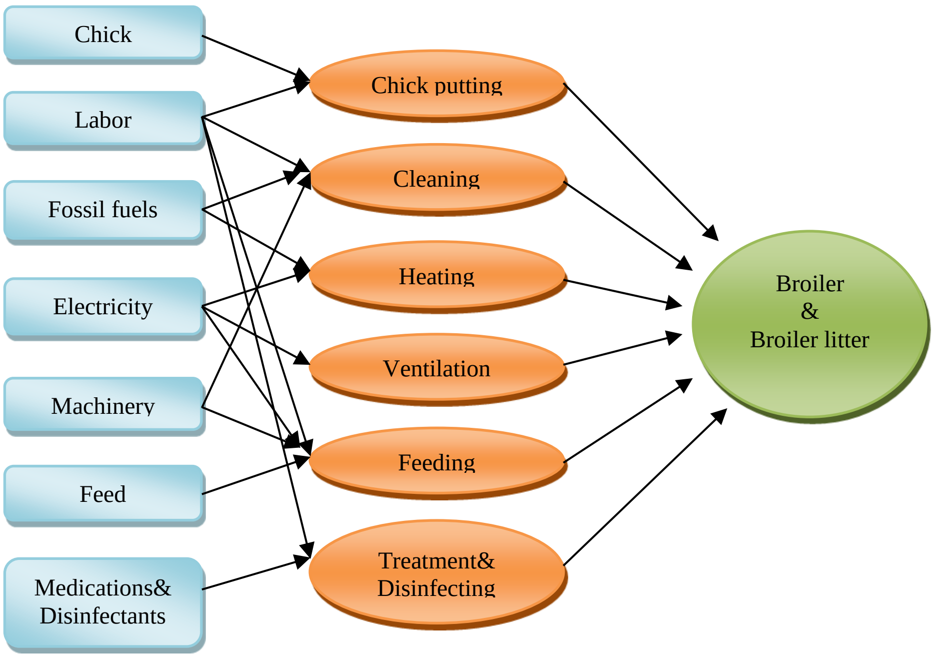

Fig 1. Energy inputs used in different operations of broiler production

Energy consumption indices, including energy ratio, energy productivity, specific energy and net energy gain, were calculated for three groups of broiler farms (small, medium, and large-sized) and total broiler farms by the following equations [12]:

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

$$\text{Energy productivity} = \frac{\text{Broiler meat (kg 1000 birds}^{-1})}{\text{Input energy (Mcal 1000 birds}^{-1})} \quad (2)$$

$$\text{Specific energy} = \frac{\text{Input energy (Mcal 1000 birds}^{-1})}{\text{Broiler meat (kg 1000 birds}^{-1})} \quad (3)$$

$$\text{Net energy again} = \text{Output energy}\left(\text{Mcal1000 birds}^{-1}\right) - \text{Intput energy}\left(\text{Mcal1000 birds}^{-1}\right) \quad (4)$$

Table 1. Energy coefficients of inputs of broiler production

Items	Energy coefficients (Mcal* U^{-1})	References
Input		
Labor	0.54	[13]
Machinery (h)	62.70	[14]
Diesel fuel (l)	11.38	[14]
Electricity (kWh)	2.85	[14]
Feed		
-Dicalcium phosphate (kg)	2.39	[15]
-Salt (kg)	0.38	[13]
-Maize (kg)	1.89	[13]
-Soybean (kg)	2.88	[15]
-Minerals and Vitamins (kg)	0.38	[16]
Medicines (kg)	3.26	[13]
Disinfectants (kg)	0.1	[13]
Chick (kg)	2.47	[17]
Output		
Poultry meat (kg)	2.47	[17]
Poultry litter (kg)	0.07	[17]

* *1 cal=4.184* J

2.2. Energy modeling

The impact of the energy equivalents of the inputs was modelled on broiler yield by the Cobb-Douglas function. The general form of the function is as depicted in Eq. (5). If the logarithm of both sides is derived and eight energy inputs are introduced into the equation, we will have Eq. (6), in which a_0 and e_i represent constant and error coefficient, respectively and $a_1, a_2, ... a_8$ represent the regression coefficients of the consumed energy inputs.

$$y = f(x)\exp(u) \tag{5}$$

$$\ln(y_i) = a_0 + \sum_{j=1}^{n} a_j \ln(x_{ij}) + e_i \quad i = 1,2,\ldots,n \tag{6}$$

$$\ln(y_i) = a_0 + a_1\ln(x_1) + a_2\ln(x_2) + a_3\ln(x_3) + a_4\ln(x_4) + a_5\ln(x_5) + a_6\ln(x_6) + a_7\ln(x_7) + a_8\ln(x_8) + e_i \tag{7}$$

Return to the scale rate was used to analyze the difference in broiler yield with the variations of energy inputs. This index is calculated by summing up the regression coefficients derived for each regression equation.

The sensitivity of energy inputs consumed for broiler production was calculated by marginal physical productivity (MPP), which estimates the change in yield (broiler yield) with one more unit of energy equivalent of the production inputs, assuming that the other production factors are constant. MPP was calculated by Eq.(8).

$$MPP_{xj} = \frac{GM(Y)}{GM(X_{ij})} \times a_{ij} \tag{8}$$

where, MPP_{xj} represents marginal physical productivity for jth input, a_{ij} represents the regression coefficient of the input, and $GM(Y)$ and $GM(X_{ij})$ represent the geometric means of the broiler yield and the consumed energy input, respectively [18-19].

3. Results and discussion

This section first determines the share of individual inputs for broiler production. Then, the energy indices are calculated and the results are contrasted with the results of the other studies on consumed energy indices for broiler production. A model is also proposed to estimate the broiler yield in terms of energy equivalents of eight inputs of the production system.

3.1. Energy inputs and outputs

Table 2 presents the quantities of the inputs and their equivalent energy for broiler production in Guilan Province. It was found that diesel fuel with an energy equivalent of 11,641.72 Mcal (1000 birds)$^{-1}$ was the most highly consumed input, accounting for 43.92% of the total energy input. This is in agreement with the studies conducted by Heidari et al. [8] and Amid et al. [17] in which diesel fuel energy input contributed 49% and 61.4% to the total energy input of broiler production in Yazd and Ardebil Provinces, Iran, respectively. In a study on energy consumption of broiler production in Mazandaran Province, Amini et al. [20] also reported a higher share of diesel fuel of the total energy input in traditional and modern broiler production systems (57% and 59%, respectively). Given the adverse environmental impacts of diesel fuel use, it is necessary to replace this energy resource with natural gas or bio-fuels in broiler farms of Guilan Province.

After diesel fuel, feed was the second most consumed energy input in broiler production with an energy equivalent of 9,721.15 Mcal (1000 birds)$^{-1}$. It accounted for 36.68% of the total energy input of broiler production. Similarly, chicken feed has been reported to be the second most important energy input for broiler production in Yazd, Alborz, Ardebil Provinces of Iran [8-17-21].

The third most highly consumed energy input was found to be electricity with an energy equivalent of 4,672.22 Mcal (1000 birds)$^{-1}$ capturing 17.63% of the total energy consumed for broiler production. This finding is in direct contrast with Amid et al. [17], who reported the share of electricity in the total energy input to be around 3% for broiler production in Ardebil Province. Energy equivalent of the machinery used for broiler production was estimated to be 284.40 Mcal (1000 birds)$^{-1}$ and was ranked fourth in the ranking of energy consumption rate. Disinfectants and medications had energy equivalents of 1.18 and 11.81 Mcal (1000 birds)$^{-1}$ and had less than 1% share of the total energy input.

The total energy input for broiler production was estimated at 26,505.54 Mcal (1000 birds)-1 in Guilan Province (Table 2). Total energy input for broiler production was reported to be 186,885 and 154,283 MJ (1000 birds)-1 (44,666 and 36,874 Mcal (1000 birds)-1) in Yazd and Ardebil provinces, respectively [4-8]. Therefore, the total energy input for broiler production in Guilan Province was lower than that of Yazd and Ardebil provinces.

Table 2. Energy equivalents of inputs (Mcal 1000 birds^{-1}) in broiler production in Guilan Province, Iran: small farms (<20,000 birds), medium farms (20,000–30,000 birds), large farms (>30,000 birds)

Items	Small farms	Medium farms	Large farms	Total (mean)	(%)
Inputs					
Labor	117.39	50.63	45.48	74.26	0.28
Machinery	331.05	296.15	222.07	284.40	1.07
Diesel fuel	14288.63	10758.56	10172.35	11641.72	43.92
Electricity	5167.21	5193.49	3482.20	4672.22	17.63
Feed	10076.32	9764.64	9308.00	9721.15	36.68
Medicines	20.77	8.63	7.09	11.81	0.04
Disinfectants	2.08	0.86	0.71	1.18	0.004
Chick	98.89	98.80	98.73	98.80	0.37
Total input	30102.25	26171.76	23336.70	26505.54	100
Outputs					
Poultry meat	6499.05	5579.50	5535.60	5842.19	97.43
Poultry litter	157.81	158.36	145.24	154.26	2.57
Total output	6656.86	5737.86	5680.83	5996.45	100

Table 3 presents the energy indices of broiler production in Guilan Province. The mean energy ratio was found to be 0.234. It has been reported to be 0.16 and 0.17 for traditional and modern broiler production systems, respectively [20]. The mean energy ratio for broiler production units in Ardebil Province was found to be 0.18 [4]. The higher energy efficiency found in this study shows the relative advantage of broiler production in Guilan Province compared to its neighboring provinces, namely Mazandaran and Ardebil. Energy productivity was estimated at 0.09 kg Mcal^{-1} for broiler production in Guilan Province. It was reportedly 0.02 kg Mcal^{-1} in Ardebil Province [4]. Mean specific energy and mean net energy were revealed to be 11.26 Mcal kg^{-1} and -20,509.09 Mcal (1000 birds)$^{-1}$.

Direct and indirect energy consumption for broiler production in Guilan Province were 16,388.20 and 10,117.34 Mcal (1000 birds)$^{-1}$ (61.83 and 38.17% of total energy input), respectively (Table 3). Moreover, the quantities of consumed renewable and non-renewable energy were 9,894.21 and 16,611.33 Mcal (1000 birds)$^{-1}$ (37.33 and 62.67% of total energy input), respectively.

Table 2 also includes energy equivalents of inputs consumed for broiler production in poultry farms of different sizes. The total energy input was found to be 30, 102.25, 26, 171.76, and 23,336.70 Mcal (1000 birds)$^{-1}$ in small (<20,000 birds), medium (20,000–30,000 birds) and large (>30,000 birds) farms, respectively. Different sizes of broiler farms differed in respect of the total energy input. As the size increases, the total energy input experiences a fall, which is associated with a higher managerial level of broiler production in larger 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 3 summarizes the energy consumption indices for broiler production in broiler farms with different size groups in Guilan Province. Energy ratios were calculated to be 0.232, 0.225 and 0.250 for small, medium and large-sized farms. This finding implies that large-sized farms have more optimum energy advantage.

Table 3. Energy indices for broiler production based on the farm size in Guilan Province, Iran

Indicators	Unit	Small farms	Medium farms	Large farms	Total (mean)	(%)
Energy ratio	%	0.232	0.225	0.250	0.234	-
Energy productivity	kg Mcal^{-1}	0.092	0.089	0.100	0.092	-
Specific energy	Mcal kg^{-1}	11.529	11.718	10.390	11.26	-
Net energy gain	Mcal 1000 birds^{-1}	-23445.39	-20446.78	-17655.86	-20509.09	-
Direct energy	Mcal 1000 birds^{-1}	19573.23	16015.55	13700.03	16388.20	61.83
Indirect Energy	Mcal 1000 birds^{-1}	10529.02	10169.09	9636.66	10117.34	38.17
Renewable Energy	Mcal 1000 birds^{-1}	10292.15	9926.94	9452.28	9894.21	37.33
Non-renewable Energy	Mcal 1000 birds^{-1}	19809.74	16257.70	13884.42	16611.33	62.67

Energy productivity was calculated to be 0.092, 0.089 and 0.100 kg $Mcal^{-1}$ for small, medium, and large-sized broiler farms, respectively, indicating the higher productivity of large-sized farms. Specific energy for broiler production for large, medium, and small-sized farms was revealed to be 11.529, 11.718, and 10.390 Mcal kg^{-1}, respectively, which indicates that the energy needed to produce 1 kg of broiler in large-sized farms is lower than those of small and medium-sized farms. Net energy gain for broiler production in small, medium, and large-sized farms was -23,445.39, -20,446.78 and -17,655.86 kg $(1000\ birds)^{-1}$, respectively. Thus, the net energy showed an ascending trend with the broiler farm size.

3.2. Energy modeling

The results of the broiler yield estimation model in terms of energy equivalents of inputs in Guilan Province are presented in Table 4. The energy inputs of labor, chick, diesel fuel, machinery, disinfectants, and medications had a positive impact on broiler yield, while electricity and feed had a negative effect. However, only the impact of diesel fuel and electricity was found to be significant on broiler yield at the 5% confidence level, showing regression coefficients of 0.085 and -0.327, respectively.

Sensitivity analysis indicated that 1 Mcal increase in the energy inputs of labor, chick, diesel fuel, machinery, disinfectants, and medications would increase broiler yield by 2.41, 0.07, 0.06, 1.98, 4.52 and 2.03 kg, respectively. However, 1 Mcal increase in electricity and feed would reduce it by 0.01 and 0.03 kg, respectively.

Return to the scale rate was estimated at -0.05 (Table 4). This implies that 1% increase in the energy equivalent of all inputs would reduce broiler yield by 0.05%. R2 was found to be 0.84 for the estimated model. Therefore, the independent variables (energy inputs) can capture about 84% of broiler yield variations in the broiler farms.

4. Conclusions

Results of the study showed that diesel fuel and feed were ranked the first and second energy inputs for broiler production in Guilan Province, Iran. The large-sized farms were more energy-efficient than the small and medium-sized ones.

This may be due to a better management in the use of fossil fuels and feed in large farms compared to the small and medium ones. The impact of diesel fuel and electricity was found to be significant on broiler yield.

Acknowledgments

The authors would like to thank the Rasht branch of Islamic Azad University for their support.

Table 4. The model for estimating the impact of energy inputs on broiler yield in Guilan Province, Iran (*: significant at the 5% probability level; ns: non-significant)

	Coefficient	t-ratio	P-Value	MPP
$Model: Lny_i = a_0 + \alpha_1 lnx_1 + \alpha_2 lnx_2 + \alpha_3 lnx_3 + \alpha_4 \ln x_4 + \alpha_5 lnx_5 + \alpha_6 lnx_6 + \alpha_7 lnx_7 + \alpha_8 lnx_8 + e_i$				
X1: Chick	0.003	0.31^{ns}	0.627	0.07
X2: Human labor	0.069	1.13^{ns}	0.277	2.41
X3: Diesel fuel	0.085	2.61^{*}	0.022	0.06
X4: Electricity	-0.327	-5.40^{*}	0.001	0.01
X5: Machinery	0.237	2.02^{ns}	0.064	1.98
X6: Feed	-0.130	-0.88^{ns}	0.394	0.03
X7: Disinfectants	0.002	0.12^{ns}	0.972	4.52
X8: Medicines	0.009	0.23^{ns}	0.683	2.03
R^2	0.84			
R^2_{Adj}	0.76			
Durbine Watson	1.73			
Return to scale	-0.05			

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