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Optimizing energy consumption efficiency for greenhouse cucumber production using the DEA (data envelopment analysis) approach in Markazi Province of Iran

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This paper applied a non-parametric (Data Envelopment Analysis) method to analyze the efficiency of farmers, discriminate efficient farmers from inefficient ones and to identify wasteful uses of energy in order to optimize the energy inputs for greenhouse cucumber production in Markazi province of Iran. Data were collected from 33 cucumber producers by using a face-to-face questionnaire. DEA creates a best-practice production frontier based on the growers that produce their level of greenhouse cucumber yield with the least amount of input energy. The results revealed that total operational energy of 595.24 GJ is consumed in greenhouses. Most shares of this energy are allocated to fuel and chemical by the shares of 59.15% and 12.88% respectively. Two basic DEA models, Constant Return to Scale (CRS) and Variable Return to Scale (VRS) were used to measure the technical efficiency (TE) of the greenhouses based on eight energy inputs and one output. The CRS and VRS models indicated that 11 and 22 greenhouses were efficient, respectively. The average values of TE, pure technical efficiency (PTE) and scale efficiency (SE) of greenhouses were found to be 0.93, 0.99 and 0.93 separately. Moreover, energy-saving target ratio (ESTR%) for greenhouse cucumber production was calculated as 18.18%, indicating that by following the recommendations resulted from this study, 182.21 GJ ha^{-1} of total input energy could be saved while holding the constant level of greenhouse cucumber yield.

Keywords: Data envelopment analysis, Energy saving, Fuel energy, Greenhouse cucumber production

Introduction

Cucumber is one of the most popular greenhouse vegetable products worldwide (Nassiri and Singh, 2009).

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Today's, energy consumption in agricultural activities has been intensified in response to continued growth of population, the trend for Improved the overall standard of living and limited supply of arable lands (Erdal *et al*., 2007). Greenhouse business is very capital intensive with the basic structure erected depending on main options. Choosing the best treatment plan for greenhouse operation is required for providing economic and impressive results. In greenhouse production, Management methods can be defined as a set of alternative production techniques such as structure, nutrient injection system, heating and ventilation systems, labors, cultivating programs and etc. (Banaeian *et al*., 2011).

Efficient use of energy helps to achieve increased output and productivity and contributes to the profitability and competitiveness of agriculture sustainability in rural living (Singh *et al*., 2002). Productive use of energy is one of the principal requirements of sustainable agriculture. The shares of greenhouse crop production were as follows: vegetables 59.3%, flowers 39.81%, fruits 0.54% and mushroom 0.35% (Omid *et al*., 2011). It increased dramatically in crop yields per hectare have achieved in the developing countries through the use of improved varieties together with commercial energy inputs: particularly, mineral fertilizers, farm machinery, pump irrigation and chemical pesticides. Commercial energy inputs are being used increasingly in developing countries and result in a transition from traditional to more energy-oriented agricultural production methods (Richard, 1992). Some problems in agricultural productions are mainly due to the high levels of dependency on fossil energies that causes a lot of serious environmental problems among which global warming and greenhouse gas (GHG) emissions are counted as important ones (Khoshnevisan *et al*., 2013).

It seems that there is a huge gap between industrializing and developing countries in using energy resources. This problem is even more severe in regions like Iran having almost a large quantity of oil and natural-gas resources. Energy auditing is a useful tool to characterize farming systems, quantify major inputs and identify promising strategies to improve efficiency and reduce environmental impacts. Data envelopment analysis (DEA) is a non-parametric approach, supplies a wealth of information in the form of estimates of inefficiencies in both inputs and outputs for every DMU (Decision Making Unit=farmers in this study) (Cooper *et al*., 2007).

Many authors have applied DEA in agricultural researches: Rahbari et al. (2013) used a DEA method to analyze the efficiency of greenhouse tomato producers in Esfahan province of Iran. Results indicated that energy input for tomato production was 8936.68GJ ha^{-1} and diesel fuel is the major energy inputs in this cultivation. The average values of TE, PTE and SE of greenhouses were found to be 92.48%, 99.55% and 92.81%, respectively.

Qasemi-Kordkheili *et al*. (2013) applied DEA technique for optimizing the energy use in the button mushroom production in Mazandaran province of Iran. They determined farms with the best performance and revealed that button mushroom production depends mainly on Button mushroom compost and electricity energy inputs. Button mushroom compost (5010.06 GJ ha^{-1}) and electricity (2444.17 GJ ha^{-1}) energy inputs had the highest potential for saving energy. Ajabshirchi (2013) analyzed energy use of inputs and output in corn silage production to improve energy inputs and greenhouse-gas emission in Esfahan province of Iran. Data envelopment analyses revealed that on an average 5901.31 MJ ha^{-1} from total energy input could be saved without reducing the yield. With respect to the improving of energy use efficiency, the maximum contribution to the whole energy savings is 36% of machinery. With regard to improving energy efficiency, the maximum share of the entire energy savings is 36% of machinery. Omid *et al*. (2011) Studied selected greenhouse benchmarking productive efficiency in Iran, using DEA. The result indicated total energy input for greenhouse cucumber 152,908.43 (MJ ha^{-1}). The average values of PTE, TE and SE was estimated to be 0.97, 0.87 and 0.90, respectively. The total energy savings were 53,301 MJ ha^{-1} that diesel fuel had a maximum share in it.

Based on the literature, there wasn’t any study on optimization of energy inputs for greenhouse cucumber production in Markazi province of Iran. The aims of this study were to Optimizing energy consumption, rank efficient and inefficient producers, identify target energy requirements and wasteful uses of energy from different inputs for greenhouse cucumber production in Markazi province of Iran.

Materials and methods

Data used in this study were obtained from 30 farmers growing single crop cucumber in a greenhouse in the Markazi provinces of Iran by using a face-to-face questionnaire method performed in season 2012. Markazi province is located in the north of Iran, within 33° 30' and 35° 35' north latitude and 48° 57' and 51° east longitude. In addition to the data obtained from surveys, previous studies of related organizations such as the Food and Agricultural Organization (FAO) and Ministry of Jihad-Agriculture of Iran (MAJ) were also utilized during this study. The number of operations involved in the cucumber production, and their energy requirements influence the final energy balance. The selection of greenhouses was based on random sampling method.

Energy equivalents used

Energy inputs, including human labor, machinery, diesel fuel and natural gas, electricity, chemical fertilizers, farmyard manure (FYM), chemicals, water for irrigation and output yield values of cucumber have been used to estimate the energy equivalences in this study.

Energy equivalents

Table 1. Energy equivalents of inputs and outputs

Inputs and output	**Unit**	**Energy equivalent (MJ unit^{-1})**	**Ref.**
1. Human Labor	h	1.96	(Kitani, 1999)
2. Machinery	kg	62.7	(Verma, 1987)
3. Fuel			
(a) Diesel fuel	l	47.8	(Cervinka, 1980)
(b) Natural gas	m^3	49.5	(Cervinka, 1980)
4. Chemical fertilizers			
(a) Nitrogen (N)	kg	78.1	(Kitani, 1999)
(b) Phosphate (P2O5)	kg	17.4	(Kitani, 1999)
(c) Potassium (K2O)	kg	13.7	(Kitani, 1999)
(d) Micro	kg	8.8	(Pimentel, 1984)
5. Farmyard manure (FYM)	ton	303.1	(Kitani, 1999)
6. Chemicals			
(a) Insecticide	kg	199	(Helsel, 1992)
(b) Fungicide	kg	92	(Helsel, 1992)
(c) Herbicide	kg	238	(Helsel, 1992)
7. Electricity	kWh	11.93	(Kitani, 1999)
8. Water for irrigation	m^3	1.02	(Yaldiz, 1993)
Cucumber	kg	0.8	(Pahlavan *et al.*, 2011)

The energy equivalent of human labor is the muscle power used in greenhouse operations (Qasemi-Kordkheili *et al*., 2013).

Chemicals and chemical fertilizer's energy equivalents mean the energy consumption for producing, packing and distributing the materials, and they are given on an active ingredient basis. Farmyard manure is regarded as a source of nutrients, so the energy equivalent of farmyard manure (FYM) is equated with that of mineral fertilizer equivalents corresponding to the fertilization effect of the applied manure. Furthermore, the energy sequestered in fuels and electricity means their heating value (enthalpy), and the energy needed to make their energy available directly to the farmers (Mohammadi *et al*., 2010).

The energy equivalent of water for irrigation input means indirect energy of irrigation consist of the energy consumed for manufacturing the materials for the dams, canals, pipes, pumps, and equipment as well as the energy for constructing the works and building the on-farm irrigation systems (Khan *et al*., 2009).

For calculating the embodied energy in agricultural machinery it was assumed that the energy consumed in the production of The tractors and farm machinery be depreciated during their economic lifetime (Beheshti Tabar *et al*., 2010); therefore, the machinery energy input was calculated using the following Eq. (Gezer *et al*., 2003):

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

Where ME is the machinery energy per unit area (MJ ha^{-1}); G is the machine mass (kg); M_p The production energy of the machine (MJ kg^{-1}); t is the time that the machine used per unit area (h ha^{-1}) and T is the economic lifetime of the machine (h).

Data envelopment analysis

DEA is a non-parametric technique that computes efficiency scores in a descriptive data set; therefore, DEA does not require any assumption about the functional form (Fadavi *et al*., 2012).

In this study, they are cucumber greenhouses. So, the values of energy consumed from different energy inputs (MJ ha^{-1}), as mentioned above, were defined as input Indicators, and the yield of greenhouse cucumber production (kg ha^{-1}) was defined as output Indicator; furthermore, each greenhouse was called a decision making unit (DMU) (Monjezi *et al*., 2011). In DEA, 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) (Mousavi-Avval *et al*., 2011b).

The choice between input and output orientation depends on the unique characteristics of the set of DMUs under study. In this study, the input oriented approach was deemed to be more appropriate because there is only one output while the multiple inputs are used; furthermore as a recommendation, input conservation for giving outputs seems to be a more reasonable logic (Galanopoulos *et al*., 2006); so the greenhouse cucumber yield is held fixed and the quantity of input energy was reduced (Monjezi *et al*., 2011).

Technical efficiency

Technical efficiency can be defined as the ability of a DMU (e.g. A greenhouse) to produce maximum output given a set of inputs and technology level. The value of TE varies between zero and one; where a value of one implies that the DMU is a best performer located on the production frontier and has no reduction potential. Any value of TE lower than one indicates that the DMU uses inputs inefficiently. The TE score in the presence of multiple-input and output factors can be calculated by the ratio of the sum of weighted outputs y to the sum of weighted inputs x or in a mathematical expression as follows (Mousavi-Avval *et al*., 2011b):

$$TE_j = \frac{u_1 y_{1j} + u_2 y_{2j} + \cdots + u_n y_{nj}}{v_1 x_{1j} + v_2 x_{2j} + \cdots + v_m x_{mj}} = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{s=1}^{m} v_s x_{sj}} \qquad (2)$$

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 the number of outputs (*r* = 1, 2,…, n) and j represents j_{th} DMUs (*j*=1,2,…,k). Eq. (2) can be translated into a linear programming problem as follows (Mousavi-Avval *et al*., 2011c):

$$\begin{aligned}
&\text{Maximize } \theta = \textstyle\sum_{r=1}^{n} u_r y_{rj} \\
&\text{(i) } \textstyle\sum_{s=1}^{m} v_s x_{sj} = 1 \qquad i=1,2,\ldots,k \\
&\text{Subject to (ii) } \textstyle\sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_s x_{sj} \le 0 \qquad (3) \\
&\text{(iii) } u_r \ge 0 \quad r=1,2,\ldots,n \\
&\text{(iv) } v_s \ge 0 \quad s=1,2,\ldots,m
\end{aligned}$$

Where θ is the technical efficiency. Model (3) is known as the input oriented CCR DEA model introduced by Charnes *et al*. (1978). It assumes constant returns to scale condition under which the production possibility set is formed without any scale effect.

Pure technical efficiency

The CCR model includes both the technical and scale efficiencies. So, Banker *et al*. (1984) introduced a new variable in the CCR model to calculate the technical efficiencies of DMUs under variable return to scale conditions, known as pure technical efficiency. This model is called BCC model. In an input-oriented framework, the BCC model can be described by a dual linear programming problem as follows (Banker *et al*., 1984):

$$\begin{aligned}&\text{Maximize } z = uy_i - u_i\\ &\text{Subject to}\quad \begin{cases}(i)\ vx_i = 1\\ (ii)\ -vX + uY - u_0 e \leq 0\\ (iii)\ v \geq 0\ u \geq 0 \text{ and } u_0 \text{ is free to sign}\end{cases}\end{aligned} \tag{4}$$

Where z and u_0 are scalar and free to sign. u and v are output and inputs weight matrixes, and Y and X are corresponding output and input matrixes, respectively. The letters x_i And y_i Represent the inputs and output of its DMU.

Scale efficiency

SE relates to the most efficient scale of operations in the sense of maximizing the average productivity. A scale efficient cucumber greenhouse has the same level of technical and pure technical efficiency scores. It can be calculated as below (Nassiri and Singh, 2009):

$$\mathrm{SE} = \frac{\mathrm{TE}}{\mathrm{PTE}}$$

If a DMU is fully efficient in both the technical and pure technical efficiency scores, it is operating at the most plenteous scale size. If a DMU has the full pure technical efficiency score (PTE), but has a low technical efficiency (TE) score, then it is locally efficient but not globally efficient due to its scale size. Thus, it is reasonable to characterize the scale efficiency of a DMU by the ratio of the two scores (SarIca, 2007).

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

$$\mathrm{ESTR_j} = \frac{(\text{Energy Saving Target})_\mathrm{j}}{(\text{Actual Energy Input})_\mathrm{j}}$$

Where the energy-saving target is the total reducing amount of input that could be saved without decreasing the output level and j represents j_{th} DMU. The minimal value of energy-saving target is 0, so the value of ESTR will be between zero and unity. A zero ESTR value indicates the DMU on the frontier such as the efficient ones; on the other hand, for inefficient DMUs, the value of ESTR is larger than zero, which means that energy could be saved. A higher ESTR value implies higher-energy inefficiency and a higher-energy saving amount (Hu and Kao, 2007).

Results and discussions

Energy use pattern

Table 2 shows the energy equivalent and ranking for inputs and output of greenhouse cucumber production.

Table 2. Energy equivalent and ranking for inputs and output of greenhouse cucumber production

Input	Equivalent Energy (GJ ha^{-1})	Percent (%)
Human Labor	61.44	10.32
Machinery	0.035	0.0058
Fuel	352.11	59.15
Chemical fertilizers	50.31	8.45
Farmyard manure (FYM)	10.33	1.74
Chemicals	76.67	12.88
Electricity	43.09	7.24
Water for irrigation	1.26	0.21
Total	595.24	100
Cucumber	152.63	-

The results revealed that fuel, chemicals and human labor with 59.15, 12.88 and 10.32 percent, had the greatest share of total input energies.

Fuel was used for operations such as warming the greenhouse and soil preparation (Rahbari *et al*., 2013). The total energy for cucumber producing was calculated as 595.24 GJ ha^{-1}. Rahbari *et al*. (2013) reported that the most energy-consuming input for greenhouse tomato production in Esfahan province was that for diesel fuel, electricity and human labor, respectively. Pahlavan *et al*. (2012) concluded that the total input energy and output energy for greenhouse cucumber were 436,824 MJ ha^{-1} and 128,532 MJ ha^{-1} respectively.

According to Omid *et al*. (2011), the input energy for cucumber production was to be 152.9 GJha^{-1} and the average inputs energy consumption was highest for diesel fuel, entire chemical fertilizer and electricity.

Technical, pure technical and scale efficiency of greenhouses

Results obtained by application of the input orientated DEA are illustrated in Table 3.

Table 3. Technical, pure technical and scale efficiency and return to scale

DMU	TE	PTE	SE	RTS
1	1	1	1	Constant
2	1	1	1	Constant
3	0.81	0.98	0.82	Increasing
4	0.82	1	0.82	Increasing
5	1	1	1	Constant
6	1	1	1	Constant
7	0.97	1	0.97	Increasing
8	0.97	1	0.97	Increasing
9	1	1	1	Constant
10	0.92	1	0.92	Increasing
11	1	1	1	Constant
12	0.81	0.99	0.81	Increasing
13	0.82	0.98	0.83	Increasing
14	0.96	1	0.96	Increasing
15	1	1	1	Constant
16	1	1	1	Constant
17	0.89	0.99	0.89	Increasing
18	0.89	0.98	0.90	Increasing
19	1	1	1	Constant
20	0.96	1	0.96	Increasing
21	0.95	0.98	0.96	Increasing
22	0.93	0.99	0.93	Increasing
23	0.90	0.97	0.92	Increasing
24	0.89	1	0.89	Increasing
25	0.86	0.98	0.87	Increasing
26	0.87	1	0.87	Increasing
27	1	1	1	Constant
28	0.98	1	0.98	Increasing
29	0.75	1	0.75	Increasing
30	0.97	1	0.97	Increasing
31	0.92	0.99	0.92	Increasing
32	0.92	0.98	0.93	Increasing
33	1	1	1	Constant
Mean	0.93	0.99	0.93	

The mean radial technical efficiencies of the samples under CRS and VRS assumptions are 0.93 and 0.99 respectively. This implies first, that on average, growing rooms could reduce their inputs by 7% (1%) and still maintains the same output level. Increasing the technical efficiency of a greenhouse actually means less input usage, lower production costs and, ultimately, higher profits, which is the driving force for producers motivated to adopt new techniques (Qasemi-Kordkheili *et al*., 2013). Efficiency of DMUs is illustrated in figure 1, by using CRS and VRS models.

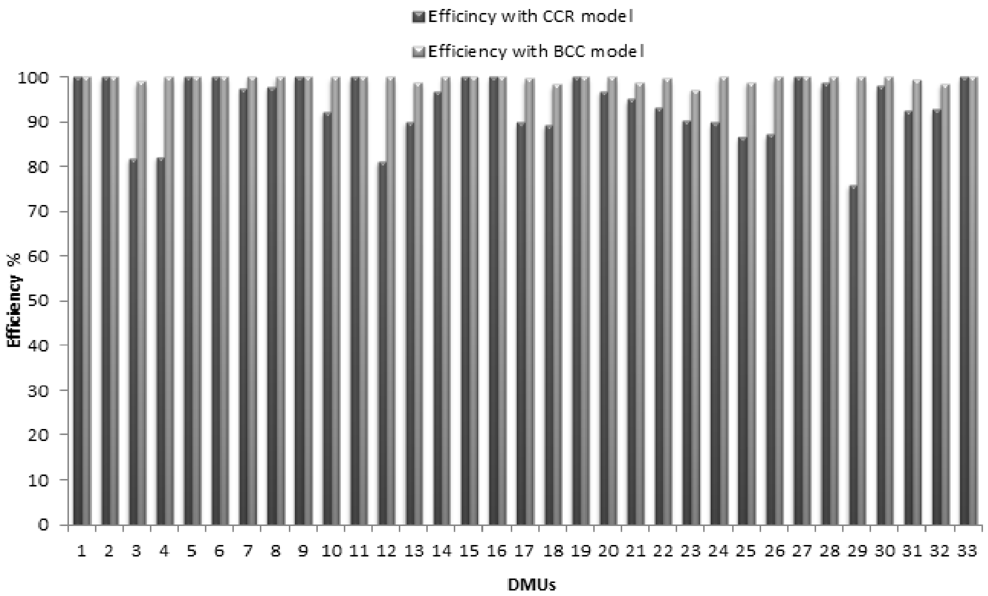

Fig.1. Efficiency of DMUs with CRS and VRS Input Oriented

Return to scale

The analysis shows that DMUs numbered 1, 2, 5, 6, 9,11,15,16,19,27 and 33 that are efficient and have the best practice. Furthermore they are operating at the most productive scale size where CRS applied and scale efficiency equals one. The return to scale (RTS) indicated that all efficient DMUs (based on technical efficiency) were operating at Constant Return to Scale (CRS), whereas all inefficient ones were at Increasing Return to Scale (IRS), which indicates that for considerable changes in yield, technological change is required. The IRS indicates that an increase in input resources produces more than the proportionate increase in outputs. The average of Scale Efficiency (SE) was as low as 0.93, which indicates that if inefficient farmers utilize their inputs efficiently, some saving in energy from the different sources is possible without any change in technological practices. In this area, no producer was found to operate at Decreasing Return to Scale (DRS). An additional 7% productivity gain would be possible- assuming no other constraining factors- provided they adjusted their growing room operation to an optimal scale. Reyhani *et al*. (2013) analyzed the Energy Efficiency of White Button Mushroom production in Iran. The results of DEA application revealed that the average technical, pure technical and scale efficiencies of producers were 0.955, 0.956 and 0.999, respectively.

Energy saving from different energy inputs

The actual energy use, optimum energy requirement and saving energy for greenhouse cucumber production based on the results of CRS model are shown in Table 4. Furthermore, the percentage of ESTR is illustrated in the last column. As it is indicated, the optimum energy requirements for greenhouse cucumber calculation showed that, 70.28 GJ ha^{-1} for fuel, 15.54 GJ ha^{-1} for chemicals, 9.50 GJ ha^{-1} for chemical fertilizers, 7.23 GJ ha^{-1} for electricity, 3.71 GJ ha^{-1} for human labor, 1.60 GJ ha^{-1} for farmyard manure 0.35 GJ ha^{-1} for water and 0.006 GJ ha^{-1} for machinery could be saved.

Table 4. Energy requirement in optimal condition and saving energy in greenhouse cucumber productionbased on CRS model

Input	**Optimal energy Requirement (GJ ha^{-1})**	**Actual energy Requirement (GJ ha^{-1})**	**Saving energy (GJ ha^{-1})**	**ESTR (%)**
Human Labor	57.73	61.44	3.71	6.03
Machinery	0.029	0.035	0.006	17.14
Fuel	281.83	352.11	70.28	19.96
Chemical fertilizers	40.81	50.31	9.50	18.88
Farmyard manure	8.73	10.33	1.60	15.48
Chemicals	61.13	76.67	15.54	20.27
Electricity	35.86	43.09	7.23	16.78
Water	0.91	1.26	0.35	27.78
Total	487.02	595.24	108.21	18.18

So if producers follow the recommendations resulted from this study, on average, about 108.21GJ ha-1 of total input energy could be saved while holding the constant output level of greenhouse cucumber yield. Mousavi-Avval *et al*. (2011c) reported that on an average, about 11.29% of the total input energy of apple production in Iran could be saved. Figure 2 shows the share of the various energy inputs in the entire input saving energy.

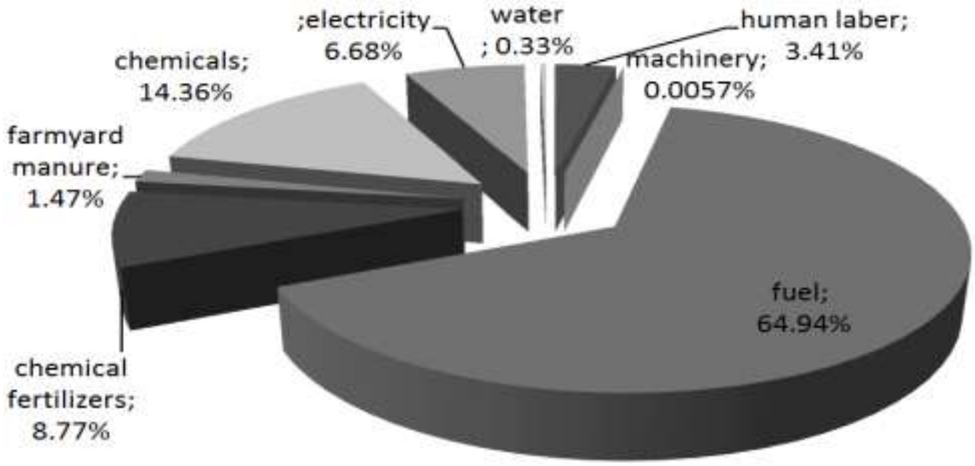

Fig. 2. Distribution of saving energy for greenhouse cucumber production in Markazi province of Iran

It is evident that, the highest contribution to the total saving energy is 64.94 % of the fuel followed by chemicals (14.36%), chemical fertilizers (8.77%), electricity (6.68%), human labor (3.41%), farmyard manure (1.47%) water (0.33%) and machinery (0.0057%) energy inputs. The results indicate that there is a greater scope to increase the energy use efficiency by accurate use of fuel and chemicals energy inputs. The highest contribution of saving fuel shows that using the heaters with low efficiency. Furthermore the high contribution of saving chemicals and chemical fertilizers that result using management of them are weak. Moreover, the contributions of human labor, machinery, farmyard manure, electricity, and water energy inputs were relatively low.

In Table 5, the PTE, actual energy use and optimum energy requirement from different energy inputs for 33 individual inefficient farmers are presented. Using this information, it is possible to advise an inefficient producer regarding the best operating practices followed by his peers. The target values of energy requirement are the recommendations resulted from this study, indicating how individual inefficient farmers can reduce their practice wise energy inputs without decreasing their output level; Therefore, the suggestion of these results will help to improve efficiency of farmers for greenhouse cucumber production in surveying the area (Mousavi-Avval *et al.*, 2011d). The energy-saving percentages of inefficient farmers are tabulated in the last column of Table 5.

Conclusion

This article described the application of DEA to the study for improving the energy use in the greenhouse cucumber production in Markazi province of

Iran. This technique allows the determination of the best-practice greenhouses and can also provide helpful insights for greenhouse management. DEA has helped in separating efficient farmers from inefficient farmers. It has also helped in finding the energy wasteful uses by inefficient farmers, ranking efficient farmers by using the CRS and VRS models and ranking energy sources by using technical, pure technical and scale efficiency. The results indicated that greenhouse cucumber production depends mainly on fuel, Chemicals and chemical fertilizers energy inputs. On an average, the total input energy could be reduced by 18.18% without reducing the output energy from its present level by adopting the recommendations based on this study. The average of energy input in greenhouse cucumber production was to be 595.64GJ ha-1, mainly due to total fuel (59.15%). Fuel, chemicals and chemical fertilizers energy inputs had the highest potential for saving energy. If the inefficient farmers paid more attention to fuel, chemicals and chemical fertilizers they would improve their energy productivity. The reduction in wasteful uses of energy may even enhance the viability of greenhouses, giving farmers a more control over energy consumption.

References

Banaeian, N., Omid, M. and Ahmadi, H. (2011). Application of data envelopment analysis to evaluate efficiency of commercial greenhouse strawberry, Research Journal of Applied Sciences, Engineering and Technology 3(3):185-193.

Banker, R., Charnes, A. and Cooper, W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manage Sci, 30:1078-1092.

Beheshti Tabar, I., Keyhani, A. and Rafiee, S. (2010). Energy balance in Iran’s agronomy(1990–2006). Renew Sustain Energy Rev, 14(2):849–855.

Cervinka, V. (1980). Fuel and energy efficiency. Handbook of Energy Utilization inAgriculture, ed. Pimentel, D., pp. 15-21.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978). Measuring the efficiency of decision making units. Eur J Operat Res, 2(6):429-444.

Cooper, W., Seiford, L.M. and Tone, K. (2007). Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. New York: Springer.

Erdal, G., Esengün, K., Erdal, H. and Gündüz, O. (2007) Energy use and economical analysis of sugar beet production in Tokat province of Turkey. Energy, 32(1):35-41.

Fadavi, R., Samavatean, N., Keyhani, A. and Mohtasebi, S.S. (2012). An Analysis of Improving Energy use with Data Envelopment Analysis in Apple Orchard. Asian Journal of Agriculture and Rural Development 2(2):277-286.

Galanopoulos, K., Aggelopoulos, S., Kamenidou, I. and Mattas, K. (2006). Assessing the effects of managerial and production practices on the efficiency of commercial pig farming. Agric Sys, 88:125-141.

Gezer, I., Acaroglu, M. and Haciseferogullari, H. (2003). Use of energy and labor in apricot agriculture in Turkey. Biomass Bioenergy 24:215–219.

Helsel, Z.R. (1992). In: Fluck RC, editor. Energy and alternatives for fertilizer and pesticide use in ‘‘Energy in world agriculture’’, Vol. 6. Amsterdam: Elsevier Science Publishing.

Hu, J.L. and Kao, C.H, (2007). Efficient energy saving targets for APEC economies. Energy Policy 35:373-382.

Kitani, O. (1999). Energy and Biomass Engineering. CIGR Handbook of Agricultural Engineering. 1(5): pp. 351.

Khan, S., Khan, M.A., Hanjra. M.A. and Mu, J. (2009). Pathways to reduce the environmental footprints of water and energy inputs in food production. Food Policy 31:141–149.

Mohammadi, A. and Omid, M. (2010). Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. Applied Energy 87(1):191–196.

Monjezi, N., Sheikhdavoodi M.J. and Taki, M. (2011). Energy use pattern and optimization of energy consumption for greenhouse cucumber production in Iran using data envelopment analysis (DEA). Modern Applied Science 5(6):139-135.

Mousavi-Avval, S.H., Rafiee, S., Jafari, A. and Mohammadi, A. (2011a) Optimization of energy consumption for soybean production using data envelopment analysis (DEA) approach. Applied Energy 88:3765–3772.

Mousavi-Avval, S.H., Rafiee, S., Jafari, A. and Mohammadi, A. (2011b). Improving energy use efficiency of canola production using data envelopment analysis (DEA) approach. Energy 36:2765-2772.

Mousavi-Avval, S.H., Rafiee, S., Jafari, A. and Mohammadi, A. (2011c). Optimization of energy consumption and input costs for apple production in Iran using data envelopment analysis. Energy, 36:909-916.

Mousavi-Avval, S.H., Rafiee, S., Jafari, A. and Mohammadi, A. (2011d) Energy storage in field operations of sunflower production using data envelopment analysis approach. International Journal Of Energy and Environment 2(5):933-944.

Nassiri, S.M. and Singh, S. (2008). Non-Parametric energy use efficiency, energy ratio and specific energy for irrigated wheat crop production. Iran Agricultural Research 27(1-2):27-38.

Nassiri, S.M. and Singh, S. (2009). Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique. Applied Energy 86:1320–1325.

Omid, M., Ghojabeige, F., Delshad, M. and Ahmadi, H. (2011). Energy use pattern and benchmarking of selected greenhouses in Iran using data envelopment analysis. Energy Conversion and Management 52:153-162.

Pahlavan, R., Omid, M. and Akram A. (2012). Application of data envelopment analysis for Performance assessment and Energy efficiency improvement opportunities in greenhouses cucumber production. J. Agr. Sci. Tech, 14:1465-1475.

Pimentel, D. and Hall, C.W. (1984). Food and Energy Resource. Academic Press, inc. pp. 512.

Qasemi-Kordkheili, P., Asoodar, M.A., Taki, M. and Keramati-E-Asl, M.S. (2013). Energy consumption pattern and optimization of energy inputs USAGE for button mushroom production. International Journal of Agriculture: Research and Review 3(2):361-373.

Rahbari, H., Mahmoudi, A. and Ajabshirchi, Y. (2013). Improving energy use effciency of greenhouse tomato production using data envelopment analysis (DEA) technique. International Journal of Agriculture: Research and Review 3(3):559-568.

Reyhani Farashah, H., Tabatabaeifar, S.H., Rajabipour, A. and Sefeedpari, P. (2013). Energy efficiency analysis of white button mushroom producers in Alburz province of Iran: A Data Envelopment Analysis Approach. Open Journal of Energy Efficiency 2:65-74.

Richard, C.F. (1992). Energy in farm production. (Elsevier: Netherlands).

SarIca, K. (2007). Efficiency assessment of Turkish power plants using data envelopment analysis. Energy 32(8):1484-1499.

Singh, H., Mishra, D. and Nahar, N.M. (2002). Energy use pattern in production agriculture of typical village in arid zone, India—part–I. Energy Conversion and Management 43:2275–2286.

Verma, S.R. (1987). Energy in Production Agriculture and Food Processing. Proceedings of the National Conference held at the Punjab Agricultural University, Ludhana. October 30-31.

Yamane, T. (1967). Elementary sampling theory. (Prentice Hall Englewood Cliffs: USA).

Yaldiz, O., Ozturk, H.H., Zeren, Y. and Bascetincelik, A. (1993). Energy use in field crops of Turkey. 5. International Congress of Agricultural Machinery and Energy, Kusadasi, Turkey, (in Turkish).

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Table 5. The actual energy use and optimum energy requirements for individual inefficient greenhouse cucumber producers based on the results of CRS

		Actual energy use (GJ ha^{-1})								Optimal energy requirement (GJ ha-1)								
DMU	**PTE**	Human Labor	Machinery	Fuel	Chemical fertilizers	FYM	Chemicals	Electricity	Water	Human Labor	Machinery	Fuel	Chemical fertilizers	FYM	Chemicals	Electricity	Water	ESTR %
3	0.98	48.51	0.027	278.00	62.99	10.41	55.94	42.32	1.19	39.68	0.022	223.42	41.21	7.72	45.75	31.92	0.880	21
4	1	30.96	0.044	273.60	34.55	10.12	40.54	43.02	1.52	25.43	0.016	148.83	27.59	5.28	33.3	21.98	0.562	39
7	1	39.2	0.02	164.00	46.81	10.6	31.66	42.7	1.07	38.20	0.0089	160.00	24.13	4.70	30.85	18.92	0.356	17
8	1	42.14	0.024	325.00	17.98	10.21	65.81	41.00	1.19	41.22	0.234	243.75	17.59	5.90	52.98	25.29	0.912	23
10	1	83.3	0.011	445.00	58.07	10.21	79.47	44.96	1.16	76.36	0.010	337.29	46.61	9.41	62.64	37.22	0.914	21
12	0.99	70.56	0.027	350.53	57.41	10.10	89.00	46.00	1.17	57.247	0.020	269.47	39.512	8.19	55.83	33.30	0.599	25
13	0.98	71.69	0.029	432.40	67.42	10.22	100.86	44.86	1.73	64.49	0.022	303.01	44.36	9.20	62.59	37.36	0.672	28
14	1	73.5	0.010	237.50	50.86	10.6	107.44	42.91	1.57	70.47	0.0096	229.50	39.95	8.77	60.47	35.89	1.17	14
17	0.99	80.43	0.030	278.65	60.73	10.23	86.13	43.95	1.73	72.18	0.019	250.05	51.67	9.18	65.05	38.10	0.806	13
18	0.99	47.07	0.030	485.00	33.35	10.35	111.61	42.19	1.03	41.98	0.026	318.70	29.76	7.63	69.99	31.148	0.927	31
20	0.98	25.48	0.030	603.80	35.65	10.03	79.07	44.07	0.88	24.65	0.029	177.79	33.18	7.03	57.65	30.13	0.534	58
21	1	38.57	0.080	425.60	35.50	10.60	105.37	43.56	0.88	36.66	0.076	364.88	33.74	9.56	71.22	39.50	0.838	15
22	0.98	69.77	0.025	432.40	67.42	10.22	63.35	45.00	1.81	65.02	0.022	310.31	48.18	9.53	59.03	38.63	0.855	22
23	0.99	82.94	0.025	473.60	59.34	10.59	101.34	42.31	0.99	74.85	0.019	331.54	46.20	9.52	61.67	38.18	0.694	27
24	0.97	85.92	0.023	485.00	87.37	10.09	83.72	39.96	0.99	77.08	0.657	327.94	44.04	9.04	56.17	35.85	0.657	30
25	1	76.44	0.025	485.00	67.40	10.22	82.81	44.95	1.65	66.11	0.019	300.40	42.79	8.84	58.59	35.67	0.646	33
26	1	20.05	0.030	345.98	20.86	10.36	64.48	44.56	1.31	17.46	0.026	156.68	18.17	4.56	37.82	19.09	0.424	49
28	0.98	77.57	0.027	274.66	77.54	10.09	69.44	41.12	1.13	76.46	0.021	270.71	56.12	9.81	68.45	40.53	0.902	5
29	1	40.47	0.533	274.66	35.05	10.09	90.27	41.98	0.84	30.73	0.341	208.58	26.62	6.27	44.94	25.96	0.476	30
30	1	22.01	0.120	347.20	11.58	10.54	38.63	42.12	1.25	21.55	0.054	215.32	11.33	4.94	33.89	20.77	0.546	34
31	0.99	69.93	0.0.25	317.00	67.56	10.22	117.90	42.95	1.66	64.56	0.023	292.67	48.35	9.44	66.91	38.75	0.730	16
32	0.98	88.20	0.027	354.00	78.07	10.61	54.59	43.08	1.02	80.22	0.015	328.53	49.03	9.56	50.66	38.00	0.949	11