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Optimization of energy consumption of dairy farms using data envelopment analysis – A case study: Qazvin city of Iran

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Abstract The aim of this study was to use the data envelopment analysis for determining the energy efficiency and find the optimum energy consumption in dairy farms of Qazvin city of Iran. In this study have been used from two approaches constant returns to scale and variable returns to scale model of data envelopment analysis for determining the degrees of technical efficiency, pure technical efficiency and scale efficiency. Moreover, the effect of optimum energy consumption on greenhouse gas emissions has been studied and also the total amount of greenhouse gas emissions. The results showed that from total number of dairy farms 42.55% and 53.19% were efficient based on constant returns to scale and variable returns to scale model, respectively. Accordingly, the average score of technical, pure technical and scale efficiencies of farmers were calculated 0.9, 0.94 and 0.953, respectively. The total optimum energy required was estimated 129,932 (MJ cow^{-1}). Energy saving target ratio for dairy farms was calculated as 12%. According to results feed intake had the highest share (85.44%) from total saving energy, followed by fossil fuels (11.19%). The total greenhouse gas emission was calculated as 5393 ($kgCO_{2eq}$. cow^{-1} $year^{-1}$) in dairy farms that this amount can be reduced to 4738 ($kgCO_{2eq}$. cow^{-1} $year^{-1}$) with optimum energy consumption. The enteric fermentation had the highest potential to reduction of total GHG emissions with 47% that has a direct connection to the amount of feed intake.

1. Introduction

Energy is one of the basic requirements for the economic and social development of a country or area. Analysis and scientific forecasts of energy consumption have major importance for the planning strategies and policies of energy use (Liang et al., 2007).

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Nowadays, agricultural sector has become major energy consumer in order to supply more food to increase population and provide enough and adequate nutrition (Samavatean et al., 2011). So analysis of energy consumption in this sector is essential as well as other manufacturing sectors. On the other hand, high energy consumption in agriculture and reducing the known energy resources have developed the philosophy of optimum energy consumption. Optimum consumption of energy helps to attain increased production and contributes to the economy, profitability and competitiveness of agricultural sustainability of rustic communities (FAO, 2008). So in addition to energy analysis it is needed to determine the optimal energy consumption in agricultural production. Energy efficiency in production is a way to achieve optimum energy consumption. Efficiency is defined as the capability to produce the outputs with a minimum resource amount needed (Mohammadi et al., 2008). Energy efficiency improvements contribute to the reductions of emissions and climate change (Varone and Aebischer, 2001).

Therefore, effective energy use in agriculture is one of the conditions for sustainable agricultural production, since it provides financial savings, fossil resources preservation and air pollution reduction (Uhlin, 1998). There are several ways to determine the efficiency that one of them is nonparametric method of data envelopment analysis (DEA). DEA is an evaluation technique based on mathematical programming, and it can determine the relative efficiency of decision making units (DMUs) (Adler et al., 2002). Many researchers have endorsed DEA as being a useful method for estimating relative energy efficiency in agriculture and livestock. The main reason for using this method in agricultural and livestock activities is that it does not need any prior assumptions on the underlying functional relationships between inputs and outputs (Seiford and Thrall, 1990). For example, Mohammadi et al. (2011) used DEA to calculate energy efficiency for kiwifruit production in Iran. Nabavi-Pelesaraei et al. (2014d) applied DEA in an analysis of energy consumption and carbon dioxide emissions in the rice production. Mousavi-Avval et al. (2011b) examined the energy efficiency of soybean production using a DEA approach. Sefeedpari (2012) employed a DEA approach to determine energy-saving targets for the dairy farms in Iran. Pahlavan et al. (2012) used DEA to assess the energy efficiency of rose production in Iran. Heidari et al. (2011) also used DEA method for determination of optimum consumption of energy in broiler production farms.

In comparison with crop production, few studies have been conducted on the energy efficiency of livestock farms. However, the number of intensive livestock systems are increasing, and the land and livelihood needs of extensive systems are crucial challenges of livestock farms (Schneider, 2010). On the other hand, the livestock production is the poor converter of energy because it is based on a double energy transformation. First, solar energy and soil nutrients are converted into biomass by green plants. When crops are fed to livestock, a major share of energy intake is spent on keeping up body metabolism and only a small portion is used to produce meat and milk (Frorip et al., 2012). So, be attentive to energy consumption and energy efficiency in livestock farms is essential.

Dairy farm is one of the most important consumers of energy and producers of GHG emissions in livestock farms. So, like other parts the energy consumer achieving sustainability in production is essential study of energy and finding the optimum consumption of energy.

Considering to little studies and the need for sufficient study in relation to energy efficiency in dairy farms, the aim of this study was the assessment of energy flow and determination of respective energy efficiency for finding the cause of wasted energy, and improving the production processes to achieve systems with more energy efficiency and less GHG emissions in dairy farms in the Qazvin city of Iran. Due to the success of DEA method, finding the relative efficiency of dairy farms has been done by this technique in this study.

2. Materials and methods

2.1. Data collection and processing

The present study was carried out in Qazvin city of Iran. Qazvin city is located between 48°85′ to 50°51′ east longitude Greenwich meridian and 36°7′ and 36°48′ north latitude and the equator. The data were collected from dairy farmers using face-to-face questionnaire in the production year 2014. A questionnaire form used in this study was designed to collect the required information related to various inputs used (fuel, electricity and feed), yield, total working hours of labors, total working hours of machinery and equipment. According to the report of Ministry of Jihad-e-Agriculture of Iran (Anon., 2014) there were 110 dairy farms in area of study. The sample size was assessed using Cochran's technique (Cochran, 1977). 50 dairy farms were randomly selected, accordingly. (Data of three farms were incomplete and were excluded from the analysis.)

Converting each agricultural input and output into energy equivalent was used from standard procedure (use of equivalent energy factor) (Mousavi-Avval et al., 2012). Table 1 shows the energy equivalents of inputs and outputs for the dairy farms. Energy inputs for dairy farms in the studied area are encompassed human labor, fossil fuels, electricity, machinery and feed while milk and meat produced and cattle manure are considered as an output energy. The total energy input is determined as the sum of the input factors multiplied by the appropriate energy conversion coefficient for each factor (Kazemi et al., 2015). The estimation of energy equivalent of machinery and equipment was done from Eq. (1) (Gezer et al., 2003):

$$ME = \frac{G \times M_P \times t}{T} \quad (1)$$

where 'ME' is the machinery energy per cow (MJ cow^{-1}), 'G' is the material mass used for manufacturing (kg), 'M_p' represents the production energy of material (MJ kg^{-1}), 't' is the time that machine used per cow (h cow^{-1}) and 'T' is the economic life time of machine (h).

On the other hand, the energy input is classified into direct and indirect and renewable and non-renewable forms (Singh et al., 2003). In this study, the indirect energy included feed and machinery while the direct energy included human labor, fossil fuels and electric energy used in the dairy farms. As well as, non-renewable energy included fossil fuels, electricity and machinery and renewable energy is consisted of human labor and feed. In this study, energy ratio, specific energy and energy productivity for dairy farms and milk production were calculated using the following equations (Nabavi-Pelesaraei et al., 2013):

Table 1 The energy content of the inputs and outputs of dairy farm.

Items (unit)	Energy content (MJ $Unit^{-1}$)	References
A. Inputs		
1. Tractor (kg a[a])	9–10	Kitani (1999)
2. Equipment and machinery (kg a)	6–8	Kitani (1999)
3. Fossil fuels		
4. Diesel (l)	47.8	Nabavi-Pelesaraei et al. (2013)
5. Gasoline (l)	46.3	Kitani (1999)
6. Oil (l)	36.7	Kitani (1999)
7. Natural gas (m^3)	49.5	Kitani (1999)
8. Electricity (kW h)	11.93	Ozkan et al. (2004)
9. Human labor (h)	1.96	Nabavi-Pelesaraei et al. (2014c)
10. Feed[b]		
(a) Concentrate (kg)	13.6	Frorip et al. (2012)
(b) Maize silage (kg)	10.41	NRC (2001)
(c) Dry alfalfa (17% CP) (kg)	10.92	NRC (2001)
(d) Barley (kg)	15.28	NRC (2001)
B. Outputs		
1. Milk (kg)	2.7	NRC (2001)
2. Meat (kg)[c]	9.22	Frorip et al. (2012)
3. Cow manure (kg dry matter)	0.3	Singh and Mittal (1992)

[a] Economic life of machine.
[b] Metabolizable energy.
[c] Live weight.

Table 2 GHG emissions factor inputs in dairy farms.

Items	Unit	GHG emissions conversion factor	References
1. Machinery	MJ	0.071	Nabavi-Pelesaraei et al. (2014a)
2. Diesel	l	2.76	Nabavi-Pelesaraei et al. (2014a)
3. Gasoline	kg	0.85	Lal (2004) and Sabzevari et al. (2015)
4. Natural gas	m^3	0.6	Lal (2004) and Sabzevari et al. (2015)
5. Electricity	kW h	0.608	Nabavi-Pelesaraei et al. (2014a)

$$E.R = \frac{E_{out}}{E_{in}} \quad (2)$$

$$NEG = E_{out} - E_{in} \quad (3)$$

$$EP = \frac{Y}{E_{in}} \quad (4)$$

$$SE = \frac{E_{in}}{Y} \quad (5)$$

where '$E.R$' energy ratio; 'NEG' is net surplus energy (MJ per head of cow), 'EP' is energy productivity (kg MJ^{-1}), 'SE' is specific energy (MJ kg^{-1}), 'E_{in}' is energy input of the system (MJ per head of cow), 'E_{out}' is energy output of the system (MJ per head of cow) and 'Y' is the yield (milk production per head of cow).

2.2. GHG emissions

Cows are involved in climate change through the emissions of GHG such as carbon dioxide, methane and nitrous oxide, directly or indirectly, in which methane and nitrous oxide have 25 times and 300 times the Global Warming Potential (GWP) of CO_2 respectively. Globally, this sector contributes 18 percent (7.1 billion tons CO_2 equivalents) of global GHG emissions (Steinfeld et al., 2013). Dairy farm, production, transportation, storage, use of machinery and process cooling lead to combustion of fossil fuel, directly or indirectly (electricity and machinery) which emits GHG into the atmosphere. The conversion factors were applied to calculate the GHG emissions shown in Table 2.

In addition to the GHG emissions from combustion, cow is an important producer of GHG emissions that is resulting from enteric fermentation (CH_4) and manure production (N_2O, CH_4). So that the IPCC (2007) has announced cattle farms are one of the most important producers of methane gas. Methane emissions mostly occur as part of the natural digestive process of animals (enteric fermentation) and manure management in livestock operations. About 80% of agricultural CH_4 and 35% of the total anthropogenic methane emissions are related to cow. For determining the amount of methane from enteric fermentation cattle were used in different equations some of them have been mentioned in Table 3.

Moreover, livestock waste is a source of nitrous oxide and methane release. In this study, the amount of nitrogen was calculated using Eq. (6) (Hollmann et al., 2008).

$$N_E = DMI \times dietaryCP \times 84.1 + BW \times 0.196 \quad (6)$$

where 'N_E' is amount of nitrogen excretion, 'DMI' is weight of feed intake (kg), '*dietary CP*' is a dietary protein, and 'BW' is weight of the cow (kg). The role of dietary protein in the nutrition of the dairy cow and overall farm sustainability can be summarized as follows: (1) effects on dry matter intake (DMI), milk yield, and milk composition, (2) effects on feed costs, (3) environmental effects, and (4) possible effects on reproduction efficiency. Feeding diets with lowered protein content reduce nitrogen input, improve nitrogen utilization efficiency, and reduce nitrogen losses from manure. Reducing dietary protein also benefits the producer by reducing feed cost and improving overall farm profitability. There are many examples where decreasing protein concentration in dairy diets dramatically decreased manure nitrogen losses without affecting animal production. These interventions, however, have to be balanced with the risk of loss in milk production. If the true animal requirements for metabolizable protein are not met, long-term production cannot be sustained. Dietary protein should not be reduced in diets that do not meet the requirements of the animal for other nutrients, particularly energy (Hristov and Giallongo, 2014).

Nitrogen oxide levels are made from accumulation of manure nitrogen is 2% amount of nitrogen excretion (IPCC, 2003).

Table 3 Estimate equations of the methane and nitrogen output of cow.

Equation predicting	References
26.49 DMI + 1.64	Mc Court et al. (2006)
0.26 LW + 52.76	
$6.14\ e^{0.0049Lw}$	Jiao et al. (2014)
22.1 DMI + 9.6	

LW: Live weight of cow.
DMI: Weight of feed intake.

As well as methane emissions from manure are considered 0.03 amount of methane emissions from enteric fermentation per head of cattle (Herrero et al., 2008). Sum of the amount of GHG emissions from various sectors of dairy farms was calculated as the amount of total GHG emissions, ultimately.

2.3. Data envelopment analysis

DEA is chosen for the analysis of the dataset of this study as an analytical tool. As mentioned, DEA is a nonparametric method of measuring the efficiency of DMUs that were introduced by Charnes, Cooper, and Rhodes (CCR) for the first time. The original CCR model was applicable on the assumption of constant returns to scale (CRS) (Charnes et al., 1978). Considering the CCR approach which is engaged with constant returns to scale, the efficiency frontier is a straight line intersecting the point of origin and the best performer(s). Diagram CCR model is shown in Fig. 1.

The best performer is determined by the highest ratio of output to input. In Fig. 1, P_2 has this condition. Therefore it is considered as the reference DMU to all other units.

Banker et al. (1984) developed CCR model by introducing the so-called "convexity constraint" which changed the efficiency frontier from being a straight line to a convex hull. The new model called BCC model was built based on variable returns to scale (VRS). This model has two advantages over the CCR model. Firstly more units could be considered being efficient and secondly inefficient units were now compared to more appropriate peers. In Fig. 2 diagram BCC model is shown with same DMUs as used for the CCR model (Fig. 1). As seen in using BCC model, more number of units are efficient (P_1, P_2, P_3 and P_4).

These models provide opportunities to investigate technical and pure technical efficiencies of various units under investigation.

2.4. Technical efficiency

Technical efficiency (TE) represents the ability of a DMU for producing maximum output due to the set of inputs and technology (output-oriented) or achieving minimizing inputs while maintaining the same level of outputs, (input-oriented) (Farrell, 1957). TE can be calculated by the ratio of sum of weighted outputs to sum of weighted inputs (Cooper et al., 2006).

$$TE_j = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \quad (7)$$

where u_r is the weight given to output n, y_r is the amount of output n, vs is the weight given to input n, x_s is the amount of input n, r, is number of outputs ($r = 1, 2, \ldots, n$), s is number of inputs ($s = 1, 2, \ldots, m$) and j represents jth of DMUs ($j = 1, 2, \ldots, k$). In solving an optimization problem, each DMU sets its own weights to maximize its efficiency subject to the condition that all efficiencies of other DMUs remain less than or equal to 1 and the values of the weights are greater than or equal to 0 (Gelan and Muriithi, 2010).

2.5. Pure technical efficiency

Pure technical efficiency (PTE) is TE of BCC model. It can be defined by Dual Linear Program (DLP) as follows (Mobtaker et al., 2013):

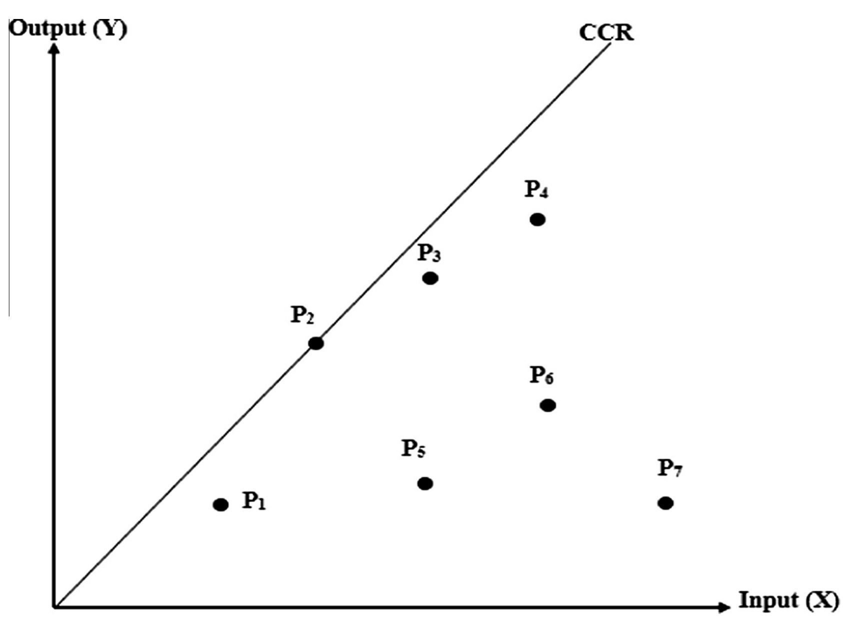

Figure 1 Efficiency frontier of the CCR model.

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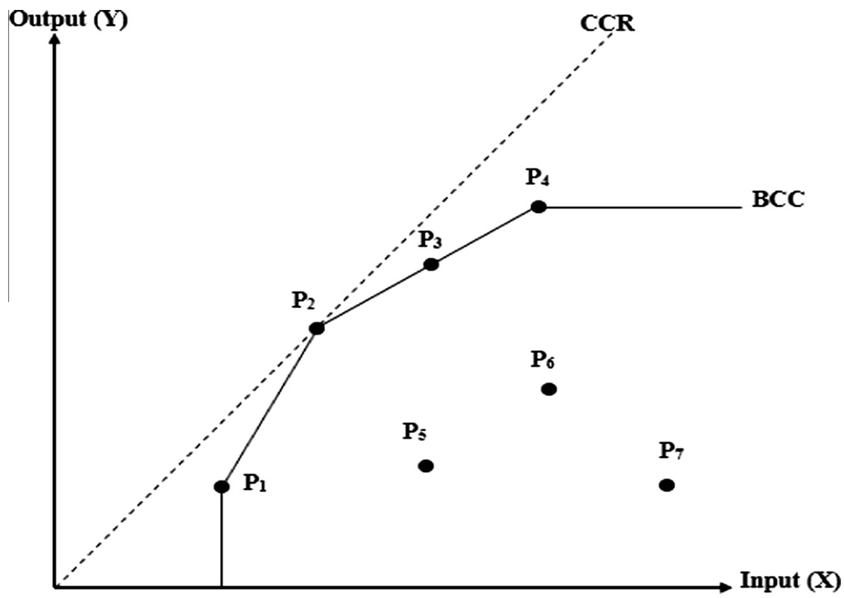

Figure 2 Efficiency frontier of the BCC model.

$$\begin{aligned} &Maximize \quad z = uy_i - u_i \\ &Subjected\ to \quad vx_i = 1 \\ &-vX + uY - u_oe \leqslant 0 \\ &v \geqslant 0,\ u \geqslant 0\ and\ u_o\ free\ in\ sing \end{aligned} \tag{8}$$

where 'z' and 'u_o' are scalar and 'free in sign', 'u' and 'v' are output and input weight matrixes and 'Y' and 'X' are corresponding output and input matrixes, respectively. The letters 'x_j' and 'y_j' refer to the inputs and output of jth DMU.

2.6. Scale efficiency

Scale efficiency (SE) shows the effect of DMU size on efficiency of system. In other words, it indicates that some part of inefficiency refers to inappropriate size of DMU, and if DMU moved toward the best size the overall efficiency (technical) can be improved at the same level of technologies (inputs) (Ajabshirchi, 2013). The relationship among the SE, TE and PTE can be expressed as follows (Abdi et al., 2013):

$$\text{Scale efficiency} = \frac{\text{Technical efficiency}}{\text{Pure technical efficiency}} \tag{9}$$

In the analysis of efficient and inefficient DMUs the energy-saving target ratio (ESTR) index can be used, which reflects the inefficiency level for each DMU with respect to energy consumption. The Equation is as follows (Hu and Kao, 2007):

$$\text{ESTR} = \frac{(\text{Energy Saving Target})}{(\text{Actual Energy Input})} \tag{10}$$

where the energy-saving target is the total reducing amount of input that could be saved without decreasing the output level.

Also, in order to determine the energy efficiency of the DMUs was applied the software of Efficiency Measurement Systems (EMS), Version 1.3. Using EMS software were built two models CCR and BCC. To find the most efficient units, they should be ranked according to the number of referrals to inefficient units. The benchmark ranking method is the most prevalent technique in DEA studies; therefore it was used in the present study.

3. Results and discussion

3.1. Energy use pattern

Amount of energy inputs and outputs of dairy farms is given in Table 4. Considering the results, the total energy consumed for one year was 147,659 (MJ cow^{-1}) that feed with the average energy 135,079 (MJ cow^{-1}) and 91.48% of total consumable energy has the highest energy consumption. Fossil fuels and electricity were dimensionally placed with the average energy of 9405 and 2056 (MJ cow^{-1}), respectively. In a similar study conducted the total fossil fuels and electricity consumption in dairy farm were estimated as 7824 and 1699 (MJ cow^{-1}) (Sefeedpari et al., 2014). As well as, based on the results direct and indirect energies used were calculated as 11,973 (8.11%) and 135,686 (91.89%) (MJ cow^{-1}) for dairy farms, respectively. Share of renewable energy was computed as 135,590 (91.82%) (MJ cow^{-1}). Sefeedpari (2012) calculated the amount of renewable energy as 52.86% in dairy farms. Considering the in dairy farms studied, fossil fuels and electricity were used as power for running the equipment of dairy farms as milking machines, cooling, feed processing, heating and cow manure gathering from the farm surface and transportation, etc., and for improving the sustainability in production and reduction of fossil fuels consumption and GHG emissions, the use of renewable energy resources such as solar energy or biogas is essential in dairy farms. Replacing renewable energy sources instead of fossil fuels and electricity will increase energy efficiency.

The amount of output energy was calculated as 23,642 (MJ cow^{-1}) that 91.36% of the energy of production was related to milk. 5.62% and 3.02% were related to meat and manure, respectively.

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Table 4 Amounts of energy inputs and output for dairy farms.

Items	Total energy equivalent (MJ cow^{-1})	SD	Max	Min	Percentages (%)
A. Inputs					
Tractor and implement and machinery (kg a)	606.9	251.3	1684	211.2	0.41
Fossil fuels (l)	9405	3711	19,098	2588	6.37
Electricity (kW h)	2056	1195	3886	666	1.39
Human labor (h)	511.4	157.3	915.7	264.9	0.35
Feed	135,079	15,423	169,673	105,723	91.48
B. Outputs					
Milk (kg)	21,600	2552	25,185	14,078	91.36
Meat (kg)	1328	220.7	1842	888.7	5.62
Cow manure (kg dry matter)	713.5	227.7	1527	312.8	3.02

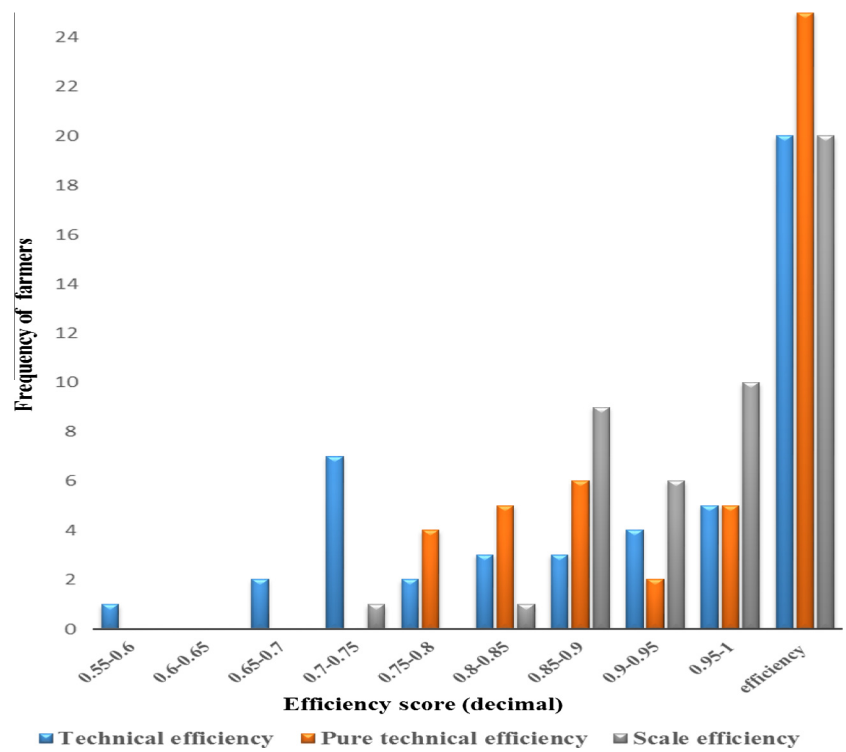

Figure 3 Efficiency score distribution of dairy farms.

3.2. Identifying efficient and inefficient farmers

The results of CCR model of DEA showed that from total of 47 farmers, 20 farms were efficient than other farms that these results show that 42.55% of farms in energy consumption, manage and choose a scale have acted correctly. TEs of DMUs evaluated using the CCR model were 0.578–1 with the standard deviation of 0.121 for DMUs. The average of TE for inefficient units (27 DMUs) was 0.826 that it shows, and inefficient DMUs can reach to efficiency without changes in yield with decrease in 17.4% of inputs.

Based on the BCC model were efficient 25 farms. DMUs (3, 14, 18, 25, 35) were inefficient when using CCR model but they are efficient when using BCC model, meaning that these DMUs have acted effectively in terms of management of farm because of their inefficiency return to the wrong scale of farm.

Table 5 Average technical, pure and scale efficiency of dairy farms (47 DMUs).

Particular	Average	SD	Min	Max
Technical efficiency	0.9	0.121	0.578	1
Pure technical efficiency	0.94	0.079	0.756	1
Scale efficiency	0.953	0.063	0.71	1

Using the BCC model was evaluated PTE. The range of PTE was from 0.756 to 1. Most of the differences in the TE and PTE of the DMU 43 (40.69%) that it shows and DMU 43 has chosen wrong scale for itself with regard to energy consumption. The distribution of efficiency scores (TE, PTE and SE) of farmers is shown in Fig. 3. As seen in Fig. 3, technically

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Table 6 Results of technical efficiency analysis.

DMU	TE score	Frequency in referent set	Benchmarks
1	0.696		7 (0.52) 37 (0.18) 42 (0.14)
2	0.951		8 (0.02) 24 (0.91) 28 (0.06)
3	0.983		24 (0.58) 38 (0.10) 45 (0.23)
4	0.843		7 (0.25) 8 (0.02) 24 (0.52) 28 (0.01) 37 (0.14)
5	1.000	4	
6	0.957		28 (0.27) 37 (0.13) 38 (0.55)
7	1.000	11	
8	1.000	6	
9	0.852		24 (0.43) 28 (0.44) 38 (0.10) 45 (0.04)
10	0.834		24 (0.37) 28 (0.12) 38 (0.26) 45 (0.23)
11	0.929		8 (0.37) 24 (0.04) 28 (0.39) 37 (0.17)
12	1.000	3	
13	1.000	0	
14	0.936		28 (0.84) 38 (0.07) 45 (0.11)
15	0.743		8 (0.01) 24 (0.40) 28 (0.41)
16	1.000	1	
17	0.819		24 (0.52) 26 (0.10) 37 (0.07) 39 (0.19)
18	0.873		16 (0.10) 28 (0.09) 45 (0.66)
19	1.000	0	
20	1.000	1	
21	0.789		7 (0.16) 24 (0.15) 37 (0.08) 42 (0.48)
22	0.789		24 (0.27) 38 (0.54) 45 (0.07)
23	0.744		7 (0.03) 24 (0.61) 38 (0.04) 42 (0.15)
24	1.000	14	
25	0.934		12 (0.06) 24 (0.19) 28 (0.30) 38 (0.15) 39 (0.14)
26	1.000	1	
27	1.000	0	
28	1.000	13	
29	0.982		28 (0.68) 37 (0.28)
30	0.748		7 (0.08) 12 (0.01) 24 (0.25) 37 (0.62) 42 (0.06)
31	0.711		7 (0.50) 37 (0.27)
32	0.703		7 (0.12) 8 (0.14) 37 (0.25) 38 (0.33)
33	0.746		8 (0.34) 38 (0.49)
34	0.672		5 (0.08) 7 (0.30) 37 (0.05) 38 (0.41)
35	0.957		5 (0.56) 44 (0.33)
36	0.716		5 (0.24) 7 (0.59) 37 (0.02)
37	1.000	15	
38	1.000	13	
39	1.000	3	
40	0.886		20 (0.14) 28 (0.24) 37 (0.20) 38 (0.41) 39 (0.04)
41	1.000	0	
42	1.000	4	
43	0.578		5 (0.04) 7 (0.09) 24 (0.43) 37 (0.06) 38 (0.06)
44	1.000	1	
45	1.000	6	
46	0.938		7 (0.09) 12 (0.11) 28 (0.36) 37 (0.37)
47	1.000	0	

Table 7 Optimum energy requirement and saving energy for dairy farms.

Inputs	Optimum energy requirement (MJ cow^{-1})	Saving energy (MJ cow^{-1})	Saving energy (%)	Contribution to the total savings energy (%)
1. Tractor and implement and machinery (kg a)	460.7	146.1	24.08	0.83
2. Fossil fuels (l)	7420	1984	21.09	11.19
3. Electricity (kW h)	1675	380.5	18.50	2.15
4. Human labor (h)	441.9	69.5	13.59	0.39
5. Feed (kg)	119,933	15,146	11.21	85.44
Total energy required	129,932	17,726	12	100

and pure technically inefficient farms with the score range of 0.95–1, were 5 and 5 of overall farmers, respectively. These amounts for the range of 0.9–0.95 were 4 and 2 of farmers, respectively. These DMUs have the high potential to achieve efficiency.

The summary statistics for the three estimated measures of efficiency are shown in Table 5. The results revealed that on average, the technical, pure technical and scale efficiency scores were 0.9, 0.94 and 0.953, respectively. In another study on dairy farms, TE, PTE and SE of farmers were calculated as 0.88, 0.93 and 0.95, respectively (Sefeedpari, 2012). Given that the average scale efficiency was 0.953, it can be said that in the study area, units have good size.

3.3. Benchmarking

DEA selects the DMU with the highest efficiency as reference and weighs other DMUs with it. The DEA has proven to be a powerful tool for performance evaluation and benchmarking so that organization or companies' operations can be improved. Benchmarking is "a process of measuring and comparing to identify ways to improve processes and achieve higher performance" (Keehley, 1997). In this study, benchmarking approach was applied to rank efficient dairy farms. This was done with respect to the number of times an efficient DMU appears in a referent set (Mousavi-Avval et al., 2011b, c). In Table 6 is given the performance ranking of the 47 DMUs using benchmarking approach. As shown in Table 6, DMU 37 appeared in the benchmark referent set of most inefficient DMUs (as highlighted in the column of benchmarks). So, DMU 37 with 15 repetitions was introduced in the top ranking. In other words Inefficient DMUs select DMU 37 and/or combination of DMU 37 and other efficient DMUs as the best reference DMUs for modeling in energy consumption.

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Table 8 The source wise actual and target energy use for inefficient units in the dairy farms (based on CCR model).

DMU	TE[a]	Actual energy use (MJ cow^{-1})					Optimum energy requirement (MJ cow^{-1})					ESTR (%)
		Fossil fuels	Human labor	Machinery	Electricity	Feed	Fossil fuels	Human labor	Machinery	Electricity	Feed	
1	0.696	15,497	915.7	783.3	3109	134,958	6088	417.8	542.9	2188	95,105	32.79
2	0.951	9931	349.8	921.4	1901	123,006	9497	345.7	373.2	1466	116,202	6.04
3	0.983	8230	443	448.3	1337	116,289	7986	341.5	366.5	1300	113,022	2.94
4	0.843	9813	440.2	846.7	2391	130,400	8296	373.2	468.4	1880	110,138	15.79
6	0.957	9090	447.1	539.3	1943	131,461	5781	424.3	489.7	1467	124,568	7.49
9	0.852	7966	392	640.2	1774	157,715	6738	949.9	508.2	1504	133,876	14.78
10	0.834	9380	461.5	530.4	1671	163,072	7462	386.3	443	1397	126,027	22.49
11	0.929	17,428	352.1	681.1	2391	139,806	7166	330.7	636.4	1630	131,037	12.36
14	0.936	4661	502	786.9	1636	160,466	4470	299.6	614.1	1588	150,995	6
15	0.743	8629	333.8	813.9	1684.	146,540	5478	248.4	419.7	1238	109,149	26.24
17	0.819	9902	511	361.8	1850	133,105	7855	403.8	297	1516	53,781	56.18
18	0.873	6708	378.3	491.6	1284	141,734	5860	329.3	410.4	1125	124,168	12.41
21	0.789	9256	572.3	532.6	2419	121,931	5960	452.3	422.7	1638	96,166	22.32
22	0.789	8640	627.5	826.4	1591	137,227	6756	404.9	393.6	1245	107,283	22.04
23	0.744	9692	715.4	794.2	1727	127,351	5135	344.6	400.7	1358	108,219	17.69
25	0.934	5438	379.3	451.2	1570	121,287	5072	352.4	348	1374	113,209	6.79
29	0.982	10,944	317.9	604	1727	148,676	4862	314.3	542.8	1658	138,883	9.86
30	0.748	11,454	610.4	1684	2764	169,673	8638	459.9	426.9	2084	127,584	25.23
31	0.711	15,947	715.4	910.6	3886	126,286	6658	487	337.6	1369	91,486	32.08
32	0.703	14,539	572.3	806.7	3238	147,665	6405	446.7	423.2	1618	101,841	33.62
33	0.746	12,923	508.7	823.8	3454	135,496	6880	380.4	519.6	1234	101,425	27.91
34	0.672	9656	701.3	746.4	2540	144,658	6055	440.8	493.9	1713	98,011	32.58
35	0.957	8308	817.6	379.6	2961	109,969	7444	652.4	362.6	1896	105,159	5.65
36	0.716	12,757	715.4	849.4	3109	130,359	6552	462.6	588.9	2201	93,473	30.11
40	0.886	7006	689.5	564.8	1872	157,279	6203	462.9	500.9	1661	139,556	11.36
43	0.578	10,457	562.9	519.5	2123	136,767	6084	278.4	302.1	1186	79,504	41.92
46	0.938	5795	381.5	689	2303	136,346	5400	356.3	524.3	1833	127,786	6.6
Ave	0.826	10,001	533.8	704.7	2231	138,130	6547	412.8	450.2	1569	111,764	20.04
SD	0.111	3182	160.8	257	693.3	14,821	1211	134.1	91.43	296.8	20,669	13.05

[a] Technical Efficiency (TE).

Table 9 Improvement of energy indices for dairy farms.

Items	Unit	Present quantity	Optimum quantity	Difference (%)
Energy use efficiency	–	0.157	0.178	12
Energy productivity	kg MJ^{-1}	0.054	0.061	12
Specific energy	MJ kg^{-1}	18.45	16.24	–13.64
Net energy	MJ cow^{-1}	−124,509	−106,783	16.6
Direct energy	MJ cow^{-1}	11,973 (8.11%)[a]	9538 (7.34%)	−25.52
Indirect energy	MJ cow^{-1}	135,686 (91.89%)	120,393 (92.64%)	−12.70
Renewable energy	MJ cow^{-1}	135,590 (91.82%)	120,375 (92.65%)	−12.87
Non-renewable energy	MJ cow^{-1}	12,068 (8.18%)	9557 (7.35%)	−23.31
Total energy input	MJ cow^{-1}	147,659 (100%)	129,932 (100%)	−12

[a] Numbers in parentheses indicate percentage of total optimum energy requirement.

In other words inefficient DMU follows the DMU 37 and other efficient DMUs as a benchmark. For example, the benchmark DMUs for DMU 29 are expressed as 28 (0.68) and 37 (0.28), where 28 and 37 are the DMU numbers and the amounts between brackets are the intensity vector λ for the respective DMUs. Finally, using efficient farmers as benchmarks, inefficient farms identify the reasons for inefficiency and then they can find ways for improving production processes and reducing energy consumption.

3.4. Optimum energy requirement and saving energy

The saving energy and optimum energy of dairy farms using CCR model are given in Table 7. According to the results obtained, total optimum energy requirement in dairy farms is 129,932 (MJ cow^{-1}). The percentage of energy saving target ratio in total optimum energy was calculated as 12%. As shown in Table 7, the highest percentage of ESTR belonged to machinery with 24.08%, followed by fossil fuels with

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Table 10 GHG emissions based on present and target energy use.

Inputs	Present GHG emissions ($kgCO_{2eq.}$ cow^{-1}) (C)	Target GHG emissions ($kgCO_{2eq.}$ cow^{-1}) (D)	GHG emissions reduction (C-D)	Difference (%) (D–C) * 100/D
1. Fossil fuels	414.7	327.3	87.4	−26.70
2. Electricity	103.3	84.24	19.06	−22.70
3. Machinery	43.09	32.71	10.38	−31.72
4. Manure	469.5	417	52.5	−12.56
5. Enteric fermentation	4362	3876	486	−12.53
Total GHG emissions	5393	4738	655	−13.82

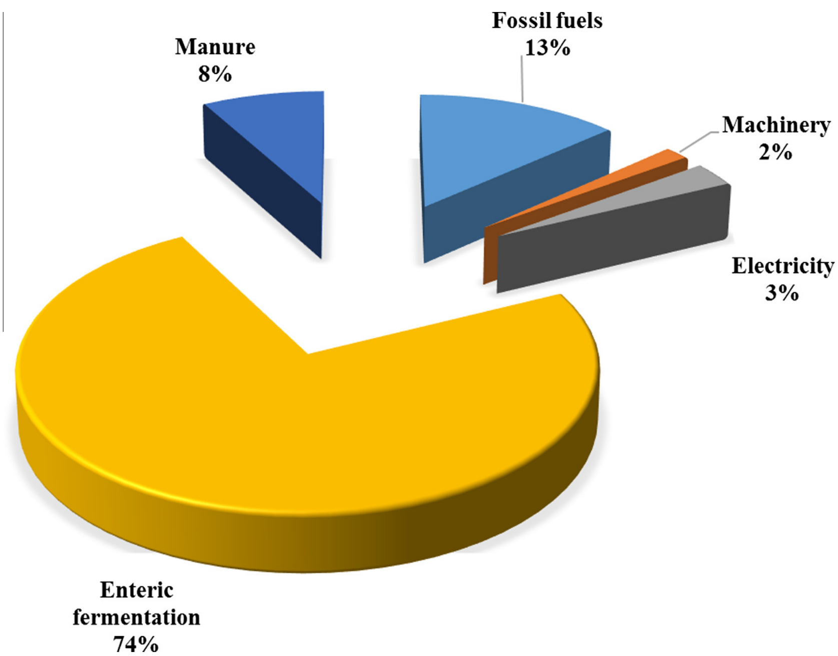

Figure 4 Total potential reduction of GHG emissions for dairy farms.

21.09% and electricity with 18.5%. On the other hand, the highest contribution to the total savings energy related to feed with 85.44% followed by fossil fuels and electricity with 11.19% and 2.14%, respectively. In similar study Sefeedpari (2012) reported the saving energy by the DEA approach was about 12,234 MJ cow^{-1} for dairy farms. So, she reported. Feed (46%) and electricity (36%) had highest contribution to the total saving energy in dairy farms.

The major reasons for high consumption of energy can be attributed to the lack of enough information for farmers, unawareness of correct diet formulation and existence of some wrong beliefs among farmers that feeding more will result in better yield, lack of programs to educate farmers, inappropriate plan of buildings and corrals and finally use of depreciated and energy-intensive equipment and machinery. Alleviating the problems mentioned can save energy consumption without reducing the yield, greatly.

In Table 8 are given the actual energy consumption and target energy consumption for inefficient DMUs by using the model CCR. ESTR was calculated between 2.94% and 56.18% that most of it is for DMU 17 with the score of efficiency of 0.819 and least of it is for DMU 3 with the score of efficiency of 0.983.

3.5. Improvements of energy indices

In Table 9 are shown energy indices calculated for dairy farms with actual and target energy consumption. Based on results, energy use efficiency for present and target use of energy was calculated as 0.157 and 0.178, respectively that it represents an improvement of 12 percent of this index. Energy productivity, specific energy and net energy were computed as 0.061 (kg MJ^{-1}), 16.24 (MJ kg^{-1}) and −106,783 (MJ cow^{-1}) for target utilization of energy, respectively. The results show that compared with current energy consumption, these energy indices can be improved by 12%, −13.64%, and 16.6% using target energy consumption presented by the DEA method, respectively. With the consumption of optimal energy are reduced energy percentages for direct, indirect, renewable and non-renewable energies 25.52%, 12.7%, 12.87% and

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23.31%, respectively. So, applying the DEA method for energy optimization can save the non-renewable resources for dairy farms. In a similar study using DEA, level improving indices of energy in agricultural production is obtained. For example Nabavi-Pelesaraei et al. (2014c) reported the energy use efficiency, energy productivity, specific energy are improved as 14.7%, 14.4% and 12.6%, by optimization of energy inputs in orange production with DEA. Also, Pahlavan et al. (2012) determined amount of improved energy use efficiency for rose production 77.29%. Mousavi-Avval et al. (2011a) showed that by optimization of energy consumption, energy efficiency, energy productivity and net energy in comparison with the actual energy use can be increased by 12.93%, 12.44% and 68.57%, respectively in apple production.

3.6. Decrease of GHG emissions

In the last step of this study were examined GHG emissions of dairy farms based on present and the target energy consumption. Amount of GHG emissions from the dairy farm was estimated in two parts. In the first part amount of GHG emissions result to biological activity livestock was determined. The methane released from enteric fermentation was estimated as 174.5 kg for per head of cow in a year. This amount of methane is equivalent 4362 $kgCO_{2eq}$. for per head of cow.

In research in China was estimated amount of methane output from enteric fermentation of dairy cow using the IPCC guidelines 100 and 102.2 kg for each year (Xue et al., 2014). In another study for dairy cow was estimated methane output between 80 and 175 kg per year in dairies of Australia (Gollnow et al., 2014). Nitrogen oxide released from the accumulation of manure was calculated as 1.13 kg of equivalents 338.62 kg carbon dioxide. Also manure caused the release of 5.23 kg of methane equivalent to 130.8 kg of carbon dioxide per head of cow during the period.

In the second part was estimated the amount of GHG emissions resulting from combustion of fossil fuels, generation of electricity and machinery which were produced in dairy farms. The total GHG emissions were calculated 444.2 ($kgCO_{2eq}$. cow^{-1} $year^{-1}$). In Table 10 are shown the total GHG emissions based on present and the target energy consumption. As can be seen the use of optimum energy will be reduced 655 $kgCO_{2eq}$. GHG emissions per head of cow that it will be achieved with the converter inefficient to efficient DMUs.

As seen in Table 10, largest percentage difference between present and the target GHG emissions belonged to the equipment and machinery use (31.72%), but the enteric fermentation had the highest potential to reduction of total GHG emissions with 74%, followed by fossil fuels (with 13%) and manure (with 8%). The share of each input in potential of GHG emissions reduction is shown in Fig. 4.

Using techniques DEA estimated the reduction of GHG emissions in extensive research in the field of agriculture. For example, Nabavi-Pelesaraei et al. (2014b) have shown that if all inefficient DMUs use inputs based on the efficient farms pattern which was determined by the DEA approach, total GHG emissions can be reduced by 371 $kgCO_{2eq}$. ha^{-1} in watermelon production. So, amount of reduction of GHG emissions in the orange production was calculated 184 $kgCO_{2eq}$. ha^{-1} (Nabavi-Pelesaraei et al., 2014c).

Finally, it can be said non-parametric method of DEA is a useful instrument to identify efficient and inefficient farms and it helps inefficient farmers that they can find reasons of inefficiency and reduced excess consumption of their DMU for avoiding wasting money and energy.

4. Conclusions

The main aim of this study was the optimization of energy consumption for increase of energy efficiency and reduction of GHG emissions in dairy farms by using DEA methods in the Qazvin city of Iran. In the present study, the total average energies of input and output were calculated as 147,659 (MJ cow^{-1}) and 23,149 (MJ cow^{-1}), respectively. Feed and fossil fuels had the largest share with 91.48% and 6.37%, respectively in energy use. The total of 47 dairy farms considered for the analysis, 42.55% and 53.19% were efficient based on CCR and BCC models, respectively. The average amount of technical, pure technical and scale efficiency scores of farms was calculated as 0.9, 0.94 and 0.953, respectively. The optimum energy requirement was estimated 129,932 (MJ cow^{-1}) based on the results of CCR model that had a decrease of 12 percent compared to present energy consumption that highest share of total saving energy belonged to feed with 85.44%. In this study, the total GHG emissions of present and target were computed about 5393 and 4738 ($kgCO_{2eq}$. cow^{-1} $year^{-1}$), respectively. So, GHG emissions can be reduced to the value of 655 ($kgCO_{2eq}$. cow^{-1} $year^{-1}$) with optimum energy consumption. The highest share of reducing GHG emissions related to enteric fermentation (74%) has directly related with feed intake. Given a significant amount of reduced energy consumption of dairy farming, it is necessary to use evolutionary algorithms such as genetic algorithms for optimization milk production in the study area. Genetic algorithms belong to the larger class of evolutionary algorithms which generate solutions to optimization problems using techniques inspired by natural evolution. At the end the optimal energy is estimated using a variety of methods and best pattern use to be introduced to dairy farmers. Finally it can be said optimization of energy consumption can help the farmers for achieving sustainable agriculture with reduction of fossil fuels and electricity and GHG emissions. Also optimization of energy consumption has led to falling prices of the product.

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