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Energy use pattern and optimization of energy required for broiler production using data envelopment analysis

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A B S T R A C T

A literature review shows that energy consumption in agricultural production in Iran is not efficient and a high degree of inefficiency in broiler production exists in Iran. Energy consumption of broiler production in Ardabil province of Iran was studied and the non-parametric method of data envelopment analysis (DEA) was used to analyze energy efficiency, separate efficient from inefficient broiler producers, and calculate wasteful use of energy to optimize energy. Data was collected using face-to-face questionnaires from 70 broiler farmers in the study area. Constant returns to scale (CCR) and variable returns to scale (BCC) models of DEA were applied to assess the technical efficiency of broiler production. The results indicated that total energy use was 154,283 MJ (1000 bird)$^{-1}$ and the share of fuel at 61.4% was the highest of all inputs. The indices of energy efficiency, energy productivity, specific energy, and net energy were found to be 0.18, 0.02 kg MJ^{-1}, 59.56 MJ kg^{-1}, and −126,836 MJ (1000 bird)$^{-1}$, respectively. The DEA results revealed that 40% and 22.86% of total units were efficient based on the CCR and BCC models, respectively. The average technical, pure technical, and scale efficiency of broiler farmers was 0.88, 0.93, and 0.95, respectively. The results showed that 14.53% of total energy use could be saved by converting the present units to optimal conditions. The contribution of fuel input to total energy savings was 72% and was the largest share, followed by feed and electricity energy inputs. The results of this study indicate that there is good potential for increasing energy efficiency of broiler production in Iran by following the recommendations for efficient energy use.

1. Introduction

Agricultural production has become more energy intensive in an effort to supply more food to the increasing population and provide sufficient and adequate nutrition. Considering the limited natural resources and the effect of the use of

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different energy sources on the environment and human health, it is necessary to investigate energy consumption patterns in agriculture [1]. Measuring the efficiency of farming is required in both developing and developed countries [2]. Efficiency is defined as the ratio of the weighted sum of outputs to inputs or as the actual output to the optimal output ratio. The optimal input or output amounts are necessary to specify the production frontier [3].

Improved energy efficiency is a key indicator of sustainable energy management; in order to enhance energy efficiency, production yield must increase or energy must be conserved without affecting yield [4,5]. Data envelopment analysis (DEA) is a non-parametric technique for measuring and evaluating the relative efficiencies of decision-making units (DMUs) with common multi-inputs and multi-outputs [6]. DEA evaluates the efficiency of each DMU relative to an estimated production possibility frontier as determined by all DMUs [7]. The advantage of DEA is that it does not require prior assumptions on the underlying functional relationships between inputs and outputs [8].

Many authors have applied DEA to agricultural research. Pahlavan et al. [9] used DEA on data for energy use in tomato production in Iran. They estimated the technical, pure technical, and scale efficiencies of farmers to estimate productivity of tomato producers based on the amount of energy inputs for the output of tomato yield. Mohammadi et al. [10] employed DEA to analyze the efficiency of kiwifruit producers in Mazandaran province of Iran. Their results indicated that 12.17% of total energy input could be saved if the recommendations of the study were implemented.

Heidari et al. [11] applied DEA to determine the efficiency of farmers with regard to energy use in broiler production in Yazd province based on The CCR and BCC models. The CCR rated 10 farmers as efficient and the BCC rated 16 farmers as efficient. They estimated the technical, pure technical, and scale efficiency of farmers to be 0.9, 0.93 and 0.96, respectively. Sefeedpari [12] applied DEA to determine the efficiency of input use in dairy farms in Iran using data obtained from 35 dairy farmers in Tehran province and found the mean technical efficiency to be 0.88 for all regions. It was concluded that DEA was a useful tool for improving the productivity efficiency of farms. Sefeedpari et al. [13] studied energy use patterns of poultry farms in Iran and reported that technical, pure technical, and scale efficiency was 0.85, 0.93, and 0.91, respectively. Their results showed that 22% of overall resources could be saved by increasing the performance of inefficient DMUs to the highest level. The present study analyzed and ranked the efficiency of farmers and identified target energy requirements and wasteful energy practices from different inputs to specify energy use patterns for broiler production in Ardabil province of Iran.

2. Materials and methods

2.1. Sampling design

The study was carried out at broiler farms in Ardabil province of Iran. This province is located in northwestern Iran at 47°15′ to 48°56′ E longitude and 37°09′ to 39°42′N latitude [14]. Data was collected from farmers using a face-to-face questionnaire in September–October 2013. The sample size was determined to be 70 farms by the Neyman method [15].

2.2. Energy equivalents of inputs and outputs

Input sources for the poultry farms were chicks, human labor, machinery, fuel, feed, and electricity. Output sources were broilers and manure. Energy conversion factors were used to convert each input and output into energy equivalents. The energy equivalents were determined by multiplying the quantity per 1000 birds by their conversion factors (Table 1).

Using the energy equivalents for inputs and output in Table 1, the energy ratio (energy use efficiency), energy productivity, specific energy, and net energy were calculated as [26,27]:

$$\text{Energy use efficiency} = \frac{\text{Energy output } (\text{MJ}(1000\text{ bird})^{-1})}{\text{Energy input } (\text{MJ}(1000\text{ bird})^{-1})} \quad (1)$$

$$\text{Energy productivity} = \frac{\text{Yield } (\text{kg}(1000\text{ bird})^{-1})}{\text{Energy input } (\text{MJ1000 bird}^{-1})} \quad (2)$$

$$\text{Specific energy} = \frac{\text{Energy input } (\text{MJ ha}^{-1})}{\text{Yield } (\text{kg}(1000\text{ bird})^{-1})} \quad (3)$$

$$\text{Net energy} = \text{Energy output } (\text{MJ}(1000\text{ bird})^{-1}) - \text{Energy input } (\text{MJ}(1000\text{ bird})^{-1}) \quad (4)$$

Energy demand can be divided into direct and indirect energy or renewable and non-renewable energy. Direct energy (DE) includes human labor, diesel fuel, and electricity and indirect energy (IDE) includes energy embodied in chicks, machinery, and feed used for broiler farm production. Renewable energy (RE) comprised chicks, human labor, and feed; non-renewable energy (NRE) comprised diesel fuel, machinery, and electricity.

2.3. Data envelopment analysis (DEA)

DEA methodology was applied to determine the relative efficiency of broiler producer units and calculate the amount of energy savings. In DEA, an inefficient DMU can be made efficient either by reducing the input level while holding the output constant (input oriented) or by increasing the output level while holding the inputs constant (output oriented) [10,28,29]. In the present study, the input-oriented model was assumed to be more appropriate because only two outputs existed while multiple inputs were used. Likewise, in farming systems, a producer has more control over inputs than output levels and input conservation for given outputs is more logical.

DEA is a mathematical procedure that uses linear programming to assess the efficiency of DMUs. A non-parametric piecewise frontier which maintains optimal efficiency over the datasets was composed of DMUs and is constructed by DEA to measure comparative efficiency. DMUs located on the efficiency frontier are efficient, offer the best efficiency among all DMUs, and generate maximum output using a minimum level of inputs [30]. The concepts used in parametric and DEA approaches are shown in Fig. 1 for seven