Application of Parametric and Non-parametric Method to Analyzing of Energy Consumption for Cucumber Production in Iran

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Abstract

This study applied a parametric (Cobb-Douglas production function) and non-parametric (Data Envelopment Analysis) method to examine the energy equivalents of inputs and output, 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 cucumber greenhouse production in Esfahan province of Iran. Data were collected from 25 cucumber greenhouses in Esfahan province (Iran) by using a face-to-face questionnaire. Results showed that the cucumber production consumed a total 124447.5MJ ha^{-1} and diesel fuel is the major energy inputs in this cultivation. The CCR and BCC models indicated 6 and 9 greenhouses were efficient, respectively. The average values of TE, PTE and SE of greenhouses were found to be 0.90, 0.95 and 0.94, respectively. The results also revealed that about 8.12% of the total input resources could be saved if the farmers follow the input package recommended by the DEA. Econometric model evaluation showed that the impact of human power for cucumber production was significant at 1% levels and had the highest effect among all the inputs in this research, also the regression coefficient of fertilizer energy was found negative, indicating that power consumption for fertilizer is high in the surveyed greenhouses.

Keywords: Cobb-Douglas production function, Data envelopment analysis, Energy efficiency, Iran

1. Introduction

Cucumber is one of the major greenhouse vegetables products worldwide. In Iran, it was cultivated on 78000 ha and the production was 1.72 million tons in 2007. From 2002 to 2007, greenhouse areas of Iran increased from 3380 ha to 6630 ha with an increasing rate of 96%. The shares of greenhouse crops production were as follows: vegetables 59.3%, flowers 39.81%, fruits 0.54% and mushroom 0.35% (Omid, et al., 2010).

Greenhouses use large quantities of locally available non-commercial energies, such as manure, animate and seed energies and commercial energies directly and indirectly in the form of diesel, electricity, fertilizer, pesticides, irrigation water, machinery, etc. (Mandal, et al., 2002; Heidari and Omid, 2011). Efficient use of these energies helps to achieve increased productivity and contributes to the economy, profitability and competitiveness of agricultural sustainability of rural communities (Manes and Singh, 2005; Hatirli, et al., 2006; Heidari and Omid, 2010).

In the developed countries, an increase in the crop yield was mainly due to an increase in the commercial energy inputs in addition to improved crop varieties (Faidley, 1992). Generally, land productivity is measured as the total measure of crop productivity. The yield that is the amount of crop produced per unit area (kg ha^{-1}), has been considered as the total measure of productivity (Singh, et al., 2003). However, it is only a partial measure of agricultural productivity like other measures, such as human labor productivity, seed productivity and diesel productivity. In addition, parametric analysis has been the predominantly applied tool in these studies (Ozkan, et al., 2004; Omid, et al., 2010). Similarly, the energy use efficiency (output energy to input energy ratio) and specific energy, i.e., input energy to yield ratio (MJ kg^{-1}) of farmers in crop production systems are indices, which can define the efficiency and performance of farms (Acaroglu, 1998; Omid, et al., 2010). Many experimental works have been conducted on energy use in agriculture (Canakci and Akinci, 2006). Cetin and Vardar (2008) studied on differentiation of direct and indirect energy inputs in agro industrial production of tomatoes. Erdal et al. (2007) have studied on energy consumption and economical analysis of sugar beet production. Damirjan et al. (2006) studied the energy and economic analysis of sweet cherry production. Alam, et al. (2005) studied the energy flow in agriculture of Bangladesh for a period of 20 years. Satori et al. (2005) studied the comparison of energy consumption on two farming system of conservation and organic in Italy.

In recent years, Data Envelopment Analysis (DEA) as a non-parametric method has become a central technique in productivity and efficiency analysis applied in different aspects of economics and management sciences. Although within this context, several researchers have focused on determining efficiency in agricultural units and various products ranging from cultivation and horticulture to aquaculture and animal husbandry for example: surveying the quantity of inefficient resources which are used in cotton production in Panjab in Pakistan (Shafiq and Rehman, 2000), reviewing energy performance used in paddy production (Nassiri and Singh, 2009), surveying improving energy efficiency for garlic production (Samavatian, et al., 2009), evaluation and development of optimum consumption of energy resources in greenhouse cultivation in Tehran province (Gochebeyg, et al., 2009), checking the efficiency and returning to the scale of rice farmers in four different areas of Panjab state in India by using Non-parametric method of data envelopment analysis (Nassiri and Singh, 2010), determination of the amount of energy consumption in wheat cultivation of Fars province with the approach of data envelopment analysis (Houshyar, et al., 2010). A further comparative review of frontier studies on agricultural products can be found in (Sharma, et al., 1999; Iraizoz, et al., 2003; Galanopoulos, et al., 2006; Singh, et al., 2004; Chauhan, et al., 2006; Banaeian, et al., 2010; Mousavi-Avval, et al., 2010; Banaeian, et al., 2011; Canakci and Akinci, 2006).

Based on the literature, the main objective of this study is to use a parametric and non-parametric method exploring the relationship between output and energy inputs using various functional forms and optimization of energy inputs for cucumber production in Esfahan province of Iran. In addition, the relationship is examined for different energy sources in the form of renewable and non-renewable, direct and indirect energy.

2. Materials and Methods

2.1 Selection of Case Study Farms and Data Collection

Data were collected from growers in Esfahan province producing cucumber, by using a face-to-face questionnaire in the production year 2010-2011. The survey was carried out in 10 villages where important cucumber production exists. A total of 25 growers were randomly selected from the villages using the stratified random sampling method.

2.2 Energy Equivalents Used

Based on the energy equivalents of the inputs and output (Table 1), the energy ratio (energy use efficiency), energy productivity, specific energy and net energy were calculated (Singh, et al., 1997; Mohammadi and Omid, 2010):

$$\text{Energy ratio} = \frac{\text{Energy Output (MJ ha}^{-1})}{\text{Energy Input (MJ ha}^{-1})} \quad (1)$$

$$\text{Energy productivity} = \frac{\text{Cucumber Output (kg ha}^{-1})}{\text{Energy Input (MJ ha}^{-1})} \quad (2)$$

$$\text{specific energy} = \frac{\text{Energy Input (MJ ha}^{-1})}{\text{Tomato or Cucumber Output (kg ha}^{-1})} \quad (3)$$

$$\text{Net energy} = \text{Energy Output (MJ ha}^{-1}) - \text{Energy Input (MJ ha}^{-1}) \quad (4)$$

The output-input energy ratio (energy use efficiency) is one of the indices that show the energy efficiency of agriculture. In particular, this ratio, which is calculated by the ratio of input fossil fuel energy and output food

energy, has been used to express the ineffectiveness of crop production in developed countries (Unakitan, et al., 2010; Dalgaard, et al., 2001). An increase in the ratio indicates improvement in energy efficiency, and vice versa. Changes in efficiency can be both short and long terms, and will often reflect changes in technology, government policies, weather patterns, or farm management practices. By carefully evaluating the ratios, it is possible to determine trends in the energy efficiency of agricultural production, and to explain these trends by attributing each change to various occurrences within the industry (Unakitan, et al., 2010).

For the growth and development, energy demand in agriculture can be divided into direct and indirect energies or alternatively as renewable and non-renewable energies (Kizilaslan, 2007). The indirect energy includes the chemicals, fertilizers, seeds and machinery. The direct energy includes human labor, fuel and electricity power. The non-renewable energy sources include fuel, electricity, fertilizers, chemicals and machinery, whereas the renewable energy sources include human labor, seeds and manure fertilizers (Yilmaz, et al., 2005). The energetic efficiency of the agricultural system has been evaluated by the energy ratio between output and input. Human labor, machinery, diesel, fertilizer, chemicals, water for irrigation and seed amounts, and output yield have been used to estimate the energy ratio. Energy equivalents, shown in Table 1, were used for estimation; these coefficients were adapted from several literature sources. The sources of mechanical energy used on the selected farms include tractors and diesel oil. The mechanical energy was computed regarding total fuel consumption (l ha^{-1}) in various operations; therefore, the energy consumed was calculated using conversion factors, and was expressed in MJ ha^{-1} (Bayramoglu and Gundogmus, 2009; Unakitan, et al., 2010). The energy of a tractor and its equipment reveals the amount of energy needed for unit weights and calculates repair and care energy, transport energy, total machine weight, and average economic life (Ozkan, et al., 2004).

2.3 Data Envelopment Analysis as a Non-parametric Method

DEA is a linear programming model that attempts to maximize a service unit's efficiency within the performance of a group of similar service units that are delivering the same service. In their original paper Charnes et al.(1978) introduced the generic term "decision making units" (DMU) to describe the collection of firms, departments, or divisions which have multiple incommensurate inputs and outputs and which are being assessed for efficiency. Since then it has been successfully deployed in many different sectors to assess and compare the efficiency of DMUs (Banker and Thrall, 1992; Korhonen and Luptacik, 2004). The DEA models deployed in this study are Charnes, Cooper and Rhodes (CCR), Banker, Charnes, and Cooper (BCC). Efficiency models which are summarized as follows (Sarıca and Or, 2005):

2.3.1 The CCR Efficiency Model

It is also called the technical efficiency model. The main assumption behind is "constant returns to scale", under which the production possibility set is formed without any scale effect. As Charnes et al. (1978) reported the LP model deployed to generate the CCR efficiency factors of the DMUs considered is as follows.

The CCR model (to be solved for each $DMUk_0$):

$$\max \theta_{ccR}(k_0) = \sum_{j=1}^{n} u_j y_j k_0 \tag{5}$$

$s.t.$

$$\sum_{i=1}^{m} \theta_i X_i k_0 = 1 \tag{6}$$

$$-\sum_{i=1}^{m} \theta_i X_i k_0 + \sum_{j=1}^{n} u_j y_{jk} \le 0 \qquad u_j \ge 0,\ \theta_j \ge 0 \tag{7}$$

$k = 1, \ldots, K \qquad j = 1, \ldots, n \qquad i = 1, \ldots, m$

Where u_j is the weight for output j; θ_i the weight for input i; m the number of inputs; n the number of outputs; K the number of DMU_s; y_{jk} the amount of output j of DMU_k; and x_{ik} the amount of input i of DMU_k.

2.3.2 The BCC Efficiency Model

It is also called the pure technical efficiency model. The main assumption behind is "variable returns to scale", under which the production possibility set is the convex combinations of the observed units. Banker et al (1984) reported the LP model deployed to generate BCC efficiency factors of the DMUs is as follows. The BCC model (to be solved for each DMU_{k_0}):

$$\max \theta_{BCC}(k_0) = \sum_{j=1}^{n} u_j y_{jk_0} - u(k_0) \tag{8}$$

s.t.

$$\sum_{i=1}^{m} \theta_i X_{ik_0} = 1 \tag{9}$$

$$-\sum_{i=1}^{m} \theta_i X_{ik_0} + \sum_{j=1}^{n} u_j y_{jk} - u(k_0) \le 0 \quad u_j \ge 0, \ \theta_j \ge 0 \tag{10}$$

$k = 1,..., K \qquad j = 1,..., n \qquad i = 1,..., m$

The inefficiency that a DMU might exhibit may have different causes: whether it is caused by the inefficient operation of the DMU itself or by the disadvantageous conditions, under which the DMU is operating, is an important issue to be clarified (Boussofiane et al, 1991; Mahgary and Lahdelma, 1995). In this regard, comparisons of the CCR and BCC efficiency scores deserve attention. The CCR model assumes a radial expansion and reduction of all observed DMUs (and their nonnegative combinations are possible); while the BCC model only accepts the convex combinations of the DMUs as the production possibility set. If a DMU is fully (100%) efficient in both the CRR and BCC scores, it is operating at the most productive scale size. If a DMU has the full BCC score, but a low CCR 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. So, scale efficiency is defined as:

$$SE = {}^{\theta_{CCR}}/_{\theta_{BCC}} \tag{11}$$

Where θ_{CCR} and θ_{BCC} are the CCR and BCC scores of a DMU, respectively. By definition, SE cannot be greater than one. In the analysis of efficient and inefficient DMUs, the energy saving target ratio (ESTR) index was used as follows (Hu and Kao, 2007):

$$ESTR(\%) = \frac{Energy\ saving\ target}{Actual\ energy\ input} \times 100 \tag{12}$$

Where energy saving target is the total reducing amount of input that could be saved without decreasing output level. ESTR represents the inefficiency level for each DMU with respect to energy use. The minimal value of energy saving target is zero, so the percentage of ESTR will be between zero and 100. A zero ESTR percentage shows the DMU on the frontier, such as efficient ones; on the other hand for inefficient DMUs, the ESTR percentage is larger than zero and means that energy could be saved. A higher ESTR percentage implies higher energy inefficiency and a higher energy saving amount (Hu and Kao, 2007; Mousavi-Avval, et al., 2010).

2.4 Cobb–Douglas Function as a Parametric Method

Realizing that output is a function of inputs, production function can be expressed as $Y = F\left(X_{it}\right)$ where Y is output level, X_{it} is a vector of input variables that affect output such as fertilizer, diesel fuel, electricity etc, and t is a time subscript.

In order to estimate this relationship, a mathematical function needs to be specified. For this purpose, several functions were tried, and the Cobb–Douglas production function was chosen since it produced better results among the others. The Cobb–Douglas production function is expressed in general form as follows (Hatirli, et al., 2005):

$$Ln\ Y_n = \beta_0 + \sum_{i=1}^{n} \beta_i\ Ln\ (X_{in}) + \varepsilon_n \tag{13}$$

Where Y_n denotes the yield of the n th farmer, β_0 is a constant, β_1 denotes coefficients, and ε_n is the error term, assumed normally distributed with mean 0 and constant variance σ^2.

Assuming that when the energy input is zero, the crop production is also zero, Eq. (13) reduces to:

$$Ln\ Y_n = \sum_{i=1}^{n} \beta_i\ Ln\ (X_{in}) + \varepsilon_n \tag{14}$$

Total physical energy consisted of human, electricity, diesel fuel, machinery, seed, fertilizer, water for irrigation and chemicals. Following this explanation, Eq. (14) can be given as:

$$Ln\ Y_n = \beta_1\ Ln\ FR + \beta_2\ Ln\ MA + \beta_3 Ln\ HU + \beta_4 Ln\ CH + \beta_5 Ln\ SD + \beta_6 Ln\ DS + \beta_7 Ln\ EL + \beta_8\ Ln\ WA + \varepsilon_n \tag{15}$$

Where Y is the output, FR is the fertilizer, MA is the machinery, HU is the human labor, CH is the total chemicals, SD is the seed, DS is the diesel fuel and EL is the electricity input and WA is the water for irrigation input.

The study was also aimed at investigating the relationship between output and different energy forms. More specifically, we considered different energy forms as renewable or nonrenewable, as direct or indirect. As a

functional form, the Cobb–Douglas production function was selected and specified in the following forms (Hatirli, et al., 2005):

$$Ln\, Y_n = \varphi_1 Ln\, DE + \varphi_2 Ln\, IDE + \varepsilon_n \quad (16)$$

$$Ln\, Y_n = \mu_1 Ln\, RE + \mu_2 Ln\, NRE + \varepsilon_n \quad (17)$$

Where RE and NRE denote renewable and non-renewable energy forms, respectively. DE represents direct energy and IDE denotes indirect energy. Basic information on energy inputs and cucumber yields were entered into Excel's spreadsheet and simulated using eviews and Frontier Professional Analyst 5 software.

3. Results and Discussion

3.1 Energy Use Pattern

The inputs, used in the cucumber production and their energy equivalents, together with the energy equivalent of the yield were illustrated in Table 2.

As indicated in the table about 10 kg chemicals, 871 kg chemical fertilizer and 14.2 tones manure were used in greenhouse cucumber production on a hectare basis. The use of human labor and machinery were 3789 and 40hha^{-1}, respectively. Average cucumber yield was 88123 kg ha^{-1}. The total energy input was calculated 124.44 GJha^{-1}. Diesel fuel was the energy input in the total with a share of 45%. This was followed by fertilizers (25%) and electricity (20%). The distributions of inputs used in the production of cucumber are given in Figure 1.

The energy ratio (energy use efficiency), energy productivity, specific energy, net energy and the distribution of inputs used in the production of cucumber according to the direct, indirect, renewable and non-renewable energy groups, are given in Table 3. In this table, the Energy use efficiency (energy ratio) for cucumber was calculated as 0.56, showing the inefficiency use of energy in the greenhouse cucumber production. By raising the crop yield, decreasing energy inputs consumption, insulate the roof and walls, use of renewable energy and optimization of energy consumption the energy ratio can be increased. Other authors reported similar results such as 0.69 (Heidari and Omid, 2011), 0.76 (Ozkan, et al., 2004) and 0.64 (Mohamadi and Omid, 2010). The reason of low energy ratio in this research in comparison with other researches may be including: low yield, using high energy inputs consumption, not being insulate for roof and walls, etc. It is clear that the use of renewable energy in this region is very low, indicating that cucumber production depends mainly on fossil fuels.

It is seen that the ratio of direct and indirect energy and also the ratios of renewable and non-renewable energy are fairly different from each other in cucumber. The ratio of renewable energy including the energies of human labor and farm fertilizer inputs, within the total energy in this production is very low. Renewable energy resources (solar, hydroelectric, biomass, wind, ocean and geothermal energy) are inexhaustible and offer many environmental benefits over conventional energy sources. Each type of renewable energy also has its own special advantages that make it uniquely suited to certain applications (Miguez, et al., 2006).

The use of renewable energy offers a range of exceptional benefits, including: a decrease in external energy dependence; a boost to local and regional component manufacturing industries; promotion of regional engineering and consultancy services specializing in the use of renewable energy, decrease in impact of electricity production and transformation; increase in the level of services for the rural population; creation of employment, etc. (Kaya, 2006).

Within the enterprises that were analyzed, 90% of input energy resources used for the production of cucumber was non-renewable energy**.**

3.2 Data Envelopment Analysis

Results obtained by the application of the input-orientated BCC and CCR DEA models are illustrated in Table 4. It is evident that from the total of 25 farmers, considered for the analysis, 6 (24%) and 9 (36%) had the technical and pure technical efficiency scores of one and they are recognized as technically and pure technically efficient farmers, respectively; so, they have no reduction potential on energy use. The results revealed that, the average technical (global), pure technical (local) and scale efficiency scores were 90%, 95% and 94%, respectively. Omid et al (2010) estimated the technical, pure technical and scale efficiencies of farmers as 87%, 97% and 90%, respectively, in cucumber production activities in Tehran province of Iran. In another study by Iraizoz et al. (2003) the efficiency of tomato and asparagus production in Spain was analyzed. In this study the technical, pure technical and scale efficiencies for tomato production were found to be as 75%, 80% and 94% and for asparagus production as 81%, 89% and 91%, respectively.

Table 5 shows the optimum, actual and saving energy for cucumber production based on the results of BCC model. Also, the percentages of ESTR are illustrated in the last column (this data received from Frontier Professional

Analyst software). As indicated, optimum energy requirement for diesel fuel (48123MJ ha^{-1}) was found to be the highest. Also, the optimum values of fertilizer, electricity, water for irrigation, machinery, chemicals, human labor energy inputs were calculated as 28956, 23987, 1792, 2563, 1703 and 7213.2 $MJha^{-1}$, respectively. Moreover, the results of ESTR calculation showed that, 2.2% from electricity, 13.58% from diesel fuel, 66% from water for irrigation, 5.54% from fertilizer, 2.58% from human labor, 1.11% from machinery and 2.90% from chemicals energy consumption could be saved. The percentage of total saving energy in optimum requirement over total actual use of energy was calculated as 8.12%, indicating that by following the recommendations resulted from this study, on average, about 10105.14 MJ ha^{-1} of total input energy could be saved while holding the constant output level of cucumber yield.

Figure 2 shows the share of the various energy inputs in the total input saving energy. It is evident that, the highest contribution to the total saving energy is 74.18% from diesel fuel followed by fertilizer (16.81%), electricity (5.35%) and human labor (2.1%) energy inputs. Moreover, the contributions of machinery, chemicals and water for irrigation energy inputs were relatively low. These inputs contributed to the total saving energy at less than 1%, showing that, they have been used in the right proportions by almost all the DMUs. The results indicate that there is a greater scope to increase the energy use efficiency by accurate use of diesel fuel, fertilizers and electricity energy inputs.

3.3 Econometric Model Estimation of Cucumber Production

The relationship between energy inputs and greenhouse vegetable yields were estimated by Cobb–Douglas production function (Eq.16) and using least square estimation technique was assessed. Accordingly, the yield of each kind of greenhouses was assumed to be a function of human labor, machinery, diesel fuel, fertilizers, chemicals, water for irrigation, seed and electricity energy. Autocorrelation test was performed using DurbineWatson (DW) test (Heidari and Omid, 2010). The test results indicated that DW values of cucumber was in 1.75, i.e. there was no autocorrelation at the 5% significance level in the estimated model. The R^2 coefficient was as 0.97 for this linear regression model that revealed variability of this model in the energy inputs. The result of regression for this model is shown in Table 6. It can be seen from Table 6 that for cucumber production, human labor had the highest impact (0.45) among other inputs and significantly contributed on the yield at 1% level. This indicates that with an additional use of 1% for of this input would lead to 0.45% increase in cucumber yield. The other important inputs were chemicals, diesel fuel, machinery, electricity and water for irrigation elasticity of 0.33, 0.17, 0.20, 0.12 and 0.15, respectively, at 5% significant level. The impact of seed energy on yield for this crop was statistically insignificant with a negative sign. Heidari and Omid (2010), estimated an econometric model for cucumber and tomato production in Iran. They reported that the inputs of human labor and chemicals had significant impacts on improving the yield of cucumber and tomato, respectively. The regression coefficients of fertilizer and diesel fuel inputs for both productions were found negative, indicating that power consumption for fertilizer and diesel fuel are high in the surveyed greenhouses. Mobtaker et al. (2010) estimated an econometric model for barley production in Iran. They reported that the inputs of human labor, machinery, diesel fuel, water for irrigation and electricity had significant impacts on improving the yield of barley.

The relationship between the direct (DE) and indirect (IDE) energies, as well as renewable (RE) and non-renewable (NRE) energies on the yield of cucumber production were investigated, respectively. The results are presented in Table 7. As can be seen, all the regression coefficients of DE and RE forms were positive and significant ($p < 1\%$). The regression coefficients was also significant ($p < 1\%$). Other regression coefficients contributed on the yield ($p < 5\%$). The impacts of DE, IDE, RE and NRE were estimated in the range of 0.17-1.21. The impact of IDE was more than the impact of DE on cucumber yield. Similar results can be seen in the study of Heidari and Omid(2010) for greenhouse production of tomato and cucumber in Tehran province of Iran. Statistical tests revealed that DW values were 1.98-2.33, indicating that there is no autocorrelation at the 5% significance level in the estimated models.

4. Conclusion

Based on the present paper following conclusions are drawn:

1- The total energy consumption in cucumber productions was 124447.5MJ ha^{-1}. Diesel fuel and fertilizers were found the most energy consumer among all energy sources.

2- Energy ratio for cucumber production was calculated as 0.56, indicated inefficiency use of energy in this cultivation.

3- The share of non-renewable energy for cucumber production was 90%. The use of renewable resources of energy like green manure instead of chemical fertilizers and solar energy and natural gas instead of diesel fuel should be practiced to improve the situation.

4- The results of DEA approach showed that substantial production inefficiency for farmers and therefore, a potential 8.12% reduction in total energy input use may be achieved provided all farmers operated efficiently and assuming no other constraints on this adjustment.

5- The impact of human labor energy input for cucumber production was significantly positive on yield ($p < 1\%$). The regression coefficient of diesel fuel energy for this production was found negative, indicating that fuel consumption is high in the surveyed greenhouses.

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Table 1. Energy equivalents for different inputs and outputs in cucumber production

	Unit	Energy equivalent (MJ Unit^{-1})	Reference
Inputs			
Human labor	H	1.96	Singh, 2002
Machinery	kg	64.8	Singh, 2002
Diesel fuel	L	47.8	Singh, 2002
Chemicals	kg		
Herbicides	kg	238	Singh, 2002; Shrestha, 2002
Fungicides	kg	216	Singh, 2002; Shrestha, 2002
Insecticides	kg	101.2	Singh, 2002; Shrestha, 2002
Fertilizer	kg		
Nitrogen	kg	66.14	Yaldiz et al, 1993
Phosphate	kg	12.44	Shrestha, 2002; Nagy, 1999
Potassium	kg	11.15	Shrestha, 2002; Nagy, 1999
Manure	tons	303.10	Shrestha, 2002; Nagy, 1999
Water for irrigation	M^3	1.02	Shrestha, 2002; Nagy, 1999
Electricity	kWh	11.93	Pathak and Binning, 1985 ; Esengun et al, 2007
Seed	kg	1.0	Singh, 2002
Output			
cucumber	kg	0.8	Yaldiz et al, 1993

Table 2. The physical inputs used in the production of cucumber and their energy equivalences

Input (unit)	Quantity per unit area (ha)	Total energy equivalent (MJ)	Percentage
1. Chemicals (kg)	-	-	1
Herbicides (kg)	2.5	595	
Fungicides (kg)	3.4	734	
Insecticides (kg)	4.2	425	6
2. Human labor (h)	3789	7426.4	
3. Machinery (kg)	40	2592.0	2
4. Fertilizer (kg)	-	-	25
Nitrogen fertilizer (kg)	295	19511	
Phosphate (kg)	325	4043	
Potassium (kg)	251	2798	
Manure (tones)	14.2	4304	
5. Seeds (kg)	0.15	0.12	
6. Diesel fuel (l)	1165	55687	45
7. Electricity (kWh)	2056	24528	20
8. Water for irrigation (m^3)	1769	1804	1
Total energy input (MJ)	-	124447.5	100
Yield (kg ha^{-1})	88123	70498	

Bold characters are main inputs

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Table 3. Energy output–input ratio and forms in cucumber production

Items	Unit	Cucumber	Percentage
Energy ratio	-	0.56	
Energy productivity	$kgMJ^{-1}$	0.70	
Specific energy	$MJkg^{-1}$	1.41	
Net energy	$MJha^{-1}$	-53949.5	
Energy forms [a]			
Direct energy [b]	$MJha^{-1}$	87641.4	71
Indirect energy [c]	$MJha^{-1}$	35002.12	29
Renewable energy [d]	$MJha^{-1}$	11730.52	10
Non- renewable energy [e]	$MJha^{-1}$	110913	90
Total energy input	$MJha^{-1}$	124447.5	100
Energy output	$MJha^{-1}$	70498	

[a] Energy equivalent of water for irrigation is not included

[b] include human labor, fuel and electricity power

[c] include the chemicals, fertilizers, seeds and machinery

[d] include human labor, seeds and manure fertilizers

[e] include fuel, electricity, chemicals, fertilizers and machinery

Table 4. Analyses of efficiency and return to scale in cucumber production

DMU	Technical efficiency	Pure technical efficiency	Scale efficiency	Return to scale
Gh01	89.51	92.23	97	Increasing
Gh02	96.63	97.7	98	Increasing
Gh03	100	100	100	Constant
Gh04	100	100	100	Constant
Gh05	93.31	100	93.31	Increasing
Gh06	95.43	100	95.43	Increasing
Gh07	100	100	100	Constant
Gh08	92.82	94.35	98	Increasing
Gh09	92.37	93.2	99	Increasing
Gh10	100	100	100	Constant
Gh11	92	97.59	92	Increasing
Gh12	82.81	89.7	92	Increasing
Gh13	76.23	88.9	85	Increasing
Gh14	85.12	92.7	91	Increasing
Gh15	81.35	93.4	87	Increasing
Gh16	91.47	96.1	95	Increasing
Gh17	100	100	100	Constant
Gh18	92.15	100	92.15	Increasing
Gh19	79.9	87.43	91	Increasing
Gh20	83.69	90.12	92	Increasing
Gh21	100	100	100	Constant
Gh22	87.59	92.15	95	Increasing
Gh23	85.56	87.34	97	Increasing
Gh24	79.49	91.38	86	Increasing
Gh25	83.39	93.19	89	Increasing
Average	**90.37**	**95.09**	**94.6**	-

Table 5. Energy requirement in optimal condition and saving energy for cucumber production

Input	Actual energy use ($MJha^{-1}$)	Optimal energy requirement ($MJha^{-1}$)	Saving energy ($MJha^{-1}$)	ESTR (%)
Human labor	7426.4	7213.2	213.2	2.87
Machinery	2592.0	2563	29	1.11
Fertilizer	30656	28956	1700	5.54
Chemicals	1754	1703	51	2.90
Diesel fuel	55687	48123	7564	13.58
Electricity	24528	23987	541	2.20
Water for irrigation	1804	1792	12	0.66
Seeds	0.12	0.12	0	0
Total	124447.5	114337.32	10110.2	8.12

Table 6. Economic estimation result of cucumber greenhouses

Variables	Coefficient	t- Ratio
$(E_q 7).LnY_n = \beta_1 LnFR + \beta_2 LnMA + \beta_3 LnHU + \beta_4 LnCH + \beta_5 LnSD + \beta_6 LnDS + \beta_7 LnEL + \beta_8 LnWA + \varepsilon_n$		
Human labor	0.45	5.93*
Diesel fuel	-0.17	-0.13ns
Machinery	0.20	3.54**
Chemicals	0.33	5.12**
Fertilizers	-0.07	-0.32ns
Electricity	0.12	2.12**
Water for irrigation	0.15	2.23**
Seeds	-0.05	-0.13ns
Durbin-Watson	1.75	
R^2	0.97	

* Significance at 1% level ** Significance at 5% level ns Not significant

Table 7. Econometric estimation of direct vs. Indirect and renewable vs. non-renewable energy in cucumber production

Variables	Coefficient	t- Ratio
$(E_q.16).LnY_n = \varphi_1 LnDE + \varphi 2 LnIDE + \varepsilon_n$		
DE(φ_1)	0.23	2.96*
IDE($\varphi 2$)	0.17	2.10*
Durbin-Watson	2.33	
R^2	90	
$(E_q.17).LnY_n = \mu_1 LnRE + \mu 2 LnNRE + \varepsilon_n$		
RE(μ_1)	0.78	6.23*
NRE($\mu 2$)	0.32	3.17**
Durbin-Watson	1.98	
R^2	93	

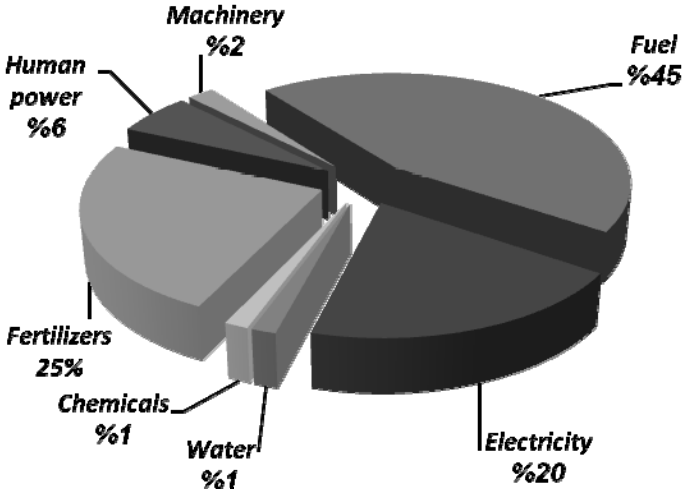

Figure 1. The anthropogenic energy input ratios in the production of cucumber

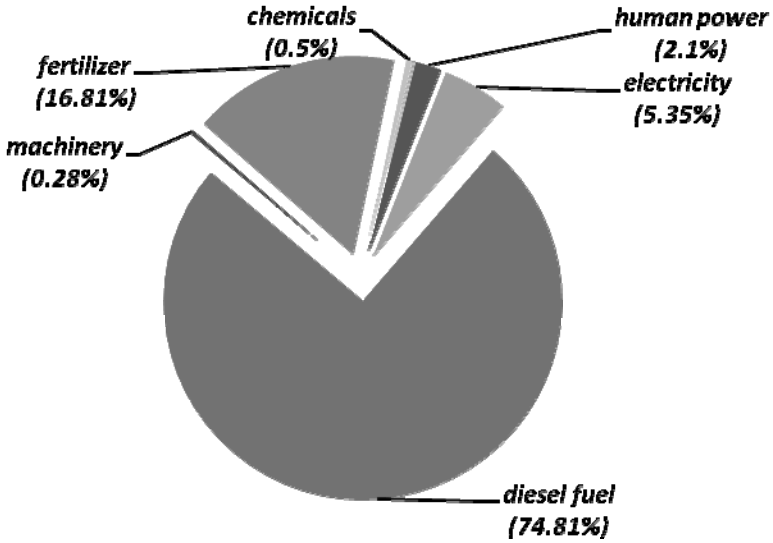

Figure 2. Distribution of saving energy from different sources for cucumber production in Iran