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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.

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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):