Iranian Journal of Applied Animal Science

# Optimization of Energy Consumption in Milk Production Units through Integration of Data Envelopment Analysis Approach and Sensitivity Analysis

Research Article

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Received on: 5 Feb 2015
Revised on: 27 Apr 2015
Accepted on: 15 May 2015
Online Published on: Mar 2016

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Online version is available on: www.ijas.ir

## ABSTRACT

The aims of this study were to evaluate the energy consumption and its modeling in industrial milk production units using data envelopment analysis (DEA) approach and sensitivity analysis. Data were collected from 44 industrial milk production units in Guilan province of Iran with face to face questionnaire method during 2012-2013. Inputs included animal feed, fossil fuels, electricity, machinery and human labor and output was milk yield. The results highlighted that the highest share of energy consumption belonged to the animal feed (82%) followed by fossil fuels (13%). The results of DEA application revealed that the technical efficiency (TE) was 44.6%, pure technical efficiency (PTE) was 74.48% and scale efficiency (SE) was 0.53 for the investigated units. The results of variable returns to scale (VRS) illustrated that out of 44 producers considered for the analysis, 15 units were purely technically efficient in energy consumption from the different sources. The greatest potential inputs for saving energy were related to animal feed and diesel fuel, respectively. About 3852.39 MJ (47.74% of total energy input) could be saved without reducing the milk yield through following recommendations resulted from this study. Moreover, sensitivity analysis results showed that with one MJ extra use of human labor, fossil fuels and animal feed energy, it would lead to an additional increase in yield by 3.14, 1.36 and 0.95 kg, respectively. Also, one MJ extra energy use for either electricity or machinery result in a decrease in milk yield by 1.03 and 7.16 kg, respectively.

KEY WORDS efficiency, energy modeling, milk production, sensitivity analysis.

## INTRODUCTION

According to the predictions, the world's population will rise to 9.5 billion in 2050 (Rahimizadeh *et al.* 2008). As a result of the increase in world population and increasing demand for food, exploitation of energy resources is growing (Rahimizadeh *et al.* 2008; Kraatz, 2012). In addition, the estimated world fossil fuel reserve depletion times for oil, gas and coal are 2044, 2046 and 2116, respectively (Shafiee and Topal, 2009). However, the indiscriminate use of fossil energy sources will have lasting adverse effects on the environment (Pishgar-Komleh *et al.* 2013). However, the agricultural sector to provide adequate food for the growing population, it is dependent on non-renewable energy sources such as fossil fuels (Bakhoda *et al.* 2012; Nikkhah *et al.* 2015; Khojastehpour *et al.* 2015). On the other hand, it should not be ignored that agricultural sector is both a producer and consumer of energy as well as it can increase or reduce the environmental impacts (Liu *et al.* 2010; Najafi *et al.* 2011; Royan *et al.* 2012; Mohammadi *et* al. 2013; Rajaeifar et al. 2014). The livestock industry is identified as one of the most important sources of protein and food supply for a growing population. The milk production of Iran in 2000 was about 5 million tonnes that up to 2012 reached over 10 million tonnes (FAO, 2012). In recent years, there has been a special attention devoted to the importance of energy consumption in livestock sector. This part has received a relatively high share of energy consumption for raw milk and animal feed preparation processing compared to the other agricultural substructures (O'Mara, 2011; Gerber et al. 2011).

There are some studies on the energy analysis of dairy farms. Maysami et al. (2013) analyzed the energy consumption of dairy farms in northern west of Iran and announced that the total energy input was 5800 MJ per ton of milk and energy use efficiency was 2.6. However, they did not consider the modelling and optimization of energy. Sefeed Pari et al. (2012) studied energy indices and greenhouse gas emissions on dairy farms in Tehran province of Iran. They claimed that the total of energy inputs and energy efficiency per ton of milk were 7809 MJ and 1.15, respectively. Divya et al. (2012) explored energy use pattern of dairy farms in India. They showed that the energy efficiency was 0.04 and the total energy inputs were equal to 9189.30 MJ per ton of milk. They claimed that the animal feed and human labor contributed most to energy consumption.

The literature review illustrated that many researchers have reported the valuable application of data envelopment analysis ((DEA) approach in energy management of agricultural production (Mohammadi et al. 2013; Mousavi-Avval et al. 2011; Pahlavan et al. 2012). The DEA approach was used to the optimization of energy for milk production in Greece. Energy use efficiency was reported 0.30 MJ per liter. The results of variable returns to scale (VRS) illustrated that from the total of 165 producers, 17 units were purely technically efficient in energy consumption (Theodoridis and Psychoudakis, 2005). In a similar study on the optimization of energy inputs of Australian dairy units, the results showed that from the total of 60 farms, 51 farms were purely technically efficient (Carter, 2000). Other investigations to determine the energy use pattern of dairy farms has been carried out in worldwide (Zucchetto and Bickle, 1984; Stokes et al. 2007; Veysset et al. 2010; Brinker and Laurent, 2011).

A literature review showed that there is a high amount of energy in milk production. While researches who evaluated energy pattern in milk production units have reproted a degree of inefficiency, the authors could not find any documented publication on optimization of energy inputs for milk production using DEA approach and sensitivity analysis. Therefore, the aim of this study is to optimize the use of energy inputs for milk production in Guilan province of Iran through integration DEA approach and sensitivity analysis model.

## MATERIALS AND METHODS

### Studied location and survey

This study was carried out on industrial dairy farms of Guilan during agricultural year of 2012-2013. Guilan is located in the north of Iran on the south of Caspian Sea, within 36˚ 34′ and 38˚ 27′ north latitude and 48˚ 53′ and 50˚ 34′ east longitude. Guilan province covers an area of 14711 $km^2$, and has a population of about 2.5 million people (Statistical Centre of Iran, 2014). In order to calculate energy optimization and sensitivity analysis, frontier analyst 4.2 and JMP8 software were used. There were 180 industrial farms of cow breeding in Guilan at the time of the study, 129 of them were dairy farms. Due to high prices of inputs such as animal feed, many production units were inactive. This study ranged from 20 to 200 cow heads with the average of 54.5 heads. Hence, 44 active farms were selected that their related information is presented in Table 1. In this study, the inputs included human labor, animal feed, fossil fuels, electricity and machinery and the milk yield served as the output. Energy equivalents are shown in Table 2, were used to estimate the inputs and output energy.

### Sensitivity analysis

In this study, Cobb–Douglas (CD) model was used to determine the effect of energy inputs on milk yield in Guilan province of Iran (Kuswardhani et al. 2013). The general form of the model is presented in equation 1. Taking the logarithm of both sides of the equation and locating five inputs into equation 1, equation comes in the form of equation 3. In this formula $a_0$ and $e_i$ are the constant and coefficient error, respectively. In addition, the returns to scale (RTS) of production was computed. RTS refer to changes in output, subsequent to a proportional change in all inputs (where all inputs increase by a constant factor; Royan et al. 2012).

$$y = f(x)\exp(u)$$

$$Lny_i = a_0 + \sum_{j=1}^{n} \alpha_j \ln(x_{ij}) + e_i \quad (i=1, 2,\ldots,n)$$

$$Lny_i = a_0 + \alpha_1 lnx_1 + \alpha_2 lnx_2 + \alpha_3 lnx_3 + \alpha_4 lnx_4 + \alpha_5 lnx_5 + e_i$$

In order to determine the sensitivity of energy inputs for milk production marginal physical productivity (MPP) approach was used which shows the change value for an increase unit in one of the energy inputs, if the other factors of production assumed to be constant. The MPP is calculated by the equation 4:

$MPP_{xj}$= ((GM(Y)/GM($X_{ij}$)) × $\alpha_{ij}$

Where:
$MPP_{xj}$: marginal physical productivity per unit of $J^{th}$ inputs.
$\alpha_{ij}$: input regression coefficient.
GM (Y): geometric mean of per ton of milk production.
GM ($X_{ij}$): geometric mean of energy input (Royan *et al.* 2012).

**Table 1** Characteristics of industrial dairy farms in Guilan province, Iran

| Subject | Characteristics |
|---|---|
| Race | Holstein |
| Average number of dairy cow | 54.55 |
| Breeding period (days) | 305 days of lactation<br>60 day dry period |
| Average yield (kg per day) | 23.27 (per cow) |
| Average feed (kg dry matter per day) | 31.80 (during lactation)<br>12.69 (during dry) |

**Data envelopment analysis (DEA)**

To evaluate the efficiency of dairy farms, there are two approaches which can be divided into parametric and non-parametric methods. In the parametric approach, through using statistical and econometric methods, the production function is estimated and then by using this function, efficiency of units is calculated.

The second group includes nonparametric methods which do not require the methods of mathematical functions distribution. One of the most important non-parametric models is the DEA approach, which is a linear programming model that measures the relative efficiency of decision making units (DMU) (Charnes *et al.* 1984). The DEA approach has different models, but the most significant of which is as follows:

**Constant returns to scale (CRS)**

The CRS approach is the first model of DEA approach proposed by Charnes *et al.* (1984). In this model, when a unit changes in the inputs, outputs are altered with a fixed ratio (increasing or decreasing), thus this model is called the constant return to scale.

For example, if the inputs are doubled, the outputs are doubled consequently. Provided that the outputs have a more than double increase and less than double increase, it is assumed that their efficiency would be increased and decreased, respectively.

The slope of the production function is constant in this model (Charnes *et al.* 1984). The details of the model presented in the equation 5.

$$\text{Max } E_p = \sum_{r=1}^{r=s} U_r Y_{rp}$$

$$\sum_{t=1}^{t=m} V_i X_{pi=1}$$

$$\sum_{r=1}^{r=s} U_r Y_{rp} - \sum_{i=1}^{i=m} V_i X_{ij} \leq 0, j= 1, 2,\dots,n,$$

$$V_i \geq \varepsilon, U_r \geq \varepsilon$$

Where:
$E_p$: efficiency rate of the $i^{th}$.
$U_r$: inputs weight.
$Y_{rp}$: output value $r^{th}$ for $DMU_p$.
$V_i$: output weight.
$X_{ip}$: input value $i^{th}$ for DMUp.
$Y_{rj}$: output value $r^{th}$ for $DMU_j$.
$X_{ij}$: input value $i^{th}$ for $DMU_j$.
j= 1, 2,…,n.
s: outputs.
m: inputs.

**Variable return to scale (VRS)**

This model was used when the same scaling, which was more and less than the maximum amount of each observed inputs and outputs, should not be plausible. In this model, with changing a unit in the inputs; the outputs change with different ratios.

These changes can be increasing or decreasing. In this model, the slope of the production function varies (Banker *et al.* 1984). The details of the model presented in the equation 6.

$$\text{Max } E_p = \sum_{r=1}^{r=s} U_r Y_{rp} + w$$

$$\sum_{t=1}^{t=m} V_i X_{pi=1}$$

$$\sum_{r=1}^{r=s} U_r Y_{rp} - \sum_{i=1}^{i=m} V_i X_{ij} + w \leq 0, j= 1, 2,\dots,n,$$

$$V_i \geq \varepsilon, U_r \geq \varepsilon \text{ free}$$

Where:
$E_p$: efficiency rate of the $i^{th}$.
$U_r$: input weight.
$Y_{rp,}$: output value $r^{th}$ for DMUp.
Vi: output weight.
$X_{ip}$: input value $i^{th}$ for $DMU_p$.
$Y_{rj}$: output value $r^{th}$ for $DMU_j$.
$X_{ij}$: Input value i th for $DMU_j$.
j= 1, 2,…,n.
s: outputs.
m: inputs.
w: free indication.

**Table 2** Energy equivalents of inputs and output in industrial milk production in Guilan province, Iran

| Energy inputs | Unit | MJ $Unit^{-1}$ | Reference |
|---|---|---|---|
| **Human labor** | | | |
| Machinery and instruments | hr | 1.96 | (Kraatz, 2012) |
| Tractor | kg a | 9-10 | (Kraatz, 2012) |
| Stationary equipment | kg a | 8-10 | (Kraatz, 2012) |
| Other machinery | kg a | 6-8 | (Kraatz, 2012) |
| Electric motor | kg a | 64.8 | (Kraatz, 2012) |
| **Fuels** | | | |
| Diesel | Litr | 47.8 | (Kraatz, 2012) |
| Natural gas | $m^3$ | 49.5 | (Kraatz, 2012) |
| Electricity | kWh | 11.93 | (Divya *et al*. 2012) |
| **Feed** | | | |
| Concentrate | kg.DM | 6.3 | (Sainz, 2003) |
| Silage | kg.DM | 2.2 | (Yaldiz *et al*. 1993) |
| Alfa-alfa | kg.DM | 1.5 | (Shortall and Barnes, 2013) |
| Straw | kg.DM | 12.5 | (Sainz, 2003) |
| Milk | Litr | 3.5 | Average of references |

DM: dry matter.
a: Economic life of machine (year).

### The variety of energy efficiency with DEA approach

Three efficiency types are calculated by using data envelopment namely: TE, PTE and SE. To calculate the TE; the CRS model was used and also to calculate PTE; the VRS model was employed. As shown in equation 7, the SE is obtained by dividing TE by PTE.

Scale efficiency (SE)= TE / PTE

In addition, the actual energy consumption and the optimal energy were obtained using the DEA approach. The two before-mentioned factors were employed to obtain capabilities of saving energy in the industrial dairies in Guilan province. Hence, the percentage of saving energy for each making decision unit (j) was evaluated using the DEA approach in equation 8 (Hu and Kao, 2007).

$ESTR_j$ (%)= (EST/AEI) × 100

Where:
j: decision making unit.
AEI: actual energy consumption.
EST: saving energy.

The EST was obtained from the difference between the actual and optimal energy per unit.

## RESULTS AND DISCUSSION

### The inputs-output energy analysis

The detailed description of energy flow for milk production in Guilan province of Iran is illustrated in Table 3. The total animal feed energy was found to be 6180.08 MJ per ton of milk. The share of animal feed energy use in total energy inputs was 82%.

It indicated that animal feed energy had the most significant contribution in milk production between all inputs. In most studies, for example dairy farms in Tehran, north western provinces of Iran and India, this input has been the most consumed input in terms of energy consumption (Divya *et al*. 2012; Maysami *et al*. 2013).

After the animal feed input, fossil fuels equal to 947.87 MJ per ton of milk were recognized i.e. the second source with high energy consumption, therefore that this input accounted for approximately 13 percent of total energy consumption of milk production in Guilan province of Iran. The value of fuel energy consumption for milk production in Tehran province of Iran was reported 1272.91 MJ.

In this case, the amount of fuel energy consumption for one ton production of milk was less than that of milk production in Tehran province, Iran. The reason was that the dairy farms in Guilan used more vacuum pump dairy with electricity energy instead of fossil fuels (diesel and natural gas).

More fossil fuels such as diesel fuel consumed by tractors to produce forage in farms and also to carry out processing of animal diet, crushing and mixing of all kinds of forage.

The electricity input was the third source of energy consumption in Guilan dairy farms, with a share of 4% of the total energy consumption and 298.19 MJ per ton of milk which was calculated. The amount of electricity energy for milk production in Tehran province of Iran was reported as 249.88 MJ per ton of milk.

In the present study, the most of electricity consumption was allocated to milking systems, heating water for washing milk pipes, milk cooling and followed by lighting units in milking parlors as the second factor.

**Table 3** The total of inputs and output energy consumption per ton of milk produced in Guilan dairy farms

| Inputs and output | Amount (unit on per ton of milk ) | Energy consumption (MJ per ton of milk) | Percent (%) | Standard deviation |
|---|---|---|---|---|
| Animal feed (kg) | 1370.08 | 6180.8 | 82 | 1348.04 |
| Fossil fuels | | | 13 | |
| Diesel fuel (liter) | 11.62 | 555.25 | | 464.52 |
| Natural gas ($m^3$) | 7.93 | 392.62 | | 324.93 |
| Electricity (kWh) | 23.66 | 298.19 | 4 | 190.91 |
| Machinery (hr) | 378.63 | 42.07 | < 1 | 40.92 |
| Human labor (hr) | 35.51 | 68.55 | < 1 | 20.17 |
| Total energy input | - | 7537.48 | | - |

In another similar study in Ireland, the input of electricity with share of 60% of the total energy consumption had the highest contribution to milking machines and cooling systems units. They also claimed that in order to save electricity in Ireland, especially in the case of milking, the use of milking vacuum pumps equipped with variable speed drive (VSD) was proposed to reduce energy costs to 50%. In addition, to manage the electricity consumption of dairies in the milk cooling units, heat exchanger which acts as a cooling system was proposed. Moreover, a suitable solution in this region to reduce the energy consumption for the heating water; the heat returning milk from cooling systems were suggested (Upton *et al.* 2010; Upton *et al.* 2013). Machinery and human labor inputs in the production of milk in Guilan province of Iran had the lowest energy consumption as well.

## The results of the sensitivity analysis

The results of the CD model to determine the effect of energy inputs on milk yield are shown in Table 4. The effect of energy inputs includes human labor, fossil fuels and animal feed on milk yield were positive and the effect of the electricity and machinery on milk yield was negative. The maximum of regression coefficient (0.82) between the inputs of energy allocated to animal feed was more than that of the other inputs. In addition, the effect of this input on milk yield was significant at 5% level (P-value<0.001). The second input affecting milk yield was the fossil fuels (diesel and natural gas) with regression coefficient equal to 0.18. Human labor was the third input affecting the milk yield (Table 4). The results of the sensitivity analysis showed that with the increase of one MJ of energy inputs including human labor, fossil fuels and animal feed, yield increases 3.14, 1.36 and 0.95 kg respectively and with an increase of one MJ of electricity and machinery equal to -1.03 and -7.16 kg respectively, yield for per ton of milk production was decreased.

## DEA results

In this study, the CRS and VRS models being input-oriented were applied for evaluating TE, PTE and SE of milk production in Guilan province of Iran.

Table 5 shows the types of efficiency and the returns to scale for each industrial milk production farms. On the other hand, Table 5 is a supplement of Table 6 that the averages of TE, PTE and SE on Guilan dairy farms were computed as 44.6, 74.48 and 0.53, respectively.

In a similar study, Uzmay *et al.* (2009) showed that the average of TE and PTE were 0.52 and 0.62 respectively, for milk production in Turkey. In a study carried out in Australia, the results showed that the TE, PTE were 0.95 and 0.94, respectively, that indicated a good management in energy inputs of dairy farms of this country, especially with using the principles of the diet formulation in animal feed (Carter, 2000).

Also, in this study the “returns to scale” factor was determined for CRS and VRS models (Table 5). Determination of this factor is obtained by output weight. If it is less than zero, the “returns to scale” factor will be increasing. If it is more than zero, the “returns to scale” factor will be decreasing. If equal to zero, the output will be with no change. Increasing returns to scale (IRS) can not reduce the production scale unit, but it can be increased to infinity. The ratio of output to input for each point on the efficient frontier in terms of inputs will be decreasing. In fact, increase in outputs is almost equal to changes in inputs (Ghojabeige *et al.* 2009).

The results of the models (VRS and CRS) are shown in Figure 1. Based on the CRS model, only 7 farms out of 44 industrial farms were efficient, whereas the rest was on the inefficient frontier. The farms of 1, 2, 4, 6, 16, 21 and 25 were fully functional, which means that these farms in both scale model were efficient.

In a study conducted in Australia with regard to the appropriate functionality in the energy efficiency of milk production of dairy about 51 farms, out of 60 farms were efficient frontiers (Carter, 2000). The results of optimization of energy inputs for dairy farms in Greece revealed that from the total of 167 dairy farms considered for the analysis, 17 farms were purely technically efficient in energy consumption from the different sources (Theodoridis and Psychoudakis, 2005).

**Table 4** Estimating the effect of energy inputs on milk yield

| | Regression coefficient | t-ratio | P-value | MPP |
|---|---|---|---|---|
| Model: $Lny_i = a_0 + \alpha_1 lnx_1 + \alpha_2 lnx_2 + \alpha_3 lnx_3 + \alpha_4 lnx_4 + \alpha_5 lnx_5 + e_i$ | | | | |
| Human labor | 0.030 | 0.21 | 0.83 | 3.14 |
| Machinery | -0.042 | -1.23 | 0.23 | -7.16 |
| Fossil fuels | 0.18 | 3.44 | 0.002 | 1.36 |
| Electricity | -0.043 | -1.02 | 0.31 | -1.03 |
| Animal feed | 0.82 | 5.35 | < 0.001 | 0.95 |
| $R^2$ | 0.72 | - | - | |
| $R^2_{Adj}$ | 0.67 | - | - | |
| Durbin watson | 1.60 | - | - | |
| Return to scale | 0.58 | | | |

MPP: marginal physical productivity.

**Table 5** Technical, pure technical, scale efficiency and returns to scale for the production of ton of milk based on CRS and VRS input oriented model

| Returns to scale | SE | PTE (%) | TE (%) | DMU (dairy farms) | Returns to scale | SE | PTE (%) | TE (%) | DMU (dairy farms) |
|---|---|---|---|---|---|---|---|---|---|
| IRS | 0.19 | 46.3 | 8.8 | 23 | CRS | 1 | 100 | 100 | 1 |
| IRS | 0.17 | 56.3 | 10.0 | 24 | CRS | 1 | 100 | 100 | 2 |
| CRS | 1 | 100 | 100 | 25 | IRS[1] | 0.88 | 90.3 | 79.6 | 3 |
| IRS | 0.20 | 54.0 | 11.0 | 26 | CRS | 1 | 100 | 100 | 4 |
| DRS[1] | 0.96 | 74.3 | 71.7 | 27 | IRS | 0.99 | 98.1 | 97.5 | 5 |
| IRS | 0.78 | 55.0 | 42.9 | 28 | CRS | 1 | 100 | 100 | 6 |
| IRS | 0.94 | 52.5 | 49.6 | 29 | IRS | 0.69 | 100 | 69.8 | 7 |
| IRS | 0.32 | 52.8 | 17.2 | 30 | IRS | 0.93 | 90.0 | 69.0 | 8 |
| IRS | 0.34 | 45.7 | 15.9 | 31 | IRS | 0.81 | 100 | 77.6 | 9 |
| IRS | 0.38 | 46.5 | 17.7 | 32 | IRS | 0.77 | 100 | 93.9 | 10 |
| IRS | 0.22 | 62.0 | 13.8 | 33 | IRS | 0.17 | 61.4 | 11.0 | 11 |
| IRS | 0.23 | 69.6 | 16.4 | 34 | IRS | 0.23 | 71.8 | 12.2 | 12 |
| IRS | 0.29 | 56.0 | 16.4 | 35 | IRS | 0.16 | 61.0 | 14.6 | 13 |
| IRS | 0.21 | 59.3 | 12.6 | 36 | IRS | 0.17 | 59.5 | 10.5 | 14 |
| IRS | 0.29 | 73.7 | 21.4 | 37 | CRS | 1 | 74.2 | 60.5 | 15 |
| IRS | 0.27 | 58.6 | 16.4 | 38 | IRS | 0.82 | 100 | 100 | 16 |
| IRS | 0.24 | 71.9 | 17.5 | 39 | IRS | 0.16 | 77.7 | 13.0 | 17 |
| IRS | 0.25 | 59.7 | 15.2 | 40 | IRS | 0.12 | 81.2 | 9.9 | 18 |
| IRS | 0.27 | 60.2 | 16.7 | 41 | IRS | 0.14 | 80.6 | 11.9 | 19 |
| IRS | 0.38 | 52.2 | 20.0 | 42 | IRS | 0.17 | 50.1 | 9.0 | 20 |
| IRS | 0.30 | 66.4 | 20.2 | 43 | CRS | 1 | 100 | 100 | 21 |
| IRS | 0.24 | 59.0 | 14.5 | 44 | IRS | 0.22 | 56.8 | 12.7 | 22 |

SE: scale efficiency; TE: technical efficiency; PTE: pure technical efficiency; DMU: decision making units; IRS: increase return to scale; CRS: constant returns to scale and DRS: decrease return to scale.

**Table 6** Average and standard deviation for variety of efficiency with CRS and VRS in Guilan province, Iran

| Max | Min | Standard deviation | Average | Variety of efficiency |
|---|---|---|---|---|
| 100 | 8.8 | 37.44 | 44.6% | TE |
| 100 | 45.7 | 19.68 | 74.48% | PTE |
| 1 | 0.12 | 0.36 | 0.53 | SE |

SE: scale efficiency; TE: technical efficiency and PTE: pure technical efficiency.

Besides, in Pennsylvania state the energy efficiency was examined using a DEA approach that about 30% of the dairy farms were efficient (Stokes *et al.* 2007). The concept of actual energy is the energy that is actually used in the industrial dairy farms and also the optimum energy is determined using the DEA approach or with covering the data and comparing them with the efficient frontier recommendation for the dairy managers to improve the efficiency in decision making farms. The average of the actual and of the optimal energy and of the saving energy for inefficient farms with the VRS model was equal to 7853.16, 4000.77 and 3852.39 MJ, respectively, and also the saving energy rate was acquired as much as 47.74% for per ton of milk production (Figure 2).

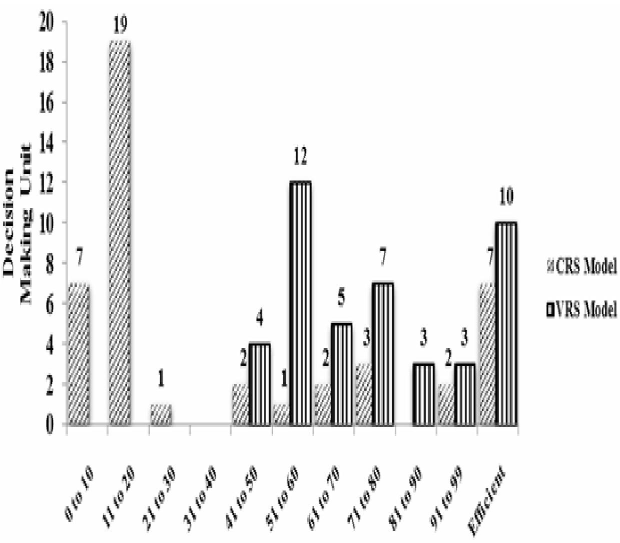


**Figure 1** The number of functional units based on CRS and VRS model

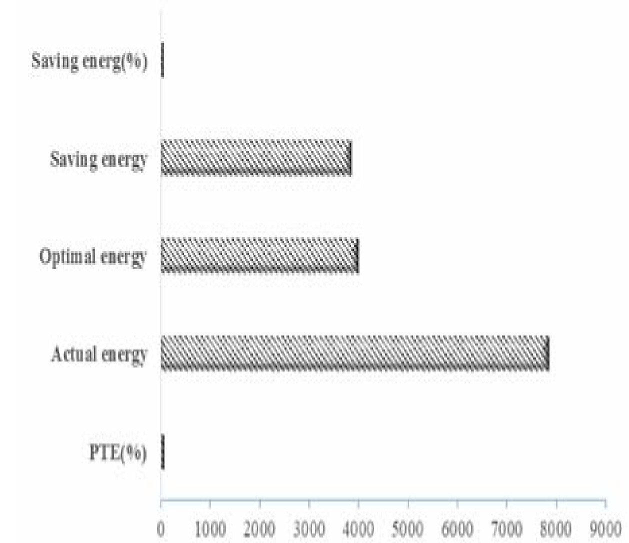


**Figure 2** Average of total actual, optimal and saving energy for inefficient units with VRS model

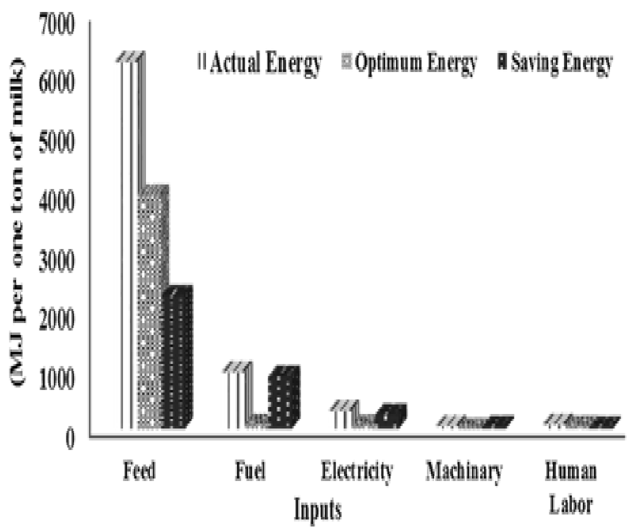


**Figure 3** Average of total actual, optimal and saving energy for each of the inputs with VRS model

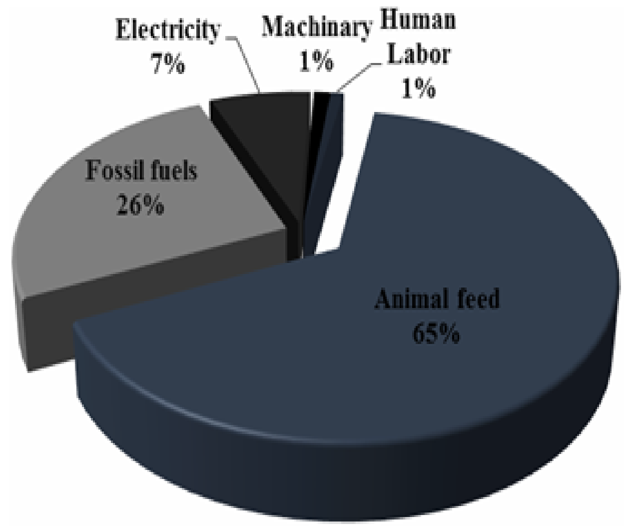


**Figure 4** Distribution of saving energy from different inputs per ton of milk in Guilan province

Furthermore, the average amount of actual energy for each input, including animal feed, fossil fuels, electricity, machinery, human labor, were equal to 6180.08, 953.96, 298.19, 42.07 and 68.55, respectively. The average amount of optimal energy for each input was equal to 3937.43, 70.03, 56.53, 3.59 and 38.86 MJ per ton of milk, respectively, so that the amount of saving energy based on equation 8 from the difference between actual energy and optimal energy can be achieved (Figure 3).

As seen in the Figure 4, the total of saving energy in Guilan industrial dairies was achieved as 3852.39 MJ per ton of milk production. The most energy consumption for saving was allocated to the animal feed input (65%).

One of the fundamental problems in Guilan dairy farms was the irrational consumption and the incorrect diet program for supplying the food for animals. A regular diet program turned to improve stability and increase energy efficiency in milk production.

In addition to employing the experts in diet formulation, one of the technologies currently used in the management of diet is the automatic feeding stations, which the animal feeding rate is variable based on the animal weight and age (Fujiwara and Rushen, 2014). Following by animal feed input in terms of possibility of saving energy, fossil fuels and electricity inputs were with a share of 26% and 7% respectively.

In order to optimize the energy consumption of these inputs; using a heat exchanger to milk cooling unit, vacuum pumps with feature of VSD and using heat milk in the milk cooling for heating water are appropriate methods (Ubbels and Bouman, 1979; Upton *et al*. 2010; Upton *et al*. 2013). On the other hand, one of the methods of replacing the fossil fuels is the usage of renewable energy systems such as biogas technology in large numbers of dairy farms (Cornejo and Wilkie, 2010; Hosseini *et al*. 2013). But, accepting and employing this technology requires further studies in the dairy industrial farms of Guilan province.

## CONCLUSION

We investigated the energy consumption of milk production in Guilan province of Iran. The results showed that the highest share of energy consumption belonged to the animal feed followed by fossil fuels. The result of DEA approach based on VRS model indicated that about 47.74% of total energy input could be saved without reducing the milk yield through following recommendations resulted from this study. Moreover, sensitivity analysis results showed that with one MJ extra use of human labor, fossil fuels and animal feed energy, it would lead to an additional increase in milk yield. Overall, to optimize the energy consumption of milk production in Guilan province of Iran, new optimized solutions such as technology of feed management, employing the experts in diet formulation and using a heat exchanger to milk cooling units are suggested.

## ACKNOWLEDGEMENT

The research leading to these results has received funding from the Ferdowsi University of Mashhad, Iran under grant agreement number 30927, is gratefully acknowledged.

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