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Energy Optimization of Traditional and Modern Farms of Broiler Production using Data Envelopment Analysis Approach

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ABSTRACT

The main objectives of this study were to analyze the energy efficiency of broiler production of Mazandaran province in north of Iran based on traditional and modern farms. For these purposes the data envelopment analysis (DEA) approach was applied to the data on energy use in broiler production in individual farms. The results indicated that the percentage of efficient units were founded about 17% and 34% in technical (CCR model) and pure technical (BCC model) for both systems. Also, about 17% of total units of traditional and modern farms had the efficient score fore scale efficiency index. Based on CCR and BCC models of DEA, the average of technical, pure technical and scale efficiency scores of traditional farms was calculated as 0.837, 0.927 and 0.906, respectively; while the modern farms results indicated that technical, pure technical and scale efficiency scores was founded as 0.873, 0.978 and 0.892, respectively. The total saving energy of traditional and modern farms was about 19907 and 6740 MJ 1000 birds^{-1}, respectively. Accordingly, it can be said, comparing to present farms, the total energy requirement of DEA method decreased as 11.16% and 3.57% for traditional and modern farms, respectively. The last part of this research illustrated that diesel fuel, feed and electrical energy had the highest share for total saving energy by the DEA method in both systems of broiler production.

Introduction

Broiler production was not recognized as an important occupation in the past; it has developed and occupied a place of pride among the livestock enterprises due to its rapid monetary turnover (Heidari et al., 2011a). Agriculture is both a user and producer of energy. All agricultural operations require energy in one form or another: human labor, animal power, fertilizer, fuels and electricity. In 1950, energy input in crop production in Thailand was approximately 9 PJ. The biological energy inputs in the form of seeds contributed the most (61%) followed by physical energy inputs from agricultural labor (21%) and draft animal (17%). After 1970, total energy input sharply increased due to the increased use of chemical fertilizer and physical energy input. By 1998, the total energy input increased around 13 times compared to 1950 while the crop production increased around six times from 7 million tons in 1950 to 44 million tons grain equivalent in 1998 (Chamsing et al., 2006). In other hands, Animal production systems use considerable quantities of support energy. Regarding this and the consequent increase in production cost, energy should be used with a greater efficiency.

The major support energy inputs in poultry industry include energy related to the production of foodstuffs, materials for buildings and machinery, electricity, fuel for heating and also human labor working on a farm. Electricity is used for refrigeration, lighting, air conditioning and other mechanical drives. Fossil fuels are used for production of hot water and heating. In poultry operations, feed cost has always been a major issue. Fuel and electricity consumption has become more intensive after the mechanized management of poultry farms (Sefeedpari et al., 2013). Data Envelopment Analysis (DEA) is known as a mathematical procedure that uses a linear programming technique to assess the efficiencies of decision-making units (DMU). A non-parametric piecewise frontier, which owns the optimal efficiency over the datasets, is composed of DMUs and is constructed by DEA for a comparative efficiency measurement. Those DMUs that are located at the efficiency frontier are efficient DMUs. These DMUs own the best efficiency among all DMUs and have their maximum outputs generated among all DMUs by taking the minimum level of inputs (Lee and Lee, 2009). In recent decade, many authors surveyed the energy issue and its optimization in animal production (especially poultry, egg and…) in the Iran and other country of the world. For example, Begum et al. (2010) calculated technical, allocative and economic efficiency of commercial poultry farms in Bangladesh using the DEA approach under a constant return to scale (CRS) and variable return to scale (VRS) specification. Heidari et al. (2011b) examined the energy efficiency of broiler production in Yazd province, Iran. Sefeedpari et al. (2012) applied DEA method for determination of energy efficiency for poultry egg producers. Sefeedpari et al. (2013) identified the sustainability and energy efficiency for poultry farms by DEA approach in Iran. Amid et al. (2015) investigated the energy consumption and economic analysis of broiler production in Ardabil province of Iran.

The main objective of this study was determination of energy efficiency and its optimization for two levels, including: traditional and modern farms of broiler production in Mazandaran province of Iran using DEA approach.

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Materials and methods

Sampling design and energy computation

Mazandaran province of Iran is one of the largest producer and consumer of broiler production in the north of Iran. Accordingly, this province (as one of the largest centers for broiler production) was considered for data collection in this study. Mazandaran province is located in the north of Iran, within 31◦ 47′ and 38◦ 05′ north latitude and 50◦ 34′ and 56◦ 14′ east longitude (Anon, 2014). The broiler farms were classified into two levels, including traditional and modern farms. So, the data were collected for each level, separately. A face-to-face questionnaire was considered for data collection in the studied region. It should be noted the determination of reliable sample size is very important in the questionnaire method of data collection. For this purpose, there are many methods for determination of sample size. In this study, the random sampling method selected for determination of sample size (Kizilaslan, 2009). Based on the random sampling method, the sample size of traditional and modern farms was calculated as 70 for each one.

The energy embodied in broiler production was classified in 6 categories covering chick, human labor, machinery (electricity motor, steel and polyethylene), diesel fuel, feed (maize, soybean meal and dicalcium phosphate, fatty acid and minerals and vitamins) and electricity; while the energy outputs were broiler yield and manure. The inputs used in the production of broiler were specified in order to calculate the energy equivalences in the study. The units in Table 1 were used to calculate the energy equivalences for all inputs. The input and output were calculated per 1000 birds and then data were multiplied by the coefficient of energy equivalent. . Data envelopment analysis (DEA)

DEA is a widely used mathematical programming approach for comparing the inputs and outputs of a set of homogenous DMUs (decision making units). DEA focuses on evaluating the performance of DMUs based on evaluation of relative efficiency of comparable DMUs by estimating an empirical efficient boundary. A DMU is considered efficient when no other DMUs can produce more outputs, using an equal or lesser amount of inputs. DEA also provides efficiency scores and reference units for inefficient DMUs. Reference units are hypothetical units on the efficient surface, which can be regarded as target units for inefficient firms. A reference unit is traditionally found on the DEA by projecting the inefficient DMU radially to the efficient surface. The advantage of using DEA is that it does not require any assumption about the shape of the frontier surface and it makes no assumptions concerning the internal operations of a DMU (Khoshroo et al., 2013).

In this study, the CCR and BCC models utilized in DEA. Charnes, Cooper, and Rhodes (CCR), (1978) introduced DEA approach at the first time. Also, BCC model first was developed by Banker et al. (1984) and they were called local efficiency model. The BCC model is referred to as the VRS (Variable Returns to scale) model and distinguished form the CCR model which is referred to as the CRS (Constant Returns to Scale) model. Also, the models with CRS envelopment surface, assume that an increase in inputs will result in a proportional increase in outputs. The VRS model allows an increase in input values to result in a non-proportional increase of output levels. The VRS surface envelops the population by connecting the outermost DMUs, including the one approached by the CRS surface. Hence the BCC model envelops more data and efficiency scores are bigger than or equal to those of CCR (Nabavi-Pelesaraei et al., 2014b).

Technical efficiency (TE)

Technical efficiency (TE) represents the ability of a DMU to produce maximum output given a set of inputs and technology (output-oriented) or, alternatively, to achieve maximum feasible reductions in input quantities given input prices and output (input-oriented). The choice between input-oriented and output-oriented measures are a matter of concern, and selection may vary according to the unique characteristics of the set of DMUs under study. Greenhouse production relies on finite and scarce resources. The producer has more control over inputs rather than output levels, which may often be exogenously bounded (e.g., CAP provisions). In addition, the inelastic demand of most agricultural product renders cost reduction a better means of increasing profitability than output growth, notwithstanding that in many cases the choice of orientation has only minor influences upon the scores obtained. Therefore the use of input-oriented DEA models are more appropriate to reduce inputs consumed in the production process (Banaeian et al., 2011).

The TE can be defined as follows (Mohammadi et al., 2013):

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

Where, ur, is the weight given to output n; yr, is the amount of output n; vs, is the weight given to input n; xs, is the amount of input n; r, is number of outputs (r = 1, 2, . . ., n); s, is the number of inputs (s = 1, 2, .., m) and j, represents jth of DMUs (j = 1, 2, . . ., k).

To solve Eq. (1), following Linear Programming (LP) was formulated:

Maximize

$$\theta = \sum_{r=1}^{n} u_r y_{rj}$$

Subjected to (2)

$$\sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_s x_{sj} \leq 0$$

$$\sum_{s=1}^{m} v_s x_{sj} = 1 \qquad u_r \geq 0, \quad v_s \geq 0, \qquad \text{and (i and j= 1, 2, 3, …, k)}$$

Where θ is the technical efficiency, Model (3) is known as the input oriented CCR DEA model assumes constant returns to scale (CRS) (Avkiran, 2001).

Pure technical efficiency

With respect to technical efficiency (in CRS model), technical efficiency of VRS model, which is called pure technical efficiency (PTE) (Banaeian et al., 2011).

The dual model is derived by construction from the standard inequality form of linear programming. Nabavi-Pelesaraei et al. (2014c) expressed it by Dual Linear Program (DLP) as follows:

Maximize z=uyi – ui

Subjected to vxi=1 (3)

–vX+uY – uoe ≤ 0

v ≥ 0, u ≥ 0 and uo free in sing

where z and u0 are scalar and free in sign; u and v are output and input weight matrixes, and Y and X are the corresponding output and input matrixes, respectively. The letters xi and yi refer to the inputs and output of its DMU.

Scale efficiency

The quantitative information about scale characteristics can be obtained from Scale efficiency; also, scale efficiency is the potential productivity gain from achieving optimal size of a DMU (Reyhani-Farashah et al., 2013). If a DMU is fully efficient in both the technical and pure technical efficiency scores, it is operating at the most productive scale size. If a DMU has the full pure technical efficiency score, but a low technical efficiency score, then it is locally efficient but not globally efficient due to its scale size. Thus, it is reasonable to characterize the scale efficiency of a DMU by the ratio of the two scores (Mobtaker et al., 2012). The relationship between technical and pure technical efficiency scores can be described by Mobtaker et al. (2012):

$$Scale\ efficiency = \frac{Technical\ efficiency}{Pure\ technical\ efficiency} \quad (4)$$

Basic information on energy inputs in broiler production were entered into Excel 2013 spreadsheets and EMS software programs.

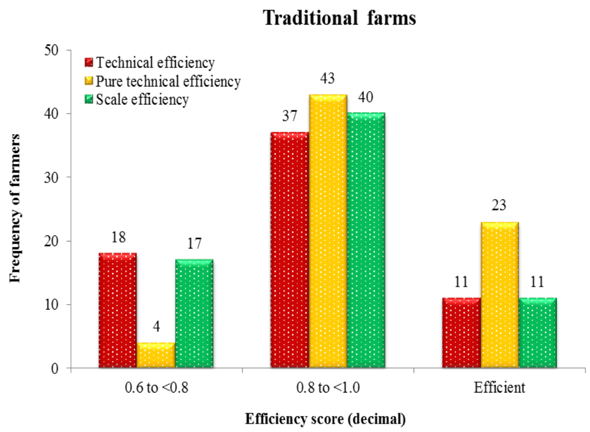
Results and Discussion

Energy consumption of traditional and modern farms

The results of the energy use of traditional and modern farms are illustrated in Table 2 for present conditions. Accordingly, the total energy use was calculated 178342.90 and 188797.91 MJ (1000 birds-1) for traditional and modern broiler farms, respectively; while the output energy of broiler yield was 28368.82 and 188797.91 MJ (1000 birds-1) for them, respectively. Moreover, diesel fuel and feed had the highest share in total energy consumption in both systems, respectively.

Efficiency estimation of farmers

The efficiency score distribution of BCC and CCR model are demonstrated for traditional and modern farms of broiler production in Fig 1. Based on CCR model, 11 and 13 units was efficient in traditional and modern farms, respectively. Moreover, the technical efficiency score of most farmers founded between 0.8 to 1 for both systems. In other hand, the BCC model results indicated the 23 and 25 broiler producers had the score of one in traditional and modern farms, respectively. Furthermore, the pure technical efficiency score was computed between 0.8 to 1 for 60% of total farms in both systems. As can be seen in Fig 1, the green column showed the scale efficiency. Accordingly, 11 and 13 producers were efficient at scale efficiency point of view.



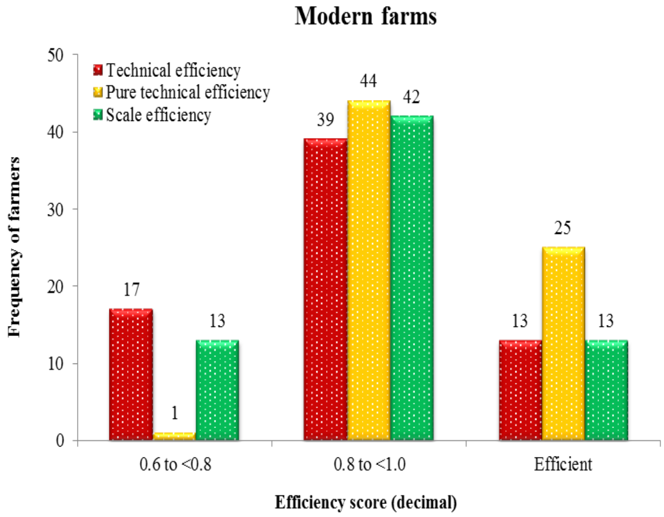


Fig 1. Efficiency score distribution of traditional and modern farms of broiler producers.

Table 3 showed the average of estimated measures of efficiency. Accordingly, average of technical was calculated as 0.837 and 0.873 for traditional and modern farms of broiler production, respectively. Also, the mean of pure technical efficiency was 0.927 and 0.978 for traditional and modern farms, respectively. As can be seen in the last row of Table 3, the scale efficiency of traditional and modern farms was found as 0.906 and 0.892, respectively. It should be noted the maximum of all indices was 1 on both systems. Heidari et al. (2011b) reported the average of technical, pure technical and scale efficiency for broiler production was 0.90, 0.93 and 0.96, respectively.

Optimum energy requirement and saving energy

The value of optimum energy with rate of saving energy are given for traditional and modern farms in Table 4 and Table 5, respectively. Based on results, the total energy requirement of traditional and modern farms was computed about 158436 and 182058 MJ (1000 birds–1), respectively. In other words, 19907 and MJ (1000 birds–1) can be reduced in DEA approach comparing present condition for traditional and modern farms, respectively. In the last column of Table 4 and Table 5, the percentage of total saving energy based on present farms is demonstrated for traditional (11.16%) and modern farms (3.57%), respectively. This result revealed the modern farms had the better condition comparing traditional farms because the difference of optimum and present farms was less than in modern farms. Also, the highest percentage of saving energy in traditional farms was belonged to electricity and machinery, respectively; while the chick and machinery had the highest percentage of saving energy in modern farms, respectively. In the last part of this study the share of each input in total saving energy for traditional and modern farms of broiler production investigated in Mazandaran province, Iran (Fig 2). The results revealed diesel fuel, feed and electricity had the highest share of total energy saving in both systems. The applying standard machinery can be improved the energy use pattern in the studied region, significantly.

Table 1. The energy equivalent of inputs and output in broiler production

Items	Unit	Energy equivalent (MJ unit^{-1})	Reference
A. Inputs			
1. Chick	kg	10.33	(Heidari et al., 2011b)
2. Human labor	h	1.96	(Nabavi-Pelesaraei et al., 2013)
3. Machinery			
(a) Electric motor	kg	64.8	(Chauhan et al., 2006)
(b) Steel	kg	62.7	(Chauhan et al., 2006)
(c) Polyethylene	kg	46.3	(Heidari et al., 2011b)
4. Diesel fuel	L	47.8	(Kitani, 1999)
5. Feed			
(a) Maize	kg	7.9	(Atligan and Hayati, 2006)
(b) Soybean meal	kg	12.06	(Atligan and Hayati, 2006)
(c) Dicalcium phosphate	kg	10	(Alrwis and Francis, 2003)
(d) Fatty acid	kg	9	(Berg et al., 2002)
(e) Minerals and vitamins	m^3	1.59	(Heidari et al., 2011b)
6. Electricity	kWh	3.6	(Kitani, 1999)
B. Outputs			
1. Broiler	kg	10.33	(Amid et al., 2015)
2. Manure	kg	0.3	(Nabavi-Pelesaraei et al., 2014a)

Table 2. Amounts of inputs, outputs and their energy equivalences in traditional and modern farms of broiler production

Items	Traditional farms		Modern farms	
	Total energy equivalent (MJ (1000 birds)$^{-1}$)	Percentages (%)	Total energy equivalent (MJ (1000 birds)$^{-1}$)	Percentages (%)
A. Inputs				
1. Chick	577.25	0.32	534.46	0.28
2. Human labor	233.08	0.13	196.29	0.10
3. Machinery	152.83	0.09	341.18	0.18
4. Diesel fuel	101517.73	56.92	111303.57	58.95
5. Feed	62682.30	35.15	59232.45	31.37
6. Electricity	13179.71	7.39	17189.94	9.10
The total energy input	178342.90	100	188797.91	100
B. Outputs				
1. Broiler	28368.82	-	31724.87	-
2. Manure	732.14	-	852.47	-

Table 3. Average technical, pure and scale efficiency of traditional and modern broiler farmers.

Particular	Traditional farms			Modern farms		
	Average	Min	Max	Average	Min	Max
Technical efficiency	0.837	0.460	1.000	0.873	0.569	1.000
Pure technical efficiency	0.927	0.717	1.000	0.978	0.913	1.000
Scale efficiency	0.906	0.489	1.000	0.892	0.573	1.000

Table 4. Optimum energy requirement and saving energy for traditional farms of broiler production

Inputs	Optimum energy requirement (MJ (1000 birds^{-1}))	Saving energy (MJ (1000 birds^{-1}))	Saving energy (%)
1. Chick	510.14	67.10	11.62
2. Human labor	202.60	30.48	13.08
3. Machinery	132.12	20.71	13.55
4. Diesel fuel	90729.28	10788.46	10.63
5. Feed	55541.13	7141.17	11.39
6. Electricity	11320.81	1858.90	14.10
Total energy requirement	158436.08	19906.82	11.16

Table 5. Optimum energy requirement and saving energy for modern farms of broiler production

Inputs	Optimum energy requirement (MJ (1000 birds^{-1}))	Saving energy (MJ (1000 birds^{-1}))	Saving energy (%)
1. Chick	469.96	64.51	12.07
2. Human labor	178.69	17.61	8.97
3. Machinery	304.05	37.13	10.88
4. Diesel fuel	108785.57	2518.00	2.26
5. Feed	56054.16	3178.29	5.37
6. Electricity	16265.70	924.24	5.38
Total energy requirement	182058.14	6739.77	3.57

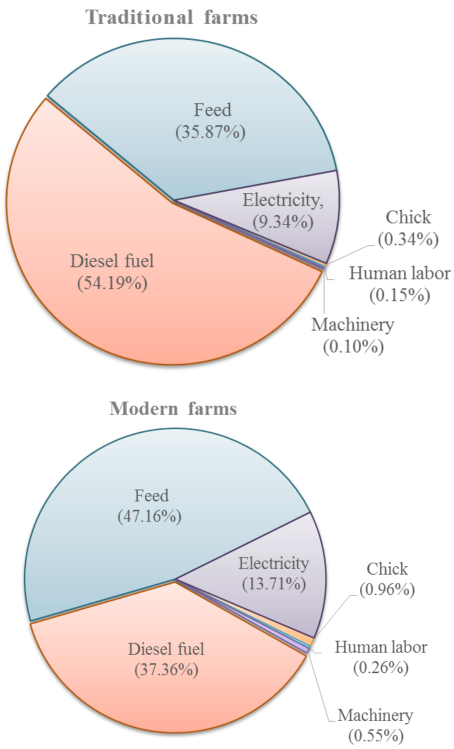


Fig 2. The share of each input in total energy saving of traditional and modern farms of broiler production.

Conclusions

Based on the results of the investigations, the following conclusions were drawn:

1. From the total of 70 broiler farmers considered for the analysis in each system, about 17% and 34% were found to be technically and pure technically efficient for both systems, respectively.
2. The mean of technical, pure technical and scale efficiency scores of traditional farms was calculated as 0.837, 0.927 and 0.906, respectively; while the modern farms results indicated that technical, pure technical and scale efficiency scores was founded as 0.873, 0.978 and 0.892, respectively.
3. The total saving energy of traditional and modern farms was about 19907 and 6740 MJ 1000 birds-1, respectively. In other words, the total energy requirement of DEA method decreased 11.16% and 3.57% for traditional and modern farms comparing present farms, respectively.
4. The diesel fuel, feed and electrical energy had the highest potential for improvement in both traditional and modern farms of broiler production in Mazandaran province, Iran.

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