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Energy use pattern and optimization of energy required for broiler production using data envelopment analysis

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A literature review shows that energy consumption in agricultural production in Iran is not efficient and a high degree of inefficiency in broiler production exists in Iran. Energy consumption of broiler production in Ardabil province of Iran was studied and the non-parametric method of data envelopment analysis (DEA) was used to analyze energy efficiency, separate efficient from inefficient broiler producers, and calculate wasteful use of energy to optimize energy. Data was collected using face-to-face questionnaires from 70 broiler farmers in the study area. Constant returns to scale (CCR) and variable returns to scale (BCC) models of DEA were applied to assess the technical efficiency of broiler production. The results indicated that total energy use was 154,283 MJ (1000 bird)$^{-1}$ and the share of fuel at 61.4% was the highest of all inputs. The indices of energy efficiency, energy productivity, specific energy, and net energy were found to be 0.18, 0.02 kg MJ^{-1}, 59.56 MJ kg^{-1}, and −126,836 MJ (1000 bird)$^{-1}$, respectively. The DEA results revealed that 40% and 22.86% of total units were efficient based on the CCR and BCC models, respectively. The average technical, pure technical, and scale efficiency of broiler farmers was 0.88, 0.93, and 0.95, respectively. The results showed that 14.53% of total energy use could be saved by converting the present units to optimal conditions. The contribution of fuel input to total energy savings was 72% and was the largest share, followed by feed and electricity energy inputs. The results of this study indicate that there is good potential for increasing energy efficiency of broiler production in Iran by following the recommendations for efficient energy use.

1. Introduction

Agricultural production has become more energy intensive in an effort to supply more food to the increasing population and provide sufficient and adequate nutrition. Considering the limited natural resources and the effect of the use of

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different energy sources on the environment and human health, it is necessary to investigate energy consumption patterns in agriculture [1]. Measuring the efficiency of farming is required in both developing and developed countries [2]. Efficiency is defined as the ratio of the weighted sum of outputs to inputs or as the actual output to the optimal output ratio. The optimal input or output amounts are necessary to specify the production frontier [3].

Improved energy efficiency is a key indicator of sustainable energy management; in order to enhance energy efficiency, production yield must increase or energy must be conserved without affecting yield [4,5]. Data envelopment analysis (DEA) is a non-parametric technique for measuring and evaluating the relative efficiencies of decision-making units (DMUs) with common multi-inputs and multi-outputs [6]. DEA evaluates the efficiency of each DMU relative to an estimated production possibility frontier as determined by all DMUs [7]. The advantage of DEA is that it does not require prior assumptions on the underlying functional relationships between inputs and outputs [8].

Many authors have applied DEA to agricultural research. Pahlavan et al. [9] used DEA on data for energy use in tomato production in Iran. They estimated the technical, pure technical, and scale efficiencies of farmers to estimate productivity of tomato producers based on the amount of energy inputs for the output of tomato yield. Mohammadi et al. [10] employed DEA to analyze the efficiency of kiwifruit producers in Mazandaran province of Iran. Their results indicated that 12.17% of total energy input could be saved if the recommendations of the study were implemented.

Heidari et al. [11] applied DEA to determine the efficiency of farmers with regard to energy use in broiler production in Yazd province based on The CCR and BCC models. The CCR rated 10 farmers as efficient and the BCC rated 16 farmers as efficient. They estimated the technical, pure technical, and scale efficiency of farmers to be 0.9, 0.93 and 0.96, respectively. Sefeedpari [12] applied DEA to determine the efficiency of input use in dairy farms in Iran using data obtained from 35 dairy farmers in Tehran province and found the mean technical efficiency to be 0.88 for all regions. It was concluded that DEA was a useful tool for improving the productivity efficiency of farms. Sefeedpari et al. [13] studied energy use patterns of poultry farms in Iran and reported that technical, pure technical, and scale efficiency was 0.85, 0.93, and 0.91, respectively. Their results showed that 22% of overall resources could be saved by increasing the performance of inefficient DMUs to the highest level. The present study analyzed and ranked the efficiency of farmers and identified target energy requirements and wasteful energy practices from different inputs to specify energy use patterns for broiler production in Ardabil province of Iran.

2. Materials and methods

2.1. Sampling design

The study was carried out at broiler farms in Ardabil province of Iran. This province is located in northwestern Iran at 47°15′ to 48°56′ E longitude and 37°09′ to 39°42′N latitude [14]. Data was collected from farmers using a face-to-face questionnaire in September–October 2013. The sample size was determined to be 70 farms by the Neyman method [15].

2.2. Energy equivalents of inputs and outputs

Input sources for the poultry farms were chicks, human labor, machinery, fuel, feed, and electricity. Output sources were broilers and manure. Energy conversion factors were used to convert each input and output into energy equivalents. The energy equivalents were determined by multiplying the quantity per 1000 birds by their conversion factors (Table 1).

Using the energy equivalents for inputs and output in Table 1, the energy ratio (energy use efficiency), energy productivity, specific energy, and net energy were calculated as [26,27]:

$$\text{Energy use efficiency} = \frac{\text{Energy output } (\text{MJ}(1000\text{ bird})^{-1})}{\text{Energy input } (\text{MJ}(1000\text{ bird})^{-1})} \quad (1)$$

$$\text{Energy productivity} = \frac{\text{Yield } (\text{kg}(1000\text{ bird})^{-1})}{\text{Energy input } (\text{MJ1000 bird}^{-1})} \quad (2)$$

$$\text{Specific energy} = \frac{\text{Energy input } (\text{MJ ha}^{-1})}{\text{Yield } (\text{kg}(1000\text{ bird})^{-1})} \quad (3)$$

$$\text{Net energy} = \text{Energy output } (\text{MJ}(1000\text{ bird})^{-1}) - \text{Energy input } (\text{MJ}(1000\text{ bird})^{-1}) \quad (4)$$

Energy demand can be divided into direct and indirect energy or renewable and non-renewable energy. Direct energy (DE) includes human labor, diesel fuel, and electricity and indirect energy (IDE) includes energy embodied in chicks, machinery, and feed used for broiler farm production. Renewable energy (RE) comprised chicks, human labor, and feed; non-renewable energy (NRE) comprised diesel fuel, machinery, and electricity.

2.3. Data envelopment analysis (DEA)

DEA methodology was applied to determine the relative efficiency of broiler producer units and calculate the amount of energy savings. In DEA, an inefficient DMU can be made efficient either by reducing the input level while holding the output constant (input oriented) or by increasing the output level while holding the inputs constant (output oriented) [10,28,29]. In the present study, the input-oriented model was assumed to be more appropriate because only two outputs existed while multiple inputs were used. Likewise, in farming systems, a producer has more control over inputs than output levels and input conservation for given outputs is more logical.

DEA is a mathematical procedure that uses linear programming to assess the efficiency of DMUs. A non-parametric piecewise frontier which maintains optimal efficiency over the datasets was composed of DMUs and is constructed by DEA to measure comparative efficiency. DMUs located on the efficiency frontier are efficient, offer the best efficiency among all DMUs, and generate maximum output using a minimum level of inputs [30]. The concepts used in parametric and DEA approaches are shown in Fig. 1 for seven

Table 1 – Energy coefficients of inputs and outputs in broiler production.

Items	Units	Energy equivalent (MJ unit^{-1})	Reference
A. Inputs			
1. Chick	kg	10.33	[16]
2. Human labor	h	1.96	[17]
3. Machinery			
Polyethylene	kg	46.3	[18]
Galvanized iron	kg	38	[13]
Steel	kg	62.7	[19]
Electric motor	kg	64.8	[19]
4. Fuel diesel	L	47.8	[20]
5. Feed			
Maize	kg	7.9	[21]
Soybean meal	kg	12.06	[21]
Di-calcium phosphate	kg	10	[22]
Minerals and vitamins	kg	1.59	[23]
Fatty acid	kg	9	[16]
6. Electricity	kWh	11.93	[24]
B. Outputs			
1. Broiler	kg	10.33	[16]
2. Manure	kg	0.3	[25]

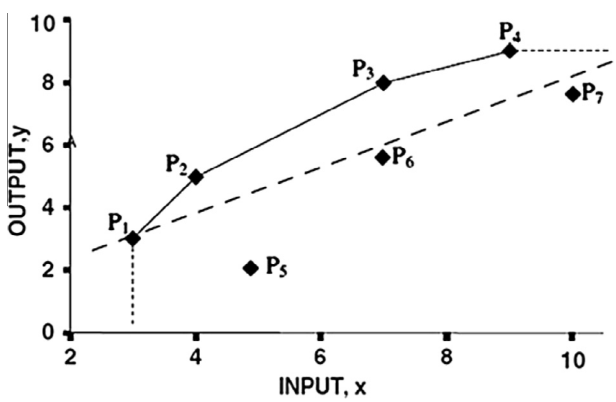

Fig. 1 – Comparison of data envelopment analysis and regression analysis [31].

DMUs with a single input (x axis) and a single output (y axis). The rhombuses represent different DMUs in the data set. In Fig. 1, P_1, P_2, P_3, and P_4 are the boundary points. The solid line joining these points forms the envelope for the data set. The DMUs lying on the boundary and represent these points are considered to be efficient DMUs. The efficiency of the DMUs P_5, P_6, and P_7 are calculated by comparison with the efficient DMUs [30,31].

Charnes, Cooper, and Rhodes (CCR) [32] introduced the DEA approach. The BCC model was developed by Banker et al. [33] and was originally called the local efficiency model. The BCC model is also known as the variable returns to scale (VRS) model and is distinguished from the CCR, which is known as the constant returns to scale (CRS) model [31].

In DEA, efficiency is defined using technical, pure technical, and scale efficiency indices. Technical efficiency is a measure evaluating DMU performance relative to that of other DMUs in consideration; it is also called global efficiency. Technical efficiency can be expressed mathematically as [5,34]:

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \cdots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \cdots + v_m x_{mj}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \tag{5}$$

where u_r denotes the weight of output n, y_r, denotes the amount of output n, v_s denotes the weight of input n, x_s denotes the amount of input n, r denotes the number of outputs ($r = 1,2,\ldots,n$), s denotes the number of inputs ($s = 1,2,\ldots,m$), and j denotes the jth DMU ($j = 1,2,\ldots,k$).

$$\begin{aligned}
&\textit{Maximize } \theta = \sum_{r=1}^{n} u_r y_{rj} \\
&\textit{Subjected to } \sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_s x_{sj} \leqslant 0 \\
&\sum_{s=1}^{m} v_s x_{sj} = 1 \\
&u_r \geqslant 0, v_s \geqslant 0, \textit{ and } (i \textit{ and } j = 1,2,3,\ldots,k)
\end{aligned} \tag{6}$$

where θ denotes technical efficiency. Model (3) is known as input-oriented CCR-DEA and assumes CRS [35].

Pure technical efficiency is a feature of the BCC model and assumes VRS. Pure technical efficiency separates technical and scale efficiencies. The advantage of this model is that it compares scale inefficient broiler farms only to efficient farms of a similar size [28]. Pure technical efficiency is technical efficiency that has the effect of scale efficiency removed [36]. The BCC model can be described as a dual linear programming problem as follows [5,10,33]:

$$\begin{aligned}
&\textit{Maximize } z = uy_i - u_i \\
&\textit{Subjected to } vx_i = 1 \\
&-vX + uY - u_o e \leqslant 0 \\
&v \geqslant 0, u \geqslant 0 \textit{ and } u_o \textit{ free in sign}
\end{aligned} \tag{7}$$

where z and u_0 denote scalar and free in sign, u and v denote output and input weight matrices, respectively, and Y and X denote output and input matrices, respectively. The variables x_i and y_i denote the inputs and output of the DMU.

Scale efficiency gives quantitative information about scale characteristics; it is the potential productivity gained by achieving an optimal size for the DMU [10]. If the DMU is scored as fully-efficient for both technical and pure technical efficiency, it operates at the most productive scale size. If a DMU is scored for full pure technical efficiency, but has a technical efficiency score, then it is considered locally efficient, but not globally efficient because of its scale size. It is reasonable to characterize the scale efficiency of a DMU as the ratio of the two scores [28]. The relationship between technical and pure technical efficiencies can be calculated as [37]:

$$\textit{Scale efficiency} = \frac{\textit{Technical efficiency}}{\textit{Pure technical efficiency}} \tag{8}$$

The results of standard DEA models separate the DMUs into efficient and inefficient DMUs. It is possible to rank inefficient units according to their efficiency scores; however, all efficient DMUs have an efficiency score of one. In DEA, it is possible for some efficient units to perform better than others [38]. A well-known method of overcoming this issue is the cross-efficiency model developed by Sexton et al. [39]. Here, the DEA efficiency scores can be aggregated into a cross-efficiency matrix in which E_{ij}, the element in the ith row and jth column, represents the efficiency score for the jth farmer calculated using the optimal weights of the ith farmer computed by the CCR model. In general, efficient farmers can be ranked according to their average cross-efficiency scores, which are calculated by averaging each column of the cross-efficiency matrix. It is a matter of judgment for analysis to select highly-ranked farmers as truly efficient ones; thus, a farmer with a high average cross-efficiency score is a better performer [10,28,40].

The energy saving target ratio (ESTR) represents the inefficiency level for each DMU with respect to energy use. ESTR is calculated as [41]:

$$ESTR_j = \frac{(\textit{energy savings target})_j}{(\textit{actual energy input})_j} \tag{9}$$

where the energy saving target is the total decrease in the input that could be made without decreasing the output and j denotes the jth DMU. This ratio represents the energy efficiency and specifies the level of inefficiency in energy savings and energy consumption for each DMU. The minimal value of energy saving target is 0 and the ESTR ranges from zero to one. A zero ESTR value indicates that the DMU exists on the frontier; a higher ESTR value implies higher energy inefficiency and higher possible energy savings [41]. Basic information on the energy inputs of broiler production were entered into Excel 2010 spreadsheets and EMS 1.3 software.

3. Results and discussion

3.1. Analysis of energy inputs and outputs

The inputs and outputs of broiler production and the energy equivalents for each are given in Table 2. The results show that the total energy consumption was 154283.87 MJ (1000 bird)$^{-1}$ and the total output energy was 27447.26 MJ (1000 bird)$^{-1}$. The last column of Table 2 lists the shares of the energy inputs. Fuel has a share of 61.48% and is the highest energy consumer followed by feed (34.87%) and electricity (3.04%). Note that fuel was also used to heat the production rooms. Similar results were reported by Heidari et al. [16] in which the highest energy factors were fuel, feed, and electricity for broiler production in Yazd province in Iran.

The energy indices of energy use efficiency, energy productivity, specific energy, and net energy are shown in Table 3. The energy use efficiency was estimated to be 0.18 and shows the inefficient use of energy in broiler production in Ardabil province. Achieving a higher rate of energy use efficiency could help improve energy use savings in the production system. It can be concluded that energy use efficiency can increase if the meat yield increases or energy input consumption decreases. Sefeedpari [12] reported that the energy ratio of dairy farms in Tehran province was 0.26. Studies have reported energy use efficiency for strawberry, cucumber and button mushroom production to be 0.15, 0.38 and 0.028, respectively [42–44].

The average energy productivity of broiler production was 0.02 kg MJ^{-1}. This means that 1 MJ of energy results in 0.02 unit outputs. The specific energy was 59.56 MJ kg^{-1} and net energy was −126836.61 MJ (1000 bird)$^{-1}$. The net energy was negative; thus, energy was being lost in broiler production.

Table 2 – Energy equivalents of inputs and outputs in broiler production.

Items (unit)	Quantity per unit (1000 bird)	Total energy equivalent MJ (1000 bird)$^{-1}$	Percentage (%)
A. Inputs			
1. Chick (kg)	47.50	490.68	0.32
2. Human labor (h)	76.59	150.12	0.10
3. Machinery (kg)	5.75	304.22	0.20
4. Fuel (L)	1984.35	94851.69	61.48
5. Feed (kg)	6674.19	53793.98	34.87
6. Electricity (kWh)	393.39	4693.17	3.04
The total energy input (MJ)		154283.87	100
B. Outputs			
1. Broiler (kg)	2590.54	26760.23	97.50
2. Manure (kg)	2290.10	687.03	2.50
The total energy output (MJ)		27447.26	100

Table 3 – Improvement of energy indices for broiler production.

Items	Unit	Value
Energy use efficiency	–	0.18
Energy productivity	kg MJ^{-1}	0.02
Specific energy	MJ kg^{-1}	59.56
Net energy	MJ $(1000\ bird)^{-1}$	−126836.61
Direct energy[b]	MJ $(1000\ bird)^{-1}$	99694.99 (64.62%)[a]
Indirect energy[c]	MJ $(1000\ bird)^{-1}$	54588.87 (35.38%)
Renewable energy[d]	MJ $(1000\ bird)^{-1}$	54434.78 (35.28%)
Non-renewable energy[e]	MJ $(1000\ bird)^{-1}$	99849.09 (64.72%)
Total energy input	MJ $(1000\ bird)^{-1}$	154283.87 (100%)

[a] Numbers in parentheses indicate percentage of total optimum energy requirement.
[b] Includes human labor, diesel fuel, electricity.
[c] Includes chick, machinery, feed.
[d] Includes chick, human labor, feed.
[e] Includes diesel fuel, machinery, electricity.

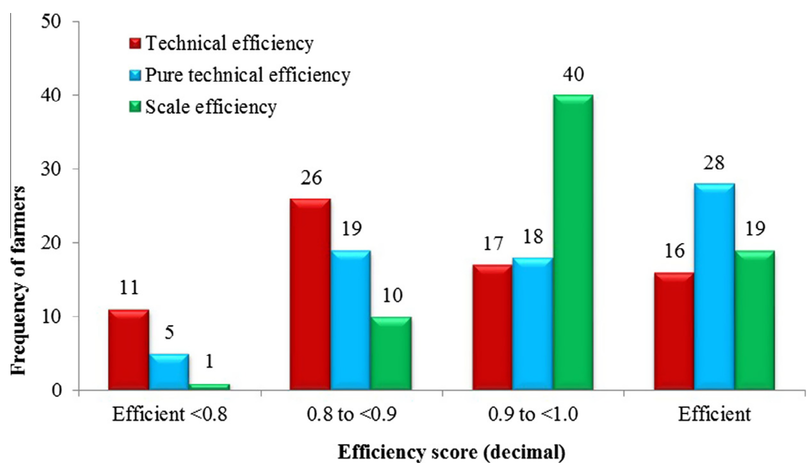

Fig. 2 – Efficiency score distribution of broiler producers.

Similar results have been reported for energy productivity, specific energy, and net energy of dairy farms as 0.12 kg MJ^{-1}, 9.48 MJ kg^{-1}, and −55217.3 MJ cow^{-1}, respectively [12].

Table 3 classifies the energy from different sources as direct–indirect or renewable-nonrenewable. The total consumed energy input was classified as direct energy (64.62%) and indirect energy (35.38%) or renewable energy (35.28%) and nonrenewable energy (64.72%). The results revealed that the share of nonrenewable energy in broiler production is very high and, among the DE and NRE sources, fuel and electricity were the most influential factors. This indicates that considerable attention on energy management should be made.

3.2. *DEA results*

The results obtained from the input-orientated BCC- and CCR-DEA models for broiler farms are shown in Fig. 2. The results indicate that of the 70 broiler producers considered for analysis, 28 (40%) had a pure technical efficiency score of 1. Of these pure technically efficient farmers, 16 (22.86%) had a technical efficiency score of 1. The rate of scale effi-

Table 4 – Average technical, pure and scale efficiency of broiler production.

Particular	Technical efficiency	Pure technical efficiency	Scale efficiency
Average	0.88	0.93	0.95
SD	0.11	09.0	0.05
Min	0.48	0.57	0.79
Max	1	1	1

Table 5 – Ranking 5 superior referred broiler farmers in Ardabil province, Iran.

Rank	DMU	Frequency in referent set
1	27	25
2	30 and 59	19
3	37	15
4	8	10
5	24	8

Table 6 – Amounts of energy inputs and output for 10 truly efficient farmers and inefficient farmers.

Items	10 truly most efficient farmers (MJ (1000 bird)$^{-1}$) (A)	Inefficient farmers (MJ (1000 bird)$^{-1}$) (B)	Difference (%) (B–A) * 100/B
Inputs:			
Human	115.21	193.59	40.49
Machinery	224.02	374.39	40.16
Diesel fuel	70785.95	119423.10	40.73
Feed	48117.91	61717.16	22.03
Electricity	3680.60	5623.87	34.55
Output:			
Broiler	26732.26	25663.91	−4.16

ciency for 19 units was unity. As can be seen, 17 units had an efficiency rate of 0.9 to 1 for technical efficiency and 18 units had the rating for pure technical efficiency.

Table 4 shows the average standard deviation (SD) and minimum and maximum scores for technical, pure, and scale efficiency of broiler farmers. The average technical, pure technical, and scale efficiency scores were 0.88, 0.93 and 0.95, respectively. The technical efficiency ranged from 0.48 to 1 (SD = 0.11). The wide variation in technical efficiency of the farmers implies that not all farmers were fully aware of the best production techniques or did not apply them at the proper times in the optimum quantity [10]. Heidari et al. [11] applied DEA to determine the efficiency of farmers in broiler production in Iran. They reported that the technical, pure technical, and scale efficiency scores were 0.90, 0.93, and 0.96, respectively. Yusuf and Malomo [45] studied the efficiency of egg production and reported the mean technical efficiency to be 0.87.

3.3. *Ranking efficient DMUs*

The benchmarking method was used to rank the efficiency of broiler farms. In this approach, an efficient unit chosen as useful for many inefficient DMUs appears frequently in the reference sets and is highly ranked. The efficient DMUs are ranked according to the number of times they appear in a reference set [29,38]. Table 5 ranks the efficient DMUs for broiler production using the BCC model. The results show that DMUs 27, 30, 59, 37, 8, and 24 appeared 25, 19, 19, 15, 10, and 8 times in the reference set, respectively. The efficient DMU that appeared most often in the reference set was ranked as the superior unit. These results are beneficial in helping inefficient farmers manage their energy source usage to attain the best energy use efficiency.

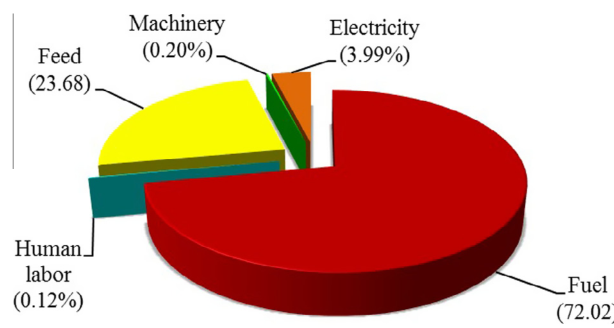

Fig. 3 – Distribution of saving energy from different sources for broiler production.

3.4. *Comparing input use pattern of efficient and inefficient farmers*

Table 6 list the quantity of source-wise physical inputs and output for the 10 most efficient farmers and inefficient farmers. The results show that the use of all inputs for efficient farmers was less than that for inefficient farmers. Although the main difference between efficient and inefficient farmers was recorded for fuel, human labor, and machinery (40.73%, 40.49%, and 40.16%, respectively), the output of efficient farmers was 4.16% greater than that of inefficient farmers. It was observed that inefficient farmers did not use resources efficiently.

3.5. *Energy savings from energy inputs*

Table 7 shows the optimum energy requirement and energy savings of the various farm inputs for broiler production from the BCC model. The total optimum energy requirement for

Table 7 – Optimum energy requirement and saving energy for broiler production.

Input	Optimum energy requirement (MJ (1000 bird)$^{-1}$)	Saving energy (MJ (1000 bird)$^{-1}$)	Saving energy (%)	Contribution to the total savings energy (%)
1. Human labor	122.84	27.28	18.17	0.12
2. Machinery	259.59	44.63	14.67	0.20
3. Fuel	78763.24	16088.46	16.96	72.02
4. Feed	48504.62	5289.36	9.83	23.68
5. Electricity	3801.65	891.53	19.00	3.99
Total energy use	131451.93	22341.26	14.53	100

Table 8 – The source wise actual and target energy use for inefficient farmers in the broiler production based on the results of BCC model.

DMU	PTE*	Actual energy use (MJ (1000 bird)$^{-1}$)					Optimum energy requirement (MJ (1000 bird)$^{-1}$)					ESTR (%)
		Human labor	Machinery	Fuel	Feed	Electricity	Human labor	Machinery	Fuel	Feed	Electricity	
1	0.99	141.12	213.16	74687.50	54864.03	3815.33	113.12	210.59	68688.76	49351.87	2630.71	14.04
3	0.90	117.60	466.43	83650.00	49113.92	6104.53	104.75	319.20	63942.34	44315.49	4660.24	19.90
6	0.86	235.20	284.42	95600.00	58678.55	3052.27	117.73	223.11	68289.05	48967.01	2616.10	26.18
9	0.86	143.73	433.91	119500.00	50787.80	4069.69	124.13	277.69	69991.10	43860.34	3514.58	23.67
12	0.87	141.12	281.79	79200.00	64265.76	3488.30	111.34	241.31	69014.88	53917.79	3039.71	15.46
13	0.97	211.68	475.60	95600.00	44197.23	5232.46	129.57	312.14	67788.83	42884.58	3889.12	26.18
15	0.90	105.28	241.46	68285.71	61033.91	4983.29	95.16	218.26	61723.46	53249.22	4424.57	10.56
17	0.86	119.69	326.83	88180.66	57588.10	3328.53	102.34	199.23	71429.36	47720.72	2845.90	20.83
18	0.96	184.68	305.82	90161.50	51703.24	3488.30	125.69	295.48	75022.06	49955.67	3370.40	11.77
19	0.91	253.65	162.18	98411.76	54625.45	4103.89	130.99	148.25	89958.18	49933.13	3360.83	18.45
20	0.91	117.60	323.69	100380.00	48185.88	6976.61	107.02	282.27	69214.02	43849.15	4093.67	20.63
21	0.97	156.80	312.53	95600.00	47731.13	6976.61	129.88	292.02	79445.93	46461.48	5027.48	14.25
23	0.93	127.95	321.41	68488.20	47736.87	5720.82	119.36	299.84	63892.64	44533.73	3721.02	12.36
25	0.96	103.49	241.07	66920.00	517910.74	5581.29	98.91	230.42	63962.14	49502.55	3729.18	10.17
26	0.97	229.97	378.27	73027.78	82482.09	3875.89	114.40	296.14	70749.31	51971.80	3754.97	24.47
28	0.91	175.02	178.33	120624.81	52719.24	7070.89	123.77	161.90	89599.60	47863.80	3275.63	25.42
29	0.57	136.84	460.43	137583.00	92073.08	7753.55	78.15	219.33	62896.82	52539.67	4428.05	47.07
31	0.96	94.08	258.16	102770.00	52551.24	3488.30	90.10	206.42	78007.96	46634.07	3340.75	12.77
32	0.86	118.60	284.88	73769.40	56127.92	4439.66	102.31	245.76	63640.86	48421.55	3830.09	13.73
34	0.93	94.08	466.27	98786.67	47572.71	5232.46	87.51	205.24	77692.27	44252.14	3580.26	24.57
35	0.67	285.09	271.75	147745.45	69099.38	7927.96	105.81	181.66	81113.16	46192.94	3513.68	45.99
38	0.81	154.00	333.26	130880.95	52736.97	5190.93	124.43	245.98	76530.05	42611.47	3136.30	29.14
40	0.86	163.07	201.16	144441.00	54012.13	4360.38	106.72	172.80	84414.39	46396.42	3343.62	25.53
41	0.96	156.80	283.74	90820.00	48707.18	5232.46	130.49	271.57	86923.82	46617.65	4905.96	7.18
45	0.84	116.48	366.73	88771.43	52551.63	3986.63	98.27	223.54	78896.45	44337.81	3363.52	20.31
46	0.87	172.48	307.97	95600.00	48587.10	6104.53	145.73	267.84	74690.50	42256.20	3049.11	22.71
47	0.85	188.16	313.01	109940.00	48968.54	5232.46	143.60	266.94	75959.45	41760.37	2903.44	25.71
48	0.92	235.20	309.18	86040.00	44712.68	7848.68	156.47	285.01	74997.59	41216.15	2800.04	25.25
49	0.82	151.20	380.63	106696.43	80808.46	3207.99	111.50	209.68	67619.56	49127.40	2616.12	33.09
50	0.97	104.21	226.67	66184.62	51975.72	4024.97	100.91	219.48	64086.56	50328.09	3201.65	6.63
54	0.86	156.80	389.22	152880.75	55975.84	3488.30	120.05	287.72	65400.62	47909.45	2987.38	27.09
56	0.89	135.89	263.33	75683.33	56102.04	5813.84	120.70	233.89	67221.94	49829.83	3653.21	16.38
57	0.88	172.48	303.87	74090.00	52630.97	5232.46	118.34	267.28	65169.56	46294.20	3791.57	19.01
60	0.95	115.29	179.15	77323.53	53962.57	3847.39	107.41	170.39	73542.41	51323.80	3659.26	5.28
61	0.79	242.47	277.68	118268.04	58654.57	5933.71	107.62	218.76	72805.99	46208.07	3794.63	34.51
62	0.82	188.16	408.81	136059.00	52138.80	4651.07	129.57	312.14	67786.98	42884.16	3889.12	29.25
64	0.87	141.12	416.57	105160.00	58356.27	5232.46	122.38	353.65	86486.47	50606.56	4537.59	14.54
66	0.76	235.20	413.47	105160.00	56492.43	7848.68	129.59	312.18	67797.69	42889.06	3889.71	35.89
67	0.82	213.25	415.59	111533.33	51308.14	4651.07	148.60	307.19	70875.92	41826.39	3311.12	28.03
68	0.75	156.80	412.10	105160.00	58843.97	6104.53	109.36	308.99	65290.34	44121.21	4447.09	29.07
69	0.87	104.53	300.76	101973.33	54767.06	4069.69	90.78	231.66	82761.56	47559.72	3544.12	16.26
70	0.89	156.80	378.60	107550.00	50586.21	4360.38	136.62	285.47	72008.17	45198.77	3896.00	16.36
Ave.	0.88	160.80	323.09	99266.39	66760.18	5074.60	115.98	250.44	72555.45	46849.56	3603.99	21.56
SD	0.08	48.60	84.06	23033.47	71967.22	1392.39	17.23	49.51	7708.32	3408.29	605.71	9.49

* Pure technical efficiency (PTE).

broiler production was 131451.93 MJ (1000 bird)$^{-1}$. Electricity showed the highest percentage of energy savings at 19.00%, followed by human labor (18.17%), and fuel (16.96%). Feed intake required the least optimization. The total percentage of energy savings for broiler production was 14.53% (22341.26 MJ (1000 bird)$^{-1}$), meaning that, if the output meat yield is constant, this value of energy could be saved.

Yusef and Malomo [45] reported that human labor and chicks were the only energy inputs for which optimization of usage would not change yield. Heidari et al. [11] studied optimization of energy use for broiler production and reported that fuel and feed energy inputs and 11% of total energy input could be saved. Fig. 3 shows the contribution of the various energy inputs for total input energy savings. The maximum contribution was 72% for fuel because fuel is normally used in broiler farms to warm the rooms. These results show that the energy saved by feed (24.68%) and electricity (about 4%) ranked second and third, respectively. Human labor and machinery had the lowest optimization energy input and was about equal for most farms. Sefeedpari et al. [13] studied improvements in energy efficiency of egg production and reported that the highest contribution to the total energy savings was 82% for feed intake followed by fuel (12%), and equipment (4%).

3.6. *Setting realistic input levels for inefficient farmers*

Table 8 shows the average pure technical efficiency, actual energy use, and optimum energy requirements (±SD) for different energy sources for individual inefficient farmers. The values for optimum energy requirement were derived and showed how individual inefficient farmers can reduce their source-wise energy inputs without decreasing yield. The percentages of energy savings for 42 inefficient farmers are shown. The ESTR was between .28% (#60) and 47.07% (#29) for the most and least inefficient broiler farmers, respectively. The average (±SD) of the inefficient units were 21.56 (±9.49), respectively. The energy consumption of inefficient farms should approach the optimum energy required, especially for fuel and feed.

4. Conclusions

The present study determined the pattern of energy consumption and optimization of energy for broiler production using data envelopment analysis in Ardabil province in Iran. The results on the investigation led to the following conclusions:

1. The average total energy inputs and outputs were 154283.87 MJ (1000 bird)$^{-1}$ and 27447.26 MJ (1000 bird)$^{-1}$, respectively. Fuel and feed were the highest consumers of energy in production at 61.48% and 34.87% of total energy use, respectively.
2. Of the 70 broiler producers considered, 28 (40%) were technically efficient according to the BCC model and 16 (23%) were identified as efficient by the CCR model.
3. The average values for technical, pure technical, and scale efficiency were 0.88, 0.93, and 0.95, respectively.
4. About 14.53% of the total input energy under current conditions could be saved without reducing the output energy from its present level by converting farms to optimal units.
5. The highest contribution to total energy savings was 72.02% for fuel, followed by feed (23.68%) and electricity (4%). Inefficient farmers should pay more attention to conserving fuel, feed, and electricity to improve their energy productivity.

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