Energy analysis and greenhouse gas emissions in broiler farms: A case study in Alborz province, Iran

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Abstract: The goal of this study was to examine the energy flows for poultry breeding in broiler production farms in Alborz province of Iran. Data were obtained randomly from 30 poultry production farms using a face to face questionnaire method. The results indicated that the total input energy was 189805.48 MJ per 1000 birds, while the output energy was 28151.17 MJ/(1000 bird). Net energy was negative, –161654.31 MJ/(1000 bird), implying that energy had been lost. Energy use efficiency was calculated as 0.15, showing the inefficient use of energy in the broiler production farms. The fuel energy (energy content of the fuel) with a share of 58.35% had the highest share of input energy and the feed energy by 29.71% was the next. Greenhouse gas (GHG) emission of the studied farms was 10267.96 kg CO_2-eq/(1000 bird). Among different inputs, feed with 48% had the highest share of GHG emissions. Cobb-Douglas frontier production function was adopted to specify the production technology of the farms. Econometric model evaluation showed that the effects of diesel fuel and feed on output energy was significant at 1% level. The marginal physical productivity (MPP) values of energy inputs based on sensitivity analysis were 0.04 and 0.51 for diesel fuel and feed, respectively. The variability results between poultry farms showed that the most variability comes from fuel consumption.

Keywords: broiler production, energy consumption, environmental analysis, GHG emissions, marginal physical productivity

Citation: Omid, M., M Khanali, and S. Zand. 2017. Energy analysis and greenhouse gas emission in broiler farms: A case study in Alborz province, Iran. Agricultural Engineering International: CIGR Journal, 19(4): 83–90.

1 Introduction

Broilers are important sources of high quality protein, mineral and vitamin to balance the human diet. They account for about 29% of meat production from farmed animals and this proportion is rising each year. Broiler is the third most consumed meat in the world, after beef and pork (Atilgan and Koknaroglu, 2006). Broiler production has long been known as one of the quickest ways for rapid increase in protein supply in a short cycle. Furthermore, broiler production is an important sector within the animal production industry, and energy use in this sector has increased with the population and standards of living. These factors have resulted in an increase in energy inputs to maximize yield, growth rate, feed efficiency and profitability as well as to minimize labor intensive in various agricultural practices (Esengun et al., 2007).

Efficient energy use in the broiler production farms is as significant as in agricultural production systems due to its potential to provide financial savings, preserve fossil fuel resources and reduce air pollutions (Uzal, 2012). Indeed, the efficient energy use which helps to achieve increased production and productivity, and contributes to the economy and profitability, should be improved due to environmental and financial reasons (Kizilaslan, 2009). Some researchers analyzed the energy efficiency in broiler production systems. Heidari et al. (2011) measured energy efficiency and conducted an econometric analysis of the broiler production farms in Yazd province of Iran. Begum et al. (2010) calculated the technical, allocative and economic efficiencies of

Received date: 2016-12-21 **Accepted date:** 2017-07-16

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commercial poultry farms in Bangladesh. Udoh and Etim (2009) measured the efficiency of broiler production in Nigeria. Atilgan and Koknaroglu (2006) analyzed the energy consumption and performance of broilers reared in different capacity poultry farms in Turkey to determine the optimum capacity for sustainability. The results of their study showed that an increase in housing capacity does not necessarily mean greater sustainability as higher stocking density interferes with growth performance.

The objectives of the present study were to carry out a detailed energy analysis in the broiler production farms in Alborz province of Iran, to investigate the efficiency of energy consumption, to determine the main inputs of energy for the purposes of improvement and reduction of energy consumption, to assess the environmental emissions related to broiler production and to conduct an econometric analysis of broiler production via mathematical modeling.

2 Material and methods

2.1 Studied area and data collection

Data used in this study were collected randomly from 30 broiler production farms in Alborz province of Iran, using a face to face questionnaire method. The sample size was determined using Neyman method and was calculated as 30 farms (Yamane, 1967).

2.2 Energy analysis

In the studied broiler farms, the input energy was included hours or amount of different energy sources such as human labor, machinery, fuel, electricity, chick and feed. The output energy was broiler meat and manure. These inputs were transformed to energy terms by appropriate energy equivalents, as given in Table 1. A detailed description for the calculation procedure of the input and output energies will be presented in this section. In order to facilitate the comparison with other studies, input and output energies were calculated for breeding 1000 birds.

In this study, the consumed fuels for heating the broiler houses were diesel fuel and natural gas. Diesel fuel and natural gas were used by 47% and 53% of the farms, respectively. Broiler farms consume electricity to power equipment such as small motors for feeders, artificial lights, ventilation fans and water pumps. The consumed electricity was calculated by multiplying the number of consumers with their power and multiplying this value by hours of operation during a production period. It is important to know the current energy usage in order to evaluate the magnitude of any energy efficiency improvement. Input feed energy was calculated based on the feed consumption and the energy equivalents for each feed ingredient (Table 1). The energy of chicken was calculated by multiplying the number of chicks, the weight of a one day old, and then by the energy equivalent of chicks. The machinery energy was estimated by multiplying the manufacturing energy of machine (Table 1) with the mass of machine, and then by its economic life. The energies of human labor, meat and manure were calculated by multiplying their number of units by the corresponding energy equivalents, as given in Table 1.

Table 1 Energy equivalents of inputs and outputs in broiler production

Input/Output	Unit	Energy equivalent, MJ unit^{-1}	Reference
A. Inputs			
1. Chick	kg	10.33	(Heidari et al., 2011)
2. Human labor	h	1.96	(Kitani, 1999; Elhami et al., 2016)
3. Machinery			
(a) Electric motor	kg	64.8	(Chauhan et al., 2006, Heidari et al., 2011)
(b) Steel	kg	62.7	(Chauhan et al., 2006)
(c) Polyethylene	kg	46.3	(Heidari et al., 2011)
4. Diesel fuel	l	47.8	(Elhami et al., 2017; Flores et al., 2016)
5. Natural gas	m^3	49.5	(Pishgar-Komleh et al., 2011; Kitani, 1999)
6. Feed			
(a) Maize	kg	7.9	(Atilgan and Koknaroglu, 2006)
(b) Soybean meal	kg	12.06	(Atilgan and Hoknaroglu, 2006)
(c) Wheat	kg	13	(Kitani, 1999)
(d) Di calcium Phosphate	kg	10	(Alrwis and Francis, 2003)
(e) Fatty acid	kg	37	(Berg et al., 2002)
(f) Minerals and vitamins	kg	1.59	(Sainz, 2003)
7. Electricity	kWh	11.21	(Pishgar-Komleh et al., 2013)
B. **Outputs**			
1. Manure	kg	10.33	(Celik and Öztürkcan, 2003)
2. Broiler meat	kg	0.3	(Kizilaslan, 2009)

Based on the energy inputs and outputs, some energy indices such as energy productivity, specific energy, net energy and energy ratio were calculated using the following Equations (1)-(4) (Kitani, 1999; Heidari et al., 2011; Ebrahimi et al., 2016):

$$\text{Energy productivity} = \frac{\text{Yield (kg/(1000 bird))}}{\text{Energy input (MJ/(1000 bird))}} \quad (1)$$

$$\text{Specific energy} = \frac{\text{Energy input (kg/(1000 bird))}}{\text{Yield (MJ/(1000 bird))}} \quad (2)$$

$$\text{Net energy gain} = \text{Energy output} - \text{Energy input} \quad (3)$$

$$\text{Energy ratio} = \frac{\text{Energy output (MJ/(1000 bird))}}{\text{Energy input (MJ/(1000 bird))}} \quad (4)$$

Energy consumption by the broiler farms can be divided into direct and indirect energies or renewable and non-renewable energies. Direct energy (DE) is used directly in the farm or agricultural unit in the form of human labor, fossil fuel and electricity. Indirect energy (IDE) includes the energy used in manufacturing, packaging and transport of feed, chicks, equipment and farm machineries (mill, mixer, feeder, drinker, fans, cooler, heater, etc.). Renewable energy (RE) sources are replenished by natural processes on a sufficiently rapid time-scale. Thus they can be consumed by humans more or less indefinitely, provided the rate of energy consumption is not too great. On the other hand, non-renewable energy (NRE) sources exist in a limited quantity on the earth. In this study, RE consists of human labor and chicks and NRE includes machinery, diesel fuel, natural gas and electricity (Singh et al., 2004).

2.3 Mathematical modeling of energy

In this study, descriptive statistics and stochastic frontier production function were used to analyze and estimate the technical efficiency and productivity of the broiler farms. The stochastic frontier production function was used to estimate the coefficients of the parameters of the production function and also to predict the technical efficiencies of the studied farms. The relation between outputs and various energy inputs was chosen as the best function in terms of statistical significance and expected signs of the parameters. The Cobb-Douglas (CD) production function has been reported by several authors for modeling the relationship between inputs (energy inputs) and output (output energy or yield). Accordingly, the output energy of the broiler farms (Y) was assumed to be specified by CD function as follows (Binuomote et al., 2008; Heidari and Omid, 2011; Manes and Singh, 2005):

$$\ln Y_i = \alpha_0 + \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + e_i \quad (5)$$

where, Y_i denotes the output energy of the i^{th} farmer; X_i (i = 1, 2, 3 and 4) indicates the input energies including fuel (X_1), electricity (X_2), feed (X_3) and others (X_4) such as chick, labor and machinery; α_i (i = 1, 2, 3 and 4) is the regression coefficient of i^{th} input or input coefficient which can be estimated by regression analysis and e_i is the error term. The constant coefficient (α_0) is zero, because when the energy input is zero, the broiler production is also zero. Equation (5) was estimated using ordinary least square (OLS) technique.

2.4 Sensitivity analysis

Sensitivity analysis studies how the variation in output of the model can be due to the variation of its input. In this study, the sensitivity analysis was carried out to assess the influence of an independent parameter, i.e., input energy on the value of the dependent parameter, i.e., output energy (the change in the quantity of total physical product resulting from a unit change in a variable input, keeping all other inputs unchanged). Sensitivity analysis was conducted based on the marginal physical productivity (MPP) method (Singh et al., 2004). The MPP of an independent parameter based on the response coefficients of the inputs, determines the change in the dependent parameter with a unit change of independent parameter, keeping all parameters constant at geometric mean level. The regression coefficients in Equation (5) of various energy inputs were used to calculate MPP of various inputs as follows (Manes and Singh, 2005):

$$MPP_{xi} = \frac{GM(P)}{GM(E_i)} \times \alpha_i = \frac{GM(Y)}{GM(X_i)} \times \alpha_i \quad (6)$$

where, MPP_{xi} is the MPP of i^{th} input; $GM(P)$ is the geometric mean of production; $GM(E_j)$ is the geometric mean of j^{th} input on farm ($E_{ji} = X_{ij}\ A_i$); $GM(Y)$ is the geometric mean of productivity, and $GM(X_j)$ is the geometric mean of j^{th} input per 1000 birds. A positive MPP indicates that with an increase in input value, the output value will be increased. A negative MPP of any input parameter means that additional use of inputs has a negative impact on the production, i.e. less production derived by more inputs. Hence, it is better to keep the variable resource in surplus rather than utilizing it as a fixed resource (Singh et al., 2004).

2.5 GHG emissions of broiler production

To estimate the greenhouse gas (GHG) emissions of the studied farms, this study focused on emissions of the four GHG emission sources including fuel, electricity, equipment and feed. GHG emission factors of these sources are presented in Table 2.

Table 2 GHG emission factors of different inputs used in the broiler production system

Input	Unit	GHG emission factors	Reference
Diesel fuel	Lit.	2.76	(Pishgar-Komleh et al., 2013)
Natural gas	m^3	0.85	(Khoshnevisan et al., 2013)
Electricity	kW h	0.608	(Khoshnevisan et al., 2013)
Machinery	MJ	0.071	(Pishgar-Komleh et al., 2013)
Feed	MJ	0.088	(Kitani, 1999)

After collection of initial data, basic information including energy inputs and outputs were entered into Excel 2013 and SPSS 17.0 software programs to calculate the energy indices and analyze the relation between energy inputs.

3 Results and discussion

3.1 Energy balance analysis

Table 3 shows the average of each input and output energy for production of 1000 birds in broiler production. Also, detailed description of the contribution of the input energies to the total energy consumption is shown in Figure 1. It is important to know the current energy usage in order to evaluate the magnitude of any energy efficiency improvement. Total average energy input and energy output were calculated as 189,805.48 and 28,151.17 MJ/(1000 bird), respectively. It is clear that there is a smaller energy output of meat and manure produced compared to the consumed energy used for production. Based on the results, the main input energy resources were fuel and feed, followed by electricity. Fuel consumption with average value of 110,756.23 MJ/(1000 bird) had the highest contribution in total energy consumption. Of the total average fuel consumption in broiler production, 28.7% and 29.7% are devoted to diesel fuel and natural gas, respectively. The contributions of fuel, feed and electricity in broiler production were 58.4%, 29.7% and 11.4%, respectively. These mentioned input energies accounted for 99.5% of the total input energy. The share of chicken energy among energy inputs was only 0.3%. Additionally, the consumed energy related to human labor and machinery were 197.83 and 258.85 MJ per 1000 birds. The results clearly demonstrated that the broiler meat with 97.9% share of total output energy dominated the energy production showing that the management of its production needs to be given priority. The results of input and output energy analyses were similar to the findings of broiler production in Yazd province by Heidari et al. (2011). The fuel consumption energy in the present study was calculated as 110,756.23 MJ/(1000 birds), which was almost the same as to the reported value of 110,632.79 MJ per 1000 birds (or 59.2% contribution) by Heidari et al. (2011) that only fuel gas had been used for heating.

Table 3 Amounts of energy inputs and outputs in the broiler production system

Input/Output	Total energy equivalent, MJ/(1000 bird)	Percentage, %
A. Inputs		
1. Chick	574.95	0.3
2. Fuel	110,756.23	58.4
Diesel	116,847.44	28.7*
Natural gas	105,426.42	29.7**
3. Feed	56,395.64	29.7
4. Electricity	21,621.99	11.4
5. Human labor	197.83	0.1
6. Machinery	258.85	0.1
B. Outputs		
1. Broiler	27,553.12	97.9
2. Manure	598.06	2.1

Note: *The contribution of diesel. **The contribution of natural gas.

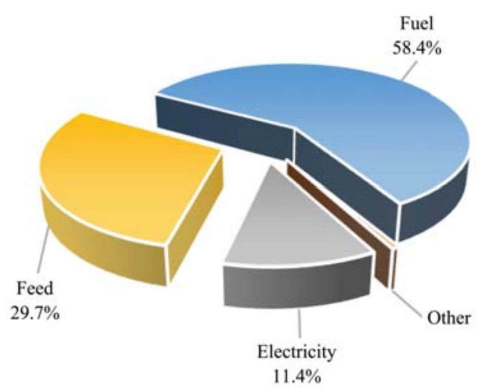

Figure 1 The share of total mean energy inputs in broiler production

In most cases of surveyed farms in this study, the intake feed was higher than enough value consumed by broilers to meet their nutrient requirements. It is suggested that the feed consumption will be performed more accurately by calculating the amount of necessary diet using Pearson square method (Van Eekeren et al., 2004). The major part of electricity was used for artificial lighting used in the lighting regimen. In lighting regimen, the broiler are subjected to adjusted photoperiods in a 24 hour period. To decrease the amount of electricity consumption, it must use the correct number of energy saving lamps inside the broiler houses.

The variability of total input energy and each energy inputs (fuel, electricity, feed, chick, labor and machinery) in broiler production units is shown in Figure 2. Fuel consumption (diesel and natural gas) had the highest variability among other inputs. The variation in fuel consumption comes from efficiency of heaters in the production salons. The amount of consumed electricity varied considerably among the producers. Farms raising heavier birds tend to incur higher annual electricity than those raising lighter birds. The types of lamps greatly determine the amount of electricity consumption.

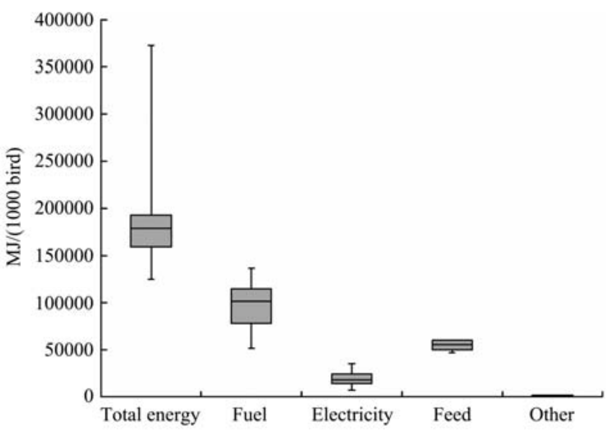

Figure 2 The variability of total energy, fuel, electricity, feed and other inputs (chick, labor and machinery) in broiler farms. The center of each box equals the median, the edges of each box represents the 25th and 75th percentiles while the whiskers show the 2.5th and 97.5th percentiles

Energy indices and different forms of energy inputs in broiler production as direct, indirect, renewable and nonrenewable are shown in Table 4. Energy ratio is one of the best energy indices to investigate the efficient use of energy in the broiler production system. The average value of energy ratio was calculated as 0.15. The low value of energy ratio indicated the inefficiency in the consumption of energy in the broiler production system. By producing more energy output (more yield) and by decreasing energy inputs consumption via better energy management, the energy ratio can be increased. Based on the results, the values of energy productivity, specific energy and net energy were calculated as 0.015 kg MJ^{-1}, 71.16 MJ kg^{-1} and –161654.31 MJ/(1000 bird), respectively. Heidari et al. (2011) in their research of the broiler production farms in Yazd province of Iran calculated the values of energy ratio, energy productivity, specific energy and net energy as 0.15, 0.01 kg MJ^{-1}, 71.95 MJ kg^{-1} and –159424.66 MJ/(1000 bird), respectively, which were in good agreement with the findings of the present study. The negative value of the calculated net energy demonstrated that energy had been lost in the broiler production system.

Table 4 Energy indices and different forms of energy inputs in broiler production

Item	Unit	Quantity	Percentage, %
Energy ratio (ER)	-	0.16	-
Energy productivity	kg MJ^{-1}	0.02	-
Specific energy	MJ kg^{-1}	71.23	-
Net energy	MJ/(1000 bird)	-161,654.31	-
Direct energy	MJ/(1000 bird)	132,576.04	69.85
Indirect energy	MJ/(1000 bird)	57,229.44	30.15
Renewable energy	MJ/(1000 bird)	57,168.41	30.12
Non-Renewable energy	MJ/(1000 bird)	132,637.07	69.88
Total energy input	MJ/(1000 bird)	189,805.48	-
Total energy output	MJ/(1000 bird)	28,151.17	-

The amounts of direct and indirect energies per 1000 birds were calculated as 132,576.04 (69.85%) and 57,229.44 MJ (30.15%), respectively. The contribution of RE was 30.12% (57,168.41 MJ/(1000 bird)) while that of NRE was 69.885 (132,637.07 MJ/(1000 bird)). It is clear that the contribution of NRE in the production is very high, thus broiler production is mostly depending on NRE sources such as fossil fuels. Similar results about the high portion of NRE consumption in broiler production have been reported by Heidari et al. (2011) and Atilgan and Koknaroglu (2006). The share of DE and IDE, and RE and NRE in the broiler production system is shown in Figure 3.

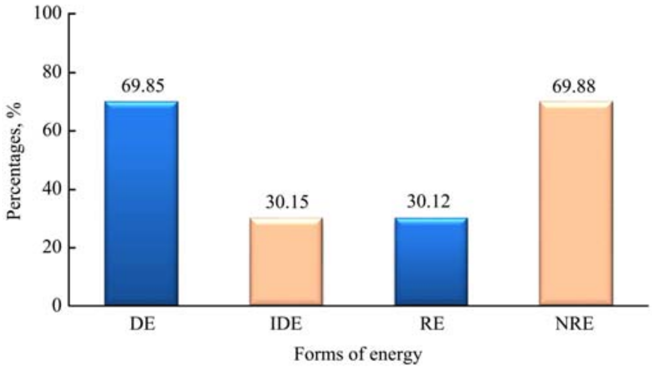

Figure 3 The share of total mean energy inputs as direct (DE), indirect (IDE), renewable (RE) and non-renewable (NRE) forms

3.2 Econometric modeling and sensitivity analysis of broiler production

Regression and sensitivity analysis results for econometric model (Equation (5), CD production function) was applied to estimate the relationship between energy inputs and the output energy using OLS estimation technique (Table 5). Considering the integrated energy of fuel, feed and electricity in broiler production with the share of 99.5% of total input energy, it was assumed that the output energy of broiler is a function of fuel, feed and electricity and others (i.e., human labor, machinery and chick with share of 0.5% of the total input energy).

Table 5 Econometric model and sensitivity analysis in broiler production

Independent variable	Coefficient	*t*-Ratio	*MPP*
Model: $\ln Y_i = \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + e_i$			
Fuel (α_1)	0.15	4.85^{**}	0.04
Electricity (α_2)	–0.05	$–1.77^{ns}$	–0.08
Feed (α_3)	1.01	10.85^{**}	0.51
Other (α_4)	–0.3	$–2.03^{ns}$	–8.22
Durbin-Watson	2.45		
R^2	0.99		
Return to scale ($\sum_{i=1}^{n} \alpha_i$)	0.81		

Note: ** significant at 1% level. ^{ns} non-significant.

Result of ANOVA showed the contribution of diesel fuel and feed energies were significant at 1% level. Other inputs such as electricity, human labor, machinery and chick had no significant effect on broiler production. Of all inputs, feed had the highest impact (1.01) followed by fuel (0.15) and electricity (–0.05) energy inputs. This revealed that 10% additional use of feed and fuel inputs would lead to the increase of output energy by 1.01%, and 1.5% increase in output, respectively. Also, with 10% increase in electricity, the output energy will be decreased by 8.3%.

Based on the results, the highest *MPP* value of inputs belonged to feed with value of 0.51. This implies that 1 MJ growth in using feed input can cause 0.51 MJ/(1000 bird) increase in output energy. Based on the values of *MPP*, with 1 MJ increase in fuel and electricity input energies per 1000 birds, the output energy increased by 0.04 MJ and decreased by 0.08 MJ, respectively.

Durbin–Watson (DW) test was performed to validate the model autocorrelation (Manzoni and Islam, 2009). The analysis for CD production function resulted 2.45 for DW value. This indicated that there was no autocorrelation existing at the 5% significance level in the developed model. The coefficient of determination (R^2) of the model was calculated as 0.99 which showed the high accuracy of the model. The return to scale (*RTS*) value (sum of the regression coefficients of energy inputs) was 0.81, i.e., less than unity for Equation (5). This shows a 1% increase in the total energy consumption would lead to 0.81 increases in the output energy. Heidari et al. (2011) reported relatively similar value of RTS as 0.96 for broiler production in Yazd province of Iran.

3.3 GHG emission of studied farms

Emissions of the four sources including fuel, electricity, equipment and feed were studied. GHG emission factors of these sources are given in Table 2. The GHG emission of studied farms was calculated as 10267.96 kg CO_2-eq/(1000 bird) as shown in Table 6. Among different inputs in the broiler production system, feed had the biggest share of GHG emissions (48%). In the study of Da Silva et al. (2014), feed had the biggest share of GHG emission among other broiler production inputs.

Table 6 GHG emissions of different inputs for production of 1000 birds

Inputs	Amount (kg CO_2-eq)	%
Fuel	4114.05	40.07
Diesel fuel	3148.16	30.66
Natural gas	965.19	9.40
Electricity	1172.72	11.42
Machinery	4962.81	48.33
Feed	18.38	0.18
Total	**10267.96**	**100**

4 Conclusions

This study was performed to analyze the energy consumption and its sensitivity on output energy in broiler farms in Alborz Province, Iran. Among energy inputs, fuel had the biggest share of total input energy (with 58%). The variability of input energies also showed the fuel had the highest variability among other input energies. The main problems facing energy usage in broiler productions are misallocation of resources, high production costs, increased competition (national and international) in agricultural trade and using insufficient resources. Therefore, these limitations must be taken into consideration in order to implement sustainable agricultural production and self-sufficient resource allocation in the broiler production system. Considering the important of fuel consumption in this study, there are some suggestions that can be taken into account in order to improve the energy efficiency of broiler farms:

1) To reduce the fuel consumption in broiler production farms, every breeder should be assured of a market near the farm and a permanent demand for meat products.

2) When new broiler farm is established, energy use efficiency should be considered, where animal welfare and proper housing systems should be selected to achieve the higher energy use efficiency as well.

3) Improving the efficiency of oil and gas-fired boilers is extremely important. Regular servicing of burners and cleaning of heat transfer surfaces is recommended, potentially, to yield more saving in fuel consumption.

4) The energy needed for heating and ventilation can be reduced by improving wall, roof and floor insulation. This will help to keep buildings warm in winter season and cool during summer season.

Acknowledgments

The authors gratefully acknowledge the financial support provided by University of Tehran.

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