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Selecting Energy Efficient Poultry Egg Producers: A Fuzzy Data Envelopment Analysis Approach

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Abstract This study examined the energy use pattern of poultry for egg production farms of Iran and ranked the selected farmers using fuzzy data envelopment analysis (FDEA) from the viewpoint of energy efficiency. Since data used in our study were not measured precisely, fuzzy forms of them could help us to reach the ideal situations. Hence, the conventional data envelopment analysis (DEA) was remodeled using triangular fuzzy numbers and finally the resulted efficiency scores of decision making units (DMUs) were compared. Those with efficiency score of less than one were reported as inefficient units and they were also ranked by calculating an index. The results of this study indicated that from 40 poultry farms selected randomly, 33 of them were inefficient. FDEA was performed using α-cut approach and eleven α-levels (0 to 1 by 0.1) were examined. According to our results, the efficiency scores showed a decreasing trend as α- levels increasing to crisp situations. It is obvious that applying fuzzy data can show the real situation more accurately. Based on the results of this study, decision makers and farmers can improve their attitudes against energy use and applying well established practices. To achieve this, firstly, we should distinguish efficient units from inefficient ones.

Keywords Energy Efficiency, Fuzzy Data Envelopment Analysis, Feed Intake, Poultry, Egg Production.

1 Introduction

Poultry meat and eggs offer considerable potential for meeting human needs for dietary animal supply [1]. Heretofore, poultry production was not enumerated as an important industry among communities but not long after that it has occupied a place of pride among the livestock enterprises. The poultry industry has become a diverse industry with a variety of business interests such as egg production, broiler production, hatchery, and poultry equipment business [2]. Poultry are acting efficiently in conversion of feed to egg and meat within a short period of time. Nutritively, poultry egg has second place after cow milk [3].

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The measurement of farm efficiency is an important field of research in either the developing and developed countries. The energy efficiency of agricultural production systems is coming under increasing scrutiny and poultry production is no exception. Energy efficiency in agricultural production could be raised by reducing purchased inputs and by increasing marketed outputs [4]. To decide about the optimized amount of inputs use, firstly, a method for detecting the efficient and inefficient units would be helpful and useful. Therefore, decision makers can focus on inefficient units to promote its efficiency. In this regard, data envelopment analysis (DEA) is a widely applied approach for measuring the relative efficiencies of a set of decision making units (DMUs), which use multiple inputs to produce multiple outputs using linear programming. From the available literature, only few authors have ranked poultry enterprises in the light of their technical efficiency scores using the conventional DEA methodology [5- 8]. Recently, in Iran, Heidari et al. [9] conducted a study on energy efficiency measurement of broilers units based on five inputs and two output parameters in Yazd province. 16 farms out of 44 poultry farms were found fully efficient.

The existing DEA models are usually limited to crisp data. But, in practice there are many problems in which, all (some) input–output levels are fuzzy numbers. In these situations, a method is needed to involve with imprecise data. Fuzzy logic has overcome this problem. This paper develops DEA models using imprecise data represented by fuzzy sets. A number of studies have been carried out on solving DEA models with application of various methods [10-14]. After a long search no related study in FDEA application in livestock farming energy use was found.

It is for this reason that this study seeks to examine the technical efficiency of various poultry egg producers in Iran in terms of energy inputs consumption using fuzzy DEA approach. In fact, little is known about level of technical efficiency of Iranian poultry layer industry in general. In point of fact, there is no study done on the benchmarking of poultry for egg production farms in Iran and its provinces.

The need for this study can therefore be seen in the desire to seek the efficient farms, increase the level of productivity in poultry production and also throw more light on the problems associated with energy use in the study area. Hence this study is aimed at serving as a useful guide to poultry farmers, policy makers and as basis on which chicken production program can be built.

2 Material and Methods

2.1 Selecting case study region and data collection

The analysis was carried out based on survey data from 40 farms in the Karaj city of Iran in 2011 production year. Karaj city with a population of 1,377,450 is located within 35° 31' and 36° 12' north latitude and 50° 11' and 51° 29' east longitude. In 2011, Karaj city with 39 poultry for layer farms was ranked as the seventh city in Iran. The significant contribution of this city to provide the demanded egg of population in Tehran province and as a whole, Iran, made us to select this city as a target zone.

Data were culled using a face to face questionnaire approach. It is worth pointing out that all the selected poultry farms were breeding Hyline-W36 chicks (entered farms when they were ten month old). A questionnaire assessing basic information at different inputs use and output production was designed. The required sample size was estimated using the following formula (Eq. 1) [15]:

$$n = \frac{\sum N_h S_h}{N^2 D^2 + \sum N_h {S_h}^2} \quad (1)$$

where n is the required sample size; N is the number of total population; N_h is the number of the population in the h stratification; S_h is the standard deviation in the h stratification, ${S_h}^2$ is the variance in the h stratification, D^2 is equal to d^2/z^2; d is the precision, $d = (\bar{x}-\bar{X})$ (5%) is the permissible error and z is the reliability coefficient (1.96, which represents 95% reliability).The permissible error in the sample size was defined to be 5% for 95% confidence, and the sample size was calculated as 38 farms and finally 40 farms were selected randomly.

2.2 Energy evaluation

The input energy resources were machinery, diesel fuel, electricity, human labor, chick and feed; while output energy sources were egg and manure. The specified inputs use and outputs yield drawn from the questionnaires were employed in order to transform their quantity to energy term. Input values were converted to energy equivalents by multiplying the quantity per 1000 birds^{-1} by their corresponding energy coefficient equivalents (embodied energy). Energy coefficient equivalents for input and output parameters derived from literature, are given in Table 1. In order to facilitate calculations, cultural energy expenditure values were given for 1000 birds and analysis was done in a laying period of 14 months.

Table 1 Energy coefficient equivalents of inputs and outputs

Inputs(unit)	Energy equivalent (MJ unit^{-1} (1000 birds) $^{-1}$)	Reference
A. Inputs		
Human labor (h)	1.96	[16,17]
Machinery (kg)		
Electric motor	64.8	[18]
Steel	62.7	[18]
Galvanized iron	38	[19]
Polyethylene	46.3	[20]
Fossil fuels (l)		
Diesel	47.8	[16]
Kerosene	36.7	[16]
Electricity (kWh)	11.93	[21]
Feed (kg)	11.29	[22, 23]
Chick	110	[24, 25]
B. Outputs		
egg (kg)	57.82	[26]
manure (kg)	0.3	[27]

2.3 Proposed model

The DEA technique, first introduced in Charnes et al. [28] research, has been broadly applied to the efficiency (productivity) measurement of many organizations in public and private sectors. DEA encompasses various kinds of models for evaluating the performance of different DMUs. Different researchers have developed some optimization models based on the return to scale parameter known as CCR (or CRS) and BCC (VRS). CCR model demonstrates constant returns to scale while BCC permits the existence of variant returns to scale. In this study, we have just addressed the BCC model.

The BCC (VRS) model, developed by Banker et al. [29], is the Variable Returns to Scale (VRS) version of the CCR model. The BCC DEA model for measuring the input oriented technical efficiency of a DMU is represented by Model 1 [29]:

$$Max \quad W_p = \sum_{r=1}^{s} u_r y_{rp}$$

s.t.

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \qquad \forall j,$$

$$u_r,\ v_i \geq 0, \qquad \forall i,\ r.$$

Model (1). BCC model

Suppose that the data of inputs and outputs cannot be precisely measured and, also, that they can be expressed as fuzzy numbers with left and right bounded supports $\tilde{x}_{ij} = (\tilde{x}_{ij}^L, \tilde{x}_{ij}^R, \tilde{\alpha}_{ij}^L, \tilde{\alpha}_{ij}^R)_{L_{ij},R_{ij}}$, $i=1,\dots,n$, $j=1,\dots,n$, $\tilde{y}_{ij} = (\tilde{y}_{ij}^L, \tilde{y}_{ij}^R, \tilde{\beta}_{ij}^L, \tilde{\beta}_{ij}^R)_{L'_{ij},R'_{ij}}$, $r=1,\dots,s$, $j=1,\dots,n$. There are different types of fuzzy numbers, but triangular fuzzy numbers are more useful so that we consider the inputs and outputs of DMUs as triangular fuzzy numbers. Therefore, The BCC model with fuzzy data can be written as [11]:

$$Min \quad \theta_0$$

s.t.

$$\sum_{j=1}^{n} \lambda_j x_{ij}^L \leq \theta_0 x_{i0}^L, \qquad i=1,\dots,m,$$

$$\sum_{j=1}^{n} \lambda_j x_{ij}^R \leq \theta_0 x_{ij}^R, \qquad i=1,\dots,m,$$

$$\sum_{j=1}^{n} \lambda_j x_{ij}^L - \sum_{j=1}^{n} \lambda_j \alpha_{ij}^L \leq \theta_0 x_{i0}^L - \theta_0 \alpha_{i0}^L, \qquad i=1,\dots,m,$$

$$\sum_{j=1}^{n} \lambda_j x_{ij}^R + \sum_{j=1}^{n} \lambda_j \alpha_{ij}^R \leq \theta_0 x_{i0}^R + \theta_0 \alpha_{i0}^R \quad i=1,\ldots,m,$$

$$\sum_{j=1}^{n} \lambda_j y_{rj}^L \geq y_{r0}^L, \quad r=1,\ldots,s,$$

$$\sum_{j=1}^{n} \lambda_j y_{rj}^R \geq y_{r0}^R, \quad r=1,\ldots,s,$$

$$\sum_{j=1}^{n} \lambda_j y_{rj}^L - \sum_{j=1}^{n} \lambda_j \beta_{rj}^L \geq y_{r0}^L - \beta_{r0}^L, \quad r=1,\ldots,s,$$

$$\sum_{j=1}^{n} \lambda_j y_{rj}^R + \sum_{j=1}^{n} \lambda_j \beta_{rj}^R \geq y_{r0}^R + \beta_{r0}^R, \quad r=1,\ldots,s,$$

$$\sum_{j=1}^{n} \lambda_j = 1,$$

$$\lambda_j \geq 0, \; j=1,\ldots,n.$$

Model (2). Fuzzy BCC model

where ~ indicates the fuzziness. The interpretation of fuzzy CCR model is similar to that primal BCC model. It is worth pointing out that our proposed FDEA models in this study are based upon the formulations of León et al. [11].

For solving the proposed model, the α-cut approach was applied and the model was transformed to a family of crisp DEA models and the solution is obtained by comparing the intervals in left and right hand side of the constraints. The above model is equivalent to a fuzzy linear programming problem with α from 0 to 1 by 0.1. The optimal value of each model per DMU can be tabulated having efficiency evaluation results for different α-levels. Drawn information would lead decision makers to specify the sensitive units and subsequently, prescribe the required modification amounts of inputs and outputs in order to lead us to change our mind about the efficiency scores [11]. It is important to note that the values of the efficiency scores lie between 0 and 1. However, the efficiency scores do not take a value of zero which means efficiency (θ) is strictly greater than 0 ($\theta > 0$). The DEA problem formulated as a FBCC model (as defined by model 2) was solved in the MATLAB 2010 software. Excel 2007 spreadsheet was utilized for energy calculations, as well.

Many authors have proposed various methods to rank the inefficient units resulted from FDEA approach [30, 32]. Most of the existing methods need the membership function of the fuzzy numbers to be ranked but the which is proposed by Chen and Klein [30], known as the area measurement method, does not require the membership function of the fuzzy efficiency scores. Hence, we found it proper in this study. According to Chen and Klein, the following index (Eq. 2) can be calculated for ranking:

$$I(\widetilde{E}_j)=\frac{\Sigma_{i=0}^{n}\left(\left(E_j\right)_{\alpha_i}^{U}-c\right)}{\left[\Sigma_{i=0}^{n}\left(\left(E_j\right)_{\alpha_i}^{U}-c\right)-\Sigma_{i=0}^{n}\left(\left(E_j\right)_{\alpha_i}^{L}-d\right)\right]},n\to\infty \qquad (2)$$

where $I(\widetilde{E}_j)$ is the ranking index, $(\tilde{E}_j)_{\alpha_i}^{U}$ and $(\tilde{E}_j)_{\alpha_i}^{L}$ are the upper and lower bounds of DMU_j (j=1,2,…,n) for each α-level (α=0,0.1,…,1) respectively. These values were calculated using the difference between α- level 0 and 1 efficiency scores. So that the upper and lower bounds were calculated. c is the minimum value of lower bound and d is the maximum value of upper bound at each distinctive α- cuts and for all DMUs. Based on the ranking indices, the larger the value of the ranking index $I(\widetilde{E}_j)$, the more preferred the number is.

3 Results and Discussion

3.1 Energy inputs and outputs of layer farms

Average capacity of surveyed farms was 58,175 birds. The minimum, maximum and average egg production of farms was 18112.5, 26182 and 21090 kg $(1000\text{bird})^{-1}$ during a production period of 14 months, respectively. According to the results, total energy used in various operations during egg production was 709.8 GJ $(1000\text{bird})^{-1}$. Feed accounts for most energy used input averaging as 521,03 MJ $(1000\text{ birds})^{-1}$ in one production period. Fuel was found to be in the second place after feed for its contribution in energy consumption (21.3%). This indicates the need for input control for reaching optimized level of input use. Cultural energy expended on feed was constituted most of the total cultural energy expenditure as Atilgan and Koknaroglu [33] concluded. In another study Alaw Qotbi [34] carried out on energy use and efficiency of poultry farms, feed was reported as the second input in the poultry housings. Results of energy use analysis and the shares for them are presented in Table 2. As educed, electricity and human labour were consumed with little shares.

Table 2 Energy equivalents of inputs and outputs in poultry for egg production

Inputs(unit)	Quantity per unit $(1000\text{birds})^{-1}$	Average MJ $(1000\text{ birds})^{-1}$	Percentage
A. Inputs			
Human labor (h)	667	1319.9	0.2
Machinery (kg)	4.2	22826	3.2
Fuel (L)	3181.6	151044.8	21.3
Electricity (kWh)	353.5	4.2	0.00
Feed (kg)	48483.1	521031.6	73.4
Chick (kg)	1309.5	13533.4	1.9
Total energy input		709759.9	
B. Outputs			
egg (kg)	20952.2	1211728.4	99.6
manure (kg)	16082.1	4833.5	0.4
total energy output		1216561.8	

Note: Different letter show significant difference of means at 5% level

3.2 FDEA results

In this paper, fuzzy version of BCC model with a symmetrical triangular fuzzy number is adopted from León et al. [11] study in which a procedure is suggested for FDEA solution. The proposed method calculates the efficiency score in a range between 0 to 1. Accordingly, when efficiency score of a DMU is equal to 1 (θ=1), it is fully efficient. Fuzzy efficiencies of DMUs with different α-values are listed in Table 3. As seen, the average, minimum and maximum values are given in the last rows and columns of the table.

It is evident from Table 3 that the efficiencies are decreased by increasing α but DMU 5, DMU 6, DMU 9, DMU 10, DMU 37 and DMU 40 are efficient for all α-levels. The last column of this table shows efficiencies by α=1. In this case, Model 2 is equivalent to the conventional BCC model (Model 1). It is evident that as α-level increases, efficiency scores are decreasing, showing that fuzziness is needed in these kinds of problems. Fig. 1 describes these changes obviously. Moreover, the fuzzy set of efficient units can be presented as follows:

$$\widetilde{E}_f=\{(5,1),(6,1),(9,1),(10,1),(36,0.1),(37,1),(40,1)\}$$

The DMUs which are not listed in the set were those with less than 1 membership values (inefficient units).

Table 3 FBCC modeling results of efficiency evaluation

DMU	α – levels											Min	Max	Mean
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1			
1	0.86	0.86	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.86	0.85
2	0.80	0.79	0.79	0.79	0.79	0.79	0.79	0.78	0.78	0.78	0.78	0.78	0.80	0.79
3	0.91	0.91	0.91	0.91	0.91	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.91	0.90
4	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.82	0.81
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	0.87	0.87	0.87	0.87	0.87	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.87	0.86
8	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.89	0.89	0.89	0.89	0.89	0.90	0.90
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.85	0.85	0.85	0.85	0.86	0.86
12	0.74	0.74	0.74	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.72	0.72	0.74	0.73
13	0.83	0.83	0.82	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.83	0.82
14	0.93	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.92
15	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.92
16	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.92
17	0.86	0.86	0.86	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.84	0.84	0.86	0.85
18	0.86	0.85	0.85	0.85	0.85	0.85	0.85	0.84	0.84	0.84	0.84	0.84	0.86	0.85
19	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.86	0.86	0.86	0.86	0.86	0.87	0.87
20	0.88	0.88	0.88	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.88	0.87
21	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.80	0.80	0.80	0.81	0.81
22	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.82	0.81
23	0.81	0.81	0.81	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.81	0.80
24	0.76	0.76	0.76	0.76	0.76	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.76	0.75
25	0.80	0.80	0.80	0.80	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.80	0.79
26	0.81	0.81	0.81	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.81	0.80
27	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
28	0.77	0.77	0.77	0.77	0.77	0.77	0.76	0.76	0.76	0.76	0.76	0.76	0.77	0.77
29	0.87	0.87	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.85	0.85	0.87	0.86

	α – levels											Min	Max	Mean
DMU	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1			
30	0.81	0.81	0.81	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.81	0.80
31	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.93	0.93
32	0.83	0.83	0.83	0.83	0.83	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.83	0.82
33	0.81	0.81	0.81	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.81	0.80
34	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.82	0.82
35	0.93	0.93	0.93	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.93	0.93
36	1	1	0.98	0.96	0.95	0.95	0.94	0.94	0.94	0.94	0.94	0.94	1.00	0.96
37	1	1	1	1	1	1	1	1	1	1	1	1	1	1
38	0.87	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.85	0.85	0.87	0.86
39	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.83	0.83	0.83	0.83	0.84	0.84
40	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Min	0.74	0.74	0.74	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.72			
Max	1	1	1	1	1	1	1	1	1	1	1			
Mean	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.86	0.86	0.86			

As it is depicted in Fig. 1, it should be noted that, except in the cases of efficient DMUs (which are crisp-efficient), the crisp evaluation of the centers of the fuzzy triangular numbers approach (whose results are those in α =1) provides results which look more pessimistic for every DMU than those from the possibility (fuzzy) approach (efficiency is decreasing as α-level rises to 1). It should be noted here that in Fig. 1, the whole efficient units are assigned as "Efficient units". Moreover, this illustration can show the sensitive units to help the decision makers to choose the proper possibility (α) level. In this regard, DMU 36 was the only sensitive unit to α-levels below 0.2. For other possibility levels the trend is the same as other inefficient DMUs. In fact, this is the result of applying fuzzy DEA to assess efficiencies when input and output data are measured imprecisely.

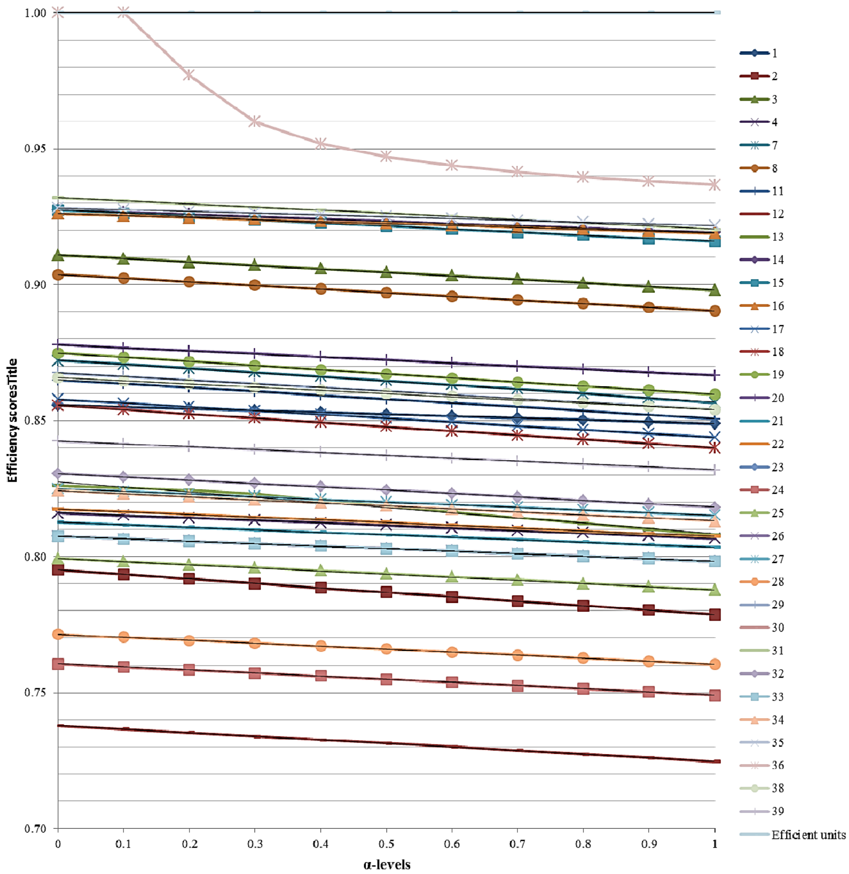

Fig. 1 Fuzzy scores under different α-levels for FBCC model.

Finally, we utilized the Chen and Klein [30] ranking method to distinguish the 40 DMUs (our target poultry farms) at eleven α values. The results are given in Table 4. As it is apparent, poultry farmers are ranked based on their energy efficiency. Consequently, the best performance farmers are identified and the policy makers' firm can use the derived information to select the preferred best system applied in each farm. The results are interesting for poultry managers and governments to evaluate the performance of their enterprises.

For being the first study on ranking poultry farmers in the view of energy efficiency using fuzzy data envelopment analysis, we did not find any relevant study to our work to compare the results.

Table 4 Ranking indices (I) and rankings (R) of the efficiency scores for the BCC model

DMU	I	R	DMU	I	R
1	0.45	15	22	0.32	23
2	0.25	31	23	0.29	26
3	0.61	7	24	0.15	33
4	0.32	24	25	0.27	30
7	0.49	11	26	0.29	27
8	0.58	8	27	0.35	21
11	0.46	14	28	0.18	32
12	0.08	34	29	0.47	12
13	0.35	20	30	0.29	29
14	0.67	4	31	0.67	3
15	0.66	6	32	0.36	19
16	0.67	5	33	0.29	28
17	0.44	16	34	0.34	22
18	0.44	17	35	0.68	2
19	0.49	10	36	0.71	1
20	0.51	9	38	0.47	13
21	0.31	25	39	0.40	18

4 Conclusions

Agricultural production systems, especially livestock products need to increase the energy use efficiency, while lower costs to compete in today's global market place. Nowadays evaluation of decision making units (DMUs), by using the mathematical programming-based techniques, has allocated to itself a wide variety of research in Operational Research (OR) field. DEA has been utilized as a multiple criteria tool for evaluation of agricultural enterprises. This paper applies a method proposed by Leon et al. [11] to find the fuzzy efficiency measures of poultry for egg farms embedded with ranking indices of inefficient units when some observations are fuzzy numbers. Although the proposed procedure is utilized to evaluate the poultry layers enterprises, the approach proposed in this paper can still be employed to a broader area of decision problems in agricultural production systems management with fuzzy data.

The present study aimed at investigating the energy use of poultry farms of Iran and ranking the target farms with application of fuzzy data envelopment analysis. Energy use analysis of the inputs and outputs of poultry farms revealed that an average of 709 GJ (1000 birds)$^{-1}$ was used and feed intake and fossil fuels are the top two energy consuming inputs accounting 73.4% and 21.3% of the total energy consumption.

Our results implied that from 40 selected poultry for egg production farms, 33 farms were identified as inefficient units and one (DMU 36) was sensitive to fuzzy application of DEA using α-cut approach meaning that it is efficient for fuzzy situations. DMU 5, DMU 6, DMU 9, DMU 10, DMU 37 and DMU 40 are efficient for all α-levels.

Based on the findings of this research, novel and evolutionary scientific practices should be used to achieve higher technical efficiency from poultry layer farming like:

1. Inefficient farmers should care more about using energy sources such as fossil fuels, feeds and electricity to promote their energy productivity.
2. Having more control on feeding layers regarding standard feeding ration patterns in order to achieve a reduction in energy wasting of feed intake; in particular the amount of feed is taken.

3. The need for educating inefficient poultry farmers for coping with mechanized poultry farming and changing their wrong attitudes towards energy source use by executing extension programs.
4. Choosing and purchasing one-day- old chicks from chosen and renowned strains.
5. Utilizing cleaner energy resources such as biogas and solar energy to generate energy required for poultry farms is strongly recommended.

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