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Reduction of energy waste in sugar beet farming using DEA approach

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ABSTRACT

In this study energy use pattern for sugar beet production in Hamadan province of Iran was studied and the degrees of technical and scale efficiency of producers were analyzed using DEA technique. The results revealed that of the average pure technical, technical and scale efficiencies of farmers were 0.83, 0.63 and 0.74, respectively. The results also suggested that, on average, a potential 45.73% (19609 MJ ha^{-1}) reduction in total energy input could be achieved provided that all farmers operated efficiently. Generally, it can be said the DEA approach was appropriate methods for energy optimization in sugar beet production.

Introduction

Sugar beet is an industrial crop that plays an important role in supplying the sugar demand in Iran. The policies of Iranian government on sugar beet cultivation and production are based on extensive intervention to preserve low sugar price and to meet consumers' demand through importing. The efficiency and productivity of sugar beet production have been interested by the sugar producers owing to their impact on lowering the costs of raw materials [1].

One of the most important principles in any production is the principle of efficiency. Efficiency can be defined as the demand that the desired goals are achieved with the minimum use of the available resources. In order to assess the relative efficiency of a business unit, it is necessary to consider the conditions and operation results of other units of the same kind and to determine the real standing of the results of such a comparison. In a simple case where units have a single output and a single input, efficiency is defined as their ratio. However, agricultural production units have multiple and incommensurate inputs and outputs. Data envelopment analysis (DEA) is a nonparametric method for measuring the relative efficiency of a set of comparable units [2].

Energy is a fundamental component in the process of economic development, as it provides imperative services that maintain economic activities and the quality of human life. Thus, shortages of energy are a serious constraint on the development of low income countries. Agricultural sector consumes energy in the forms of human labor, electricity, seeds, fertilizers, diesel fuels etc. Energy use in agriculture has developed in response to increasing populations, limited supply of arable land and desire for an increasing standard of living [3].

The efficiency and productivity of the agricultural production is so important that they have been subjected to extensive studies throughout the world. Several studies used DEA to assess the efficiency in different agricultural production systems. Khoshnevisan *et al*. [3] applied DEA to analyze the energy efficiency of wheat farms in Iran in order to separate efficient and inefficient growers and to calculate the wasteful uses of energy. Banaeian and Namdari [4] investigated optimization of energy inputs for watermelon production in Iran. In their research, DEA was use in order to investigate the efficiency of two groups of farms: Group I which was non-owners of machinery and exercised low level of farming technology and Group II which was the owners of machinery and practiced high level of farming technology. In another study conducted by Nabavi-Pelesaraei et al. [5], the DEA technique was subjected to the data of energy use and greenhouse gas (GHG) emission for rice production in Iran. In this paper, seven energy inputs and rice yield as output were considered for DEA method. The technical, pure technical and scale efficiency were determined based on Charnes-Cooper-Rhodes (CCR) and Banker-Charnes-Cooper (BCC) models.

Based on the literature, there has been no study on application of DEA for sugar beet production. The main objectives of this study were to determine the energy use efficiency, determine the efficiencies of sugar beet farmers, wasteful uses and target energy requirement for sugar beet production in Hamadan province of Iran.

Materials and methods

Data collection and processing

The study was carried out on 88 sugar beet producers in Hamadan Province, Iran. Data were collected from the farmers by using a face to face questionnaire in the production period of 2012/2013. The size of each sample was determined using Eq.(1) [4]:

$$n=[N(s\times t)2]/[(N-1)d2+(s\times t)2] \quad (1)$$

where n is the required sample size; N is the number of holdings in target population; s is the standard deviation; t is the t-value at 95% confidence limit (1.96); and d is the acceptable error (permissible error 5%). The inputs used in sugar beet production were in the form of human labor, chemical fertilizer, farm yard manure, chemicals, seed, water for irrigation, electricity and machinery; while the sugar beet yield was the single marketable output. The energy

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equivalents of these inputs and output were calculated using the energy equivalent coefficients as presented in Table 1.

Table 1. Energy equivalents of inputs and outputs in the sugar beet production system [6]

Input/output	Unit	Energy equivalent (MJ/Unit)
Human Labor	h	1.96
Machinery	h	62.70
Diesel Fuel	L	56.31
Chemical fertilizers		
Nitrogen	kg	75.46
P_2O_5	kg	13.07
K_2O	kg	11.15
Micro fertilizers	kg	120.00
Chemicals		
Herbicides	kg	328.00
Pesticides	kg	101.20
Fungicides	kg	216.00
Farmyard manure	kg	0.30
Electricity	kWh	3.60
Irrigation water	m^3	1.02
Seed	kg	50.00
Outputs		
Sugar beet	kg	16.80

Based on the energy equivalents of the inputs and outputs (Table 1), energy use efficiency, energy productivity, specific energy and net energy were calculated as follows [6]:

$$\text{Energy use efficiency} = \frac{\text{Energy output } (MJha^{-1})}{\text{energy input } (MJha^{-1})} \quad (2)$$

$$\text{Energy productivity} = \frac{\text{sugarbeet output } (kgha^{-1})}{\text{energy input } (MJha^{-1})} \quad (3)$$

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

Energy demand in agriculture can be divided into direct (DE) and indirect (IDE) energy or renewable (RE) and non-renewable (NRE) energy. The indirect energy includes energy embodied in seeds, chemical fertilizers, herbicides, pesticides, fungicides, farmyard manure, and machinery whereas the direct energy envelopes diesel fuel, irrigation water, electricity and human labor used in the sugar beet production system. The renewable energy includes of irrigation water, human labor, farmyard manure, and seeds. The non-renewable energy resources such as fossil fuels are energy resources that are not replaced or are replaced only very slowly by natural process [6].

Data envelopment analysis

DEA calculate the frontier production function of a set of decision making units (DMUs) and evaluate the relative technical efficiency of each unit, thereby allowing a distinction to be made between efficient and inefficient DMUs. In this study, DEA technique was used to evaluate the technical (TE) , pure technical (PTE) and scale efficiencies (SE) of individual farmers which use similar inputs (human labor, machinery, fuel, fertilizers, chemicals, manure, electricity, irrigation water and seed) and produce the same product (sugar beet). Each farmer called a DMU. DEA determines efficiency of DMUs relative to others in the group, evaluates inefficient units and can identify the level as well as sources of inefficiency. In DEA technique an inefficient DMU can be made efficient either by minimizing the input levels while maintaining the same level of outputs (input oriented), or, symmetrically, by increasing the output levels while holding the inputs constant (output oriented) [7]. There are two types of DEA models included: CCR (Charnes- Cooper-Rhodes) and BCC (Banker, Charns and Cooper) models. The CCR model is built on the assumption of constant returns to scale (CRS) of activities, but the BCC model is built on the assumption of variable returns to scale (VRS) of activities [8]. In this study, input oriented DEA seems more appropriate, given that it is more reasonable to argue that in the agricultural sector a farmer has more control over inputs rather than output levels. Therefore CCR and BCC input oriented models were investigated in this study.

The technical efficiency of a farmer is a comparative measure of how well it actually processes inputs to achieve its outputs, as compared to its maximum potential for doing so, as represented by its production possibility frontier. Technical efficiency (TE) can be calculated by the ratio of sum of weighted outputs to sum of weighted inputs [3].

$$TE_j = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \quad (5)$$

where 'TE_j' is the technical efficiency score given to unit *j*; *x* and *y* represent input and output and *v* and *u* denote input and output weights, respectively; *s* is the number of inputs (s = 1, 2,…, m), *r* is number of outputs (r = 1, 2,…, n) and *j* represents *j*th DMUs (j = 1,2,…, k). Eq. (6) can be translated into a linear programming [7]:

$$\text{Maximize}\,\theta = \sum_{r=1}^{n} u_r y_{ri} \quad (6)$$

$$\text{Subject to} \quad \begin{aligned} &(i) \sum_{s=1}^{m} v_s x_{si} = 1, i = 1,2,...,k \\ &(ii) \sum_{i=1}^{n} u_r y_{ri} - \sum_{s=1}^{m} v_s x_{sj} \le 0 \\ &(iii) u_r \ge 0, \quad r = 1,2,...,n \\ &(iv) v_s \ge 0, \quad s = 1,2,...,m \end{aligned}$$

where θ is the technical efficiency. Model (7) is known as the input oriented CCR DEA model introduced by Charnes *et al*. [9]. It assumes constant return to scale condition under which the production possibility set is formed without any scale effect. A DEA efficiency score, given by a specific *u*, can have a value between 0 and 1 where a value of 1 shows that the DMU is a best performer located on the production frontier and has no reduction potential. Any value of u lower than 1, however, indicates that the DMU uses inputs inefficiently.

The objective function of the model maximizes the ratio of weighted outputs to weighted inputs for the farms under consideration subject to the condition that the similar ratios for all farms (DMUs) be less than or equal to one. The optimal value of the objective function of the model is the efficiency score assigned to the *k*th DMU. If the efficiency score is one, the *k*th DMU satisfies the necessary condition to be efficient; otherwise, it is inefficient.

The technical efficiency (TE) derived from CCR model comprehends both the technical and scale efficiencies. So, Banker, Charnes developed a model, which was called BCC model to calculate the pure technical efficiency (PTE) of DMUs. This model assumes variable returns to scale (VRS), denoting that a change in inputs is expected to result in a disproportionate change in outputs [3].

Scale efficiency is the potential productivity gain from achieving optimal size of a DMU. It can be calculated by the relationship between technical and pure technical efficiencies as follows [7]:

$$\text{Scale efficiency} = \frac{\text{Technical efficiency}}{\text{Pure technical efficiency}} \quad (7)$$

where SE = 1 implies scale efficiency (or CRS) and SE < 1 indicates scale inefficiency.

In order to specify the inefficiency level of energy usage, the energy saving was calculated. Saving energy was calculated as:

$$\text{energy saving}(\%) = (1 - \text{projection energy use})/\text{present use} \times 100 \quad (8)$$

where energy saving is the total reducing amount of energy inputs that could be saved without reducing the output level.

Results and discussion

Energy use pattern analysis

The summarized information on energy use pattern of sugar beet production in Hamadan province is presented in Table 2. The energy use pattern indicated that electricity, chemical fertilizers and water for irrigation are the major energy consuming inputs for sugar beet production in the region. The average (percent) of electricity, chemical fertilizers and water for irrigation energy were 45133.50 (53%), 19425.80 (23%) and 9036.80 (11%) MJ ha^{-1}, respectively. Also, the summarized statistics for energy inputs and output are shown in Table 2. The wide variation between input energies and output energy are considerable. It was due to the mismanagement of resources usage between the producers indicating that there is a potential for improving energy use pattern of sugar beet production in the study region.

Table 2. Summary of inputs and output energies (MJ ha^{-1})

Item	Average	Max	Min	SD
Human labor	1623.27	6887.44	180.65	1048.56
Diesel Fuel	6569.12	21059.94	1629.61	3951.16
Chemical Fertilizers	19425.75	43961.00	0.00	7380.53
Farmyard manure	1336.11	18375.43	0.00	3858.39
Chemicals	860.58	4962.40	0.00	818.97
Water for irrigation	9036.80	27417.60	1799.28	5584.60
Seed	98.22	160.00	47.50	19.57
Machinery	1010.80	2309.91	335.48	431.51
Electricity	45133.45	140377.26	2558.96	30811.79
Sugar beet	898230	2016000	252000	324060

Table 3. Some energy indices in sugar beet production in Hamadan, Iran.

Item	Unit	Quantity
Energy use efficiency	-	10.51
Energy productivity	kg MJ^{-1}	0.79
Net energy	MJ ha^{-1}	813136.08
Direct energy	MJ ha^{-1}	62362.90 (73.29%)
Indirect energy	MJ ha^{-1}	22731.48 (26.71%)
Renewable energy	MJ ha^{-1}	12094.41 (14.21%)
Non-renewable energy	MJ ha^{-1}	72999.96 (85.79%)
Total energy input	MJ ha^{-1}	85500.05

The energy use efficiency, energy productivity and net energy of sugar beet production are presented in Table 3. The energy use efficiency in the production of sugar beet was found to be 10.51; showing that output energy of sugar beet is obtained about 11 times greater than total input energy. Also energy productivity and net energy were found to be 0.79 kg MJ^{-1} and 813136.08 MJ ha^{-1}, respectively. The distribution of energy consumption from direct, indirect, renewable and non-renewable energy resources was also investigated (Table 3).The results revealed that, total energy input could be classified as 62362.90 and 22731.48 MJ ha^{-1} in direct and indirect, and 12094.41 and 72999.96 MJ ha^{-1} in renewable and non-renewable energy forms, respectively. The high share of non-renewable energy (85.79%) in sugar beet production showed a high dependency of this cultivation on electricity and chemical fertilizer.

Identifying efficient and inefficient farmers

In this study, we used CCR and BCC models to evaluate technical, pure technical and scale efficiencies of sugar beet producers, respectively. Fig. 1 shows the results of the CCR and BCC models. Based on CCR results, this study shows that 14 farms from 88 farms were relatively efficient and the remaining 74 were inefficient, i.e. their efficiency score was below 1. While based on BCC model, 30 farms were efficient and the remaining were inefficient. As can be seen in Fig. 1, the rate of scale efficiency was 1 for 15 DMUs.

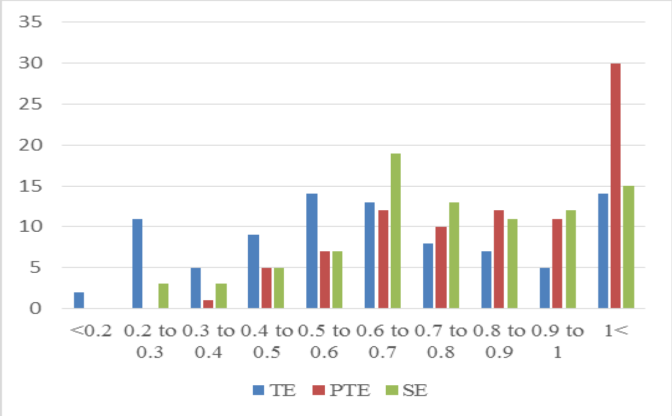

Fig 1. Efficiency score distribution of eggplant producers.

The results illustrated average of technical, pure and scale efficiency of sugar beet farmers were 0.63, 0.83 and 0.74, respectively. The mean value of SEs for the inefficient farmers (0.69) indicates that there is wide scope for improving their operating practices to enhance their energy use efficiency. The average of SE was as low as 0.74, which indicates that if inefficient DMUs utilize their inputs efficiently, considerable savings in energy from the different sources is possible without any change in technological practices.

Optimum energy requirement and saving energy

A pure technical efficiency score of less than one for a DMUs shows that, at present conditions, they are using more energy than required. Therefore, it is desired to suggest realistic levels of energy to be used from each source for every inefficient DMUs in order to avert wastage of energy without reducing the output level. Table 4 shows the optimum energy consumption and saving energy of various farm inputs based on BCC model. It gives the average energy usage in target conditions and ESTR percentage for different energy sources. Accordingly, the total optimum energy required of sugar beet production was found 66545.30 MJ ha^{-1}. Also, human labor, diesel fuel, and the total fertilizer energy requirements were found to be about 1100, 5152 and 16548 MJ ha^{-1}, respectively. Moreover, farmyard manure, chemicals, water for irrigation, seed, machinery and electrical energy inputs were required as about 254, 465, 6969, 89, 914 and 35052 MJ ha^{-1}, respectively. Table 4 shows farmyard manure had the highest inefficiency which was owing mainly to the increasing herb in the farms and therefore increasing cultivation operation. The saving for farmyard manure energy was found to be at least 1081.81 MJ ha^{-1} (80.97%). The results of saving estimation showed that if all farmers operated efficiently, the reduction of water for irrigation and electrical energy inputs, respectively, by 22.88% and 22.34% would have been possible without affecting the yield level. Electrical energy usually is consumed for pumping and operating the farm irrigation systems. The saving for seed energy input was found to be at least (9.47%), showing that the seeds are mainly used efficiently by the sugar beet farmers in the region. Moreover, the percentage of saving for total energy input was found to be 45.73%, implying that by adopting the recommendations resulting from this study, on average, about 45.73% (19609.91 MJ ha^{-1}) from total input energy could be saved without affecting the sugar beet yield.

Table 4. Optimum energy requirement and saving energy for sugar beet production

Input	Projection energy use (MJ ha^{-1})	Energy Saving (MJ ha^{-1})	Saving (%)
Human labor	1100.50	522.77	32.20
Diesel Fuel	5152.13	1417.23	21.57
Chemical Fertilizers	16548.81	2876.95	14.81
Farmyard manure	254.30	1081.81	80.97
Chemicals	465.11	364.68	45.86
Water for irrigation	6968.77	2068.03	22.88
Seed	88.93	9.30	9.47
Machinery	913.73	97.07	9.60
Electricity	35052.22	10081.23	22.34
Input energy	66545.30	19609.91	45.73

The share of each input for energy reduction by BCC optimization are demonstrated in Figure 2. The highest share of energy reduction was belonged to electricity with about 54%; followed by chemical fertilizers with 16% and water for irrigation with 11%. Given their higher potential to improve the energy use efficiency, it is presented that the usage pattern of these inputs be considered preferably, providing significant conservation of energy consumption for sugar beet production in Hamadan province. Improving pump and engine or motor efficiency, considering nighttime irrigation, employing new and appropriate irrigation systems, designing wells, pumps and distribution systems carefully and leveling farms properly can be suggested to prevent from electrical energy wastage by inefficient farmers, and so, improve the energy use efficiency.

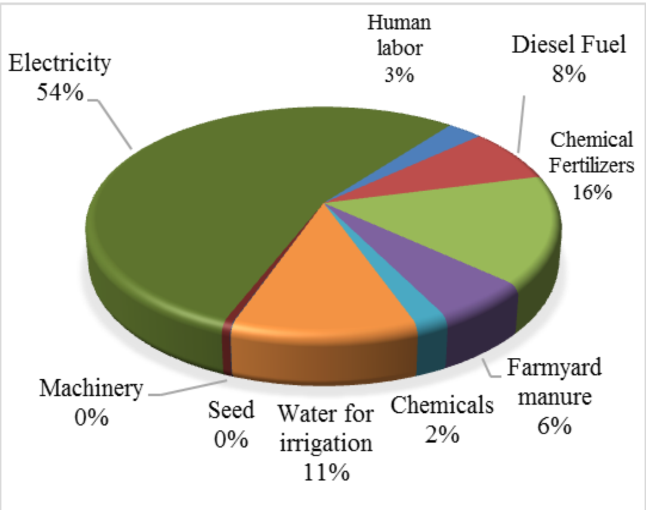

Fig 2. Distribution of saving energy from different sources for canola production.

Pahlavan *et al*. [8] reported that by adopting the recommendations based on their study, on an average, about 25.15% of the total input energy in tomato production could be saved without reducing the yield. Also, Mousavi-Avval *et al*. [7] concluded that 1696 MJ ha^{-1} (9.5%) from total energy input for canola production could be saved.

The effect of optimization of energy inputs for sugar beet production on energy indices was also investigated. The results are tabulated in Table 5. As can be seen energy use efficiency is calculated as 13.49 in target use of energy. This showed an improvement of 28.35% in energy use efficiency. Also energy productivity and net energy in target conditions were found to be 0.8 kg MJ^{-1} and 831685.15 MJ ha^{-1}, respectively.

Table 5. Improvement of energy indices for sugar beet production in Hamadan, Iran.

Item	Unit	Quantity	Improvement (%)
Energy use efficiency	-	13.49	28.35
Energy productivity	kg MJ^{-1}	0.80	1.27
Net energy	MJ ha^{-1}	831685.15	2.38
Total energy input	MJ ha^{-1}	66545.30	22.87

Furthermore, the results showed the ability of DEA method was acceptable for energy reduction in agricultural crops. It helped in detecting the wasteful uses of energy by inefficient DMUs and suggest necessary quantities of different inputs to be used by each inefficient DMUs from every energy source.

Conclusions

In this study, the non-parametric method of data envelopment analysis (DEA) was applied to analyze the efficiencies of sugar beet producers in Hamadan province of Iran in energy points of view. This technique allows the determination of the best practice farms and can also provide helpful insights for farm management. DEA has helped in segregating efficient growers from inefficient growers. It has also helped in finding the wasteful uses of energy by inefficient growers. Based on the results, the following conclusions may be drawn:

1. Sugar beet production consumed a total energy of 95094 MJ ha-1, which was mainly due to electrical energy (53%). Electricity consumption in sugar beet production is for irrigation purposes.
2. DEA has helped in segregating efficient growers from inefficient growers. It has also helped in finding the wasteful uses of energy by inefficient growers, ranking efficient growers by using the CCR and BCC models and ranking energy sources by using technical, pure technical and scale efficiency.
3. The BCC and CCR model results indicated 14, 30 and 15 units had efficient for technical, pure technical and scale efficiency, respectively.
4. The average value of technical efficiency (based on CCR model), pure technical efficiency (based on BCC model) and scale efficiency were calculated as 0.63, 0.83 and 0.74, respectively.
5. With respect to DEA method, the total energy requirement and energy saving of sugar beet production were calculated as 66545.30 and 19609.91 MJ ha-1, respectively. Also, the electricity, chemical fertilizer and water for irrigation had the highest percentage of total energy saving with 54%, 16% and 11 %, respectively.
6. Improving energy use efficiency of water pumping systems, employing new irrigation systems, applying a better machinery and utilization of alternative sources of energy such as organic fertilizers management technique can be suggested to prevent energy wastage by inefficient farmers.

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