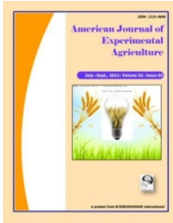

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Energy Consumption, Input–Output Relationship and Cost Analysis for Greenhouse Productions in Esfahan Province of Iran

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Authors' contributions

This work was carried out in collaboration with all authors. MT designed the study, collected data, wrote the protocol, and wrote the first draft of the manuscript. YA managed the analyses of the study. HGM performed the statistical analysis and interpreted the results. RA managed the literature searches. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

The objectives of this study were to determine the energy consumption and evaluation of inputs sensitivity for greenhouse vegetable production in the Esfahan province of Iran. Data were collected from 60 farmers using a face–to–face questionnaire method. The majority of farmers in the surveyed region were growing cucumber and tomato. The results revealed that cucumber production was the most energy intensive rather than tomato production. Cucumber production consumed a total of 124.44 G J ha^{-1} followed by tomato with 116.76 G J ha^{-1}. The energy ratio (energy use efficiency) for greenhouse tomato and cucumber were estimated to be 0.92 and 0.56 respectively. This indicated an intensive use of inputs in greenhouse vegetable production not accompanied by increase in the final product. Econometric model evaluation showed the impact of human power for both tomato and cucumber production was significant at 1% levels and had the highest impact among the other inputs in greenhouse tomato and cucumber production. Economic analysis indicated that the total costs of production for one hectare of tomato

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and cucumber production were around 34939 and 31956$, respectively. Accordingly, the benefit–cost ratio for these productions was 2.74 and 1.79, respectively. The total amounts of CO_2 for tomato and cucumber production were calculated as 4.622 and 4.930 tons ha^{-1} respectively, which indicated the high CO_2 output in both cultivations. The use of diesel fuel and pesticide is in excess for tomato and cucumber production, causing an environmental risk problem in the region.

Keywords: Cobb–douglas function; energy use; energy efficiency; greenhouse gas.

1. INTRODUCTION

Greenhouse production is one of the most intensive parts of the world agricultural production. It is intensive not only in the sense of yield and annual production, but also in the sense of the energy consumption, investments and costs (Singh et al., 2007; Heidari and Omid, 2011). 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., 2003). 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; Omid et al., 2011).

Future agricultural sustainability will be achieved from an equilibrated solution of many productive, environmental, and economic issues (Park and Seaton, 1996; Helander and Delin, 2004; Fresco, 2009). Among these, improved energy efficiency and reduced greenhouse gas (GHG) emissions are fundamental (Dyer and Desjardins, 2003; Alluvione et al., 2001). While the energy requirements of agriculture are low compared to other production sectors (Tol et al., 2009; Pinstrup–Andersen, 1999), realizing efficient use of its own energy needs is pivotal to achieving economic sustainability and GHG emission reductions (Alluvione et al., 2011; Philibert et al., 2002). Usually, energy input–output analysis is used to evaluate the efficiency and environmental impacts of the production systems. Therefore, there was an immediate need to carry out such an analysis for future steps to be taken for any improvement in greenhouse production systems regarding the energy values of the inputs and the output. By reaching beyond agricultural boundaries and including all the steps of crop input production, energy analysis is a useful indicator of environmental and long–term sustainability (Alluvione et al., 2011). Many experimental works have been conducted on energy use in agriculture. Pashaii et al. (2011) reported the energy intensity of 0.8 MJkg^{-1} for production of greenhouse tomatoes in Kermanshah, Iran. 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. Damirjan et al. (2006) studied the energy and economic analysis of sweet cherry production. Mohammdian Sabour (2007) assessed net energy gain and energy efficiency for canola in Mashhad, Iran to be 1812 MJha^{-1}, and 1.03 respectively. Erdal et al. (2007) studied on energy consumption and economical analysis of sugar beet production. Faraji (2007) reported the energy intensity of mechanized wheat production in Dasht–Abbas of Iran plain to be 0.206 MJkg^{-1}. Nguyen et al. (2007) studied energy balance of cassava and found the positive energy balance for the production of ethanol from cassava. They illustrated GHG emissions of cassava in Thailand are low (about 0.96 kg per liter of cassava–based ethanol used versus 2.6 kg CO_2). Cetin and vardar (2007) studied on differentiation of direct and indirect energy inputs in agro industrial production of tomatoes. Dyer et al. (2011) Compared fossil CO2 emissions from vegetable greenhouses in Canada with CO2 emissions from importing vegetables from the southern USA. Results showed that CO2 emissions from Canadian vegetables greenhouses were 0.35 Tg and air transport CO2 emission intensity was 1.9 times that of greenhouses. A further comparative review of studies on agricultural products can be found in (Singh et al., 2003; Singh et al., 2004; Ozkan et al., 2004; Chauhan et al., 2006; Mohammadi et al., 2008; Banaeian et al., 2010; Houshyar et al., 2010; Mobtaker et al., 2010; Mobtaker et al., 2011; Banaeian et al., 2011; Mousavi–Avval et al., 2011a; Mousavi–Avval et al., 2011b).

On this basis, the main objective of this study is to examine energy use pattern and specification of GHG emission for tomato and cucumber greenhouses in Esfahan province of Iran. Furthermore, this study aims to explore the relationship between output and energy inputs using Cobb–Douglas function form. In addition, the relationship is also examined for different energy sources in the form of renewable and non–renewable, direct and indirect energy. Once estimated, the models yield elasticity of energy inputs and energy sources for Iranian agriculture as well as a set of results that can be used by policy makers or other relevant agents in order to ensure sustainability and more efficient energy use.

2. MATERIALS AND METHODS

2.1 Data Collection and Energy Equivalent

Data were collected from growers in Esfahan province producing greenhouse vegetables, by using a face–to–face questionnaire in the production year 2010–2011. The survey was carried out in 10 villages where important undercover production exists. A total of 60 growers were randomly selected from the villages using the stratified random sampling method.

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 gain were calculated (Singh et al., 1997; Mohammadi and Omid, 2010):

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

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

$$\text{Specific energy} = \frac{\text{Energy input (MJ ha}^{-1}\text{)}}{\text{Tomato or Cucumber (kg ha}^{-1}\text{)}} \tag{3}$$

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

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 (Dalgaard et al., 2001; Unakitan et al., 2010). An increase in the ratio indicates improvement in energy efficiency and vice versa. Changes in efficiency can be both short and long term, 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 (DE) and indirect (IDE) energies or alternatively as renewable and non–renewable energies (Kizilaslan, 2009). The indirect energy includes the pesticide, fertilizers, seeds and machinery. The direct energy includes human labor, fuel and electricity power. The non–renewable energy (NRE) sources include fuel, electricity, fertilizers, pesticide and machinery, whereas the renewable energy (RE) sources include human power, 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 power, machinery, diesel, fertilizer, pesticide, 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 in the selected farms include tractors and diesel oil. The mechanical energy was computed regarding to the total fuel consumption (l ha^{-1}) in various operations; therefore, the energy consumed was calculated using conversion factors, and was expressed in $MJha^{-1}$ (Dalgaard et al., 2001; Bayramoglu and Gundogmus, 2009). 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).

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

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

2.2 Analysis of Energy with Mathematical Models

Realizing that the output is a function of inputs, production function can be expressed as

$$\mathrm{Y} = F(X_{it}) \tag{5}$$

where Y is output level, X_i 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):

$$\mathrm{Ln}\,Y_t = {}_0 + \sum_{i=1}^{n} {}_i Ln(X_{it}) + £_t \qquad (6)$$

Where Y_t denotes the yield of the t th farmer, ${}_0$ is a constant, ${}_i$ denotes coefficients, and $£_t$ 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. (6) reduces to:

$$\mathrm{Ln}\,Y_t = \sum_{i=1}^{n} {}_i Ln(X_{it}) + £_t \qquad (7)$$

Total physical energy consisted of human, electricity, diesel fuel, machinery, seed, fertilizer, water for irrigation and pesticide. Following this explanation, Eq. (7) can be given as:

$$LnY_t = {}_1LnFR + {}_2LnMA + {}_3LnHU + {}_4LnCH + {}_5LnSE + {}_6LnDS + {}_7LnEL + {}_8LnWA + £_t \qquad (8)$$

Where Y is the output, FR is the fertilizer, MA is the machinery, HU is the human power, CH is the total pesticide, SE 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):

$$LnY_t = ¨_1 LnDE + ¨_2 LnIDE + £_t \qquad (9)$$

$$LnY_t = «_1 LnRE + «_2 LnNRE + £_t \qquad (10)$$

Where RE and NRE denote renewable and non–renewable energy forms, respectively. DE represents direct energy and IDE denotes indirect energy.

Conservation farming practices, such as direct seeding and good fertilizer placement have increased soil organic carbon levels, which helps to offset GHG emissions, thereby reducing the industry's net GHG emissions (Dyer and Desjardins, 2003). Reducing GHG emissions simply means that crops and livestock are raised more efficiently, thus reducing on wasteful losses of inputs such as nitrogen (nitrous oxide) and energy (methane). Adoption of conservation practices will help to reduce GHG emissions. In this paper the corresponding amount of greenhouse gas (GHG) emissions was calculated. The diesel fuel combustion can be expressed as fossil CO_2 emissions with equivalent of 2764.2 g L^{-1} (Dyer and Desjardins, 2003). Also, the machinery and fertilizer supply terms can be expressed in terms of the fossil energy required to manufacture and transport them to the farm with CO_2 equivalents of 0.071 Tg PJ^{-1} (Neitzert et al., 1999) and 0.058 $TgPJ^{-1}$ (Dyer and Desjardins, 2007; Vergé et al., 2007) for machinery and chemical fertilizers, respectively.

The economic analysis for cucumber and tomato production was investigated. Net return, gross profit and benefit to cost ratio were calculated. The net return was calculated by subtracting the total cost of production from the gross value of production per hectare. The gross return was calculated by subtracting the variable cost of production. The benefit–cost ratio was calculated by dividing the gross value of production by the total cost of production per hectare (Zangeneh et al., 2010):

$$\text{Total production value} = \text{Yeild (kg ha}^{-1}) \times \text{Tomato or Cucumber price(\$ kg}^{-1}) \qquad (11)$$

$$\text{Gross return} = \text{Total production value (\$ ha}^{-1}) - \text{Variable cost of production (\$ ha}^{-1}) \qquad (12)$$

$$\text{Net return} = \text{Total production value (\$ ha}^{-1}) - \text{Total production cost (\$ ha}^{-1}) \qquad (13)$$

$$BC = \frac{\text{Total production value (\$ ha}^{-1})}{\text{Total production cost (\$ ha}^{-1})} \qquad (14)$$

$$productivity = \frac{\text{Total yeild (kg ha}^{-1})}{\text{Total production cost (\$ ha}^{-1})} \qquad (15)$$

Basic information on energy inputs and greenhouse yields were entered into an Excel spreadsheet and simulated using Eviews 5 software.

3. RESULTS AND DISCUSSION

3.1 Energy Use in Greenhouse Tomato Production

The inputs used in tomato production and their energy equivalents, output energy equivalent and energy ratio are illustrated in Table 2. About 10 kg pest and disease control pesticide and 971 kg chemical fertilizer were used in greenhouse tomato production on a hectare basis. The shares of nitrogen fertilizer, phosphorus and potassium were 32.5%, 38.2% and 29.3%, respectively, in the total chemical fertilizer used. The use of human power and machinery were 5815.2 hrha^{-1}and 52.3 kgha^{-1}.

The total energy equivalent of inputs was calculated as 116.76 GJha^{-1}. Diesel fuel had the highest share, of 40%, followed by fertilizer (30%) and electricity (12%), respectively. The average yield of tomatoes was found 135 tha^{-1} and its energy equivalent was calculated to be 108 GJha^{-1}.

3.2 Energy Use in Greenhouse Cucumber Production

The inputs, used in the cucumber production and their energy equivalents, together with the energy equivalent of the yield were illustrated in Table 3. As indicated in the table about 10 kg pesticide, 871 kg chemical fertilizer and 14.2 tones manure were used in greenhouse cucumber production on a hectare basis. The use of human power and machinery were 3789and 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 and tomato are given in Fig. 1.

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

Input (unit)	Quantity per unit area (ha)	Total energy equivalent (MJ)	Percentage
1. Pesticide (kg)	**9.7**	**1715.6**	**2**
Herbicides (kg)	3.1	737.8	
Fungicides (kg)	2.7	583.2	
Insecticides (kg)	3.9	394.6	
2. Human power (hr)	**5815.2**	**11397.8**	**10**
3. Machinery (kg)	**52.3**	**3389.0**	**3**
4. Fertilizer (kg)	–	**35052.7**	**30**
Nitrogen fertilizer (kg)	315.0	20834.1	
Phosphate (kg)	371.0	4615.2	
Potassium (kg)	285.0	3177.7	
Manure (tones)	21.2	6425.7	
5. Seeds (kg)	**0.1**	**0.1**	**0**
6. Diesel fuel (l)	**985.5**	**47106.9**	**40**
7. Electricity (kWh)	**1200.0**	**14316.0**	**12**
8. Water for irrigation	**3716.0**	**3790.3**	**3**
Total energy input (MJ)	–	116768.4	100
Yield (kg ha^{-1})	135000.0	108000.0	

Bold characters are main inputs

Table 3. 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. Pesticide (kg)	**10.1**	**1754.1**	**1**
Herbicides (kg)	2.5	595.0	
Fungicides (kg)	3.4	734.0	
Insecticides (kg)	4.2	425.1	
2. Human power (h)	**3789.0**	**7426.4**	**6**
3. Machinery (kg)	**40.0**	**2592.0**	**2**
4. Fertilizer (kg)	–	**30656.0**	25
Nitrogen fertilizer	2.095	19511.0	
Phosphate (kg)	325.0	4043.0	
Potassium (kg)	251.0	2798.0	
Manure (tones)	14.2	4304.0	
5. Seeds (kg)	0.15	0.12	
6. Diesel fuel (l)	**1165.0**	**55687.0**	**45**
7. Electricity (kWh)	**2056.0**	**24528.0**	**20**
8. Water for irrigation	**1769.0**	**1804.0**	**1**
Total energy input	–	124447.5	100
Yield (kg ha^{-1})	88123.0	70498.0	

Bold characters are main inputs

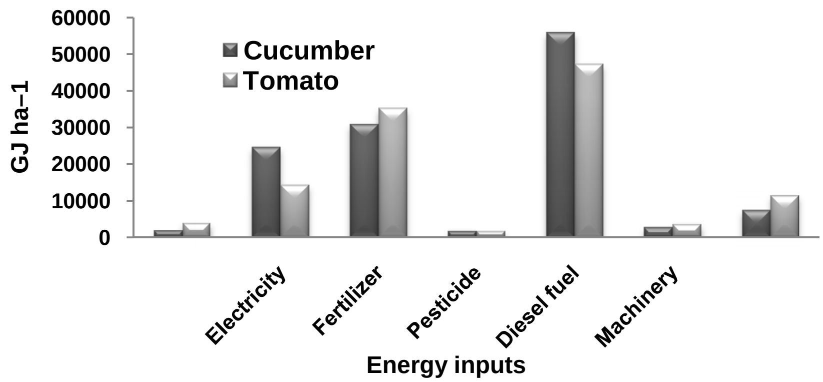

Fig. 1. The anthropogenic energy input ratios in the production of cucumber and tomato

3.3 Energy Indices in Tomato and Cucumber Production

The energy ratio (energy use efficiency), energy productivity, specific energy, net energy gain and the distribution of inputs used in the production of tomato and cucumber according to the direct, indirect, renewable and non–renewable energy groups, are given in Table 4.

Table 4. Energy output–input ratio and forms in cucumber and tomato production

Items	Unit	Cucumber	Tomato	Percentage Cucumber	Tomato
Energy ratio	–	0.56	0.92		
Energy productivity	$kgMJ^{-1}$	0.70	1.15		
Specific energy	$MJkg^{-1}$	1.41	0.86		
Net energy	$MJha^{-1}$	–53949.5	–8768.4		
Energy forms [a]					
Direct energy [b]	$MJha^{-1}$	87641.4	76611	71	66
Indirect energy [c]	$MJha^{-1}$	35002.12	40157.4	29	34
Renewable energy [d]	$MJha^{-1}$	11730.52	21613.8	19	10
Non– renewable	$MJha^{-1}$	110913	95154.5	90	81
Total energy input	$MJha^{-1}$	124447.5	116768.4	100	
Energy output	$MJha^{-1}$	70498	108000		

[a] Energy equivalent of water for irrigation is not included
[b] include human labor, fuel and electricity power
[c] include the pesticide, fertilizers, seeds and machinery
[d] include human labor, seeds and manure fertilizers
[c] include fuel, electricity, pesticide, fertilizers and machinery

It can be 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 tomato and cucumber (Fig. 2). Erdal et al. (2009) investigated the relationship between fruit yield and energy inputs used in stake tomato production under field conditions in Tokat province of Turkey. They reported that among the total energy used, 57.12% was in the form of direct energy and 77.54% was in the form of non-renewable energy.

The ratio of renewable energy including the energies of human power and farm fertilizer inputs, within the total energy in both productions 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., 2001).

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, 81% and 90% of input energy resources used for the production of tomato and cucumber was non–renewable energy.

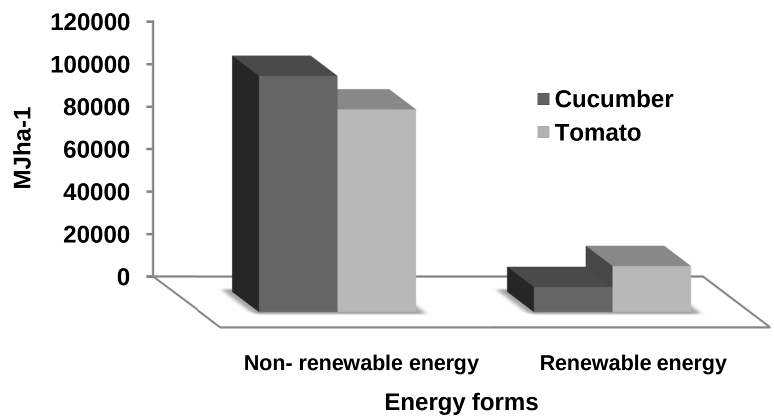

Fig. 2. Percentages of total energy input in the form of renewable (RE) and non-renewable (NRE) for cucumber and tomato production in Esfahan province of Iran

3.4 Econometric Model Estimation and Greenhouse Emission of Cucumber and Tomato Production

In order to estimate the relationship between energy inputs and output (cucumber and tomato yield), Cobb–Douglas production function was chosen and assessed using ordinary least square (OLS) estimation technique. Since the coefficient of variables in this function is in log form also represents elasticities (Mohammadi and Omid, 2010). Cobb–Douglas production function indicates a priori restriction on models of substitution among inputs.

For data used in this study, autocorrelation was tested using Durbin–Watson method (Hatirli et al., 2005). The Durbin–Watson values were found to be 1.75 and 1.89 for cucumber and tomato respectively, which indicates that there was no autocorrelation at the 5% significance level in the estimated models. The R^2 values were determined as 0.97 and 0.98 for cucumber and tomato respectively; implying that around 0.97 and 0.98 of the variability in the energy inputs was explained by this model. Regression results for Eq. (8) were estimated and are shown in Table 5 and 6. It can be seen form Table 5 that the contribution of human power and pesticide energies are significant at the 1% level on cucumber production. This indicates that with an additional use of 1% for each of these inputs would lead to 0.45% and 0.33% increase in yield. The elasticities of machinery, electricity and water for irrigation energies were estimated at 0.20, 0.12 and 0.15, respectively (all significant at the 5% level). The impact of chemical fertilizers, diesel fuel and seed energies on yield were estimated statistically insignificant with a negative sign. Mohamadi and Omid (2010) estimated an econometric model for greenhouse cucumber production in Tehran province of Iran. They concluded that among the energy inputs, human energy was found as the most important input that influences yield. Singh et al. (2004) concluded that in zone 2 of Punjab, the impact of human and electrical energies were significant to the productivity at 1% level.

Table 5. Economic estimation result of cucumber greenhouses

Variables	Coefficient	t–Ratio
$Ln Y_t = {}_1LnFR + {}_2LnMA + {}_3LnHU + {}_4LnCH + {}_5LnSE + {}_6LnDS + {}_7LnEL + {}_8LnWA + £_t$		
Human power	0.45	5.93^{*}
Diesel fuel	–0.17	$–0.13^{ns}$
Machinery	0.20	3.54^{**}
Pesticide	0.33	5.12^{*}
Fertilizers	–0.07	$–0.32^{ns}$
Electricity	0.12	2.12^{**}
Water for irrigation	0.15	2.23^{**}
Seed	–0.05	$–0.13^{ns}$
Durbin–Watson	1.75	
R^2	0.97	

* Significance at 1% level; **Significance at 5% level; ^{ns} Not significant

The effect of energy inputs on tomato production was also investigated by estimating Eq. (8) and regression result for this model is shown in Table 6. Human power had the highest impact (0.78) among other inputs and significantly contributed on the productivity at 1% level in this cultivation. It indicates that a 1% increase in the human power input led to 0.78% increase in yield in these circumstances.

Table 6. Economic estimation result of tomato greenhouses

Variables	Coefficient	t–Ratio
$LnY_t = {}_1LnFR + {}_2LnMA + {}_3LnHU + {}_4LnCH + {}_5LnSE + {}_6LnDS + {}_7LnEL + {}_8LnWA + £_t$		
Human power	0.78	5.45^{*}
Diesel fuel	–0.12	$–0.18^{ns}$
Machinery	0.27	2.09^{**}
Pesticide	0.57	4.56^{*}
Fertilizer	–0.09	$–0.28^{ns}$
Electricity	0.20	2.27^{**}
Water for irrigation	0.02	0.72^{ns}
Seed	–0.13	$–0.09^{ns}$
Durbin–Watson	1.89	
R^2	0.98	

* Significance at 1% level; **Significance at 5% level; ^{ns} Not significant

The second important input for tomato production was found as pesticide with 0.57 elasticity followed by machinery with 0.27 elasticity. Hatirli et al. (2006) developed an econometric model for greenhouse tomato production in Antalya province of Turkey and reported that human power, chemical fertilizers, biocides, machinery and water energy were important inputs significantly contributed to yield. The coefficient of diesel fuel, fertilizer and seed energy were found to be –0.12, –0.09 and –0.13, a negative value show that additional units of inputs are contributing negatively to production, i.e. less production with more input. The sensitivity of energy inputs for cucumber and tomato production with partial regression coefficients on output level are depicted in Fig. 3.

Although, the share of diesel fuel and fertilizer were 40% and 30% of the total energy input, the use of these inputs in tomato production per hectare in the research area is equal to other estimates of Iran's average.

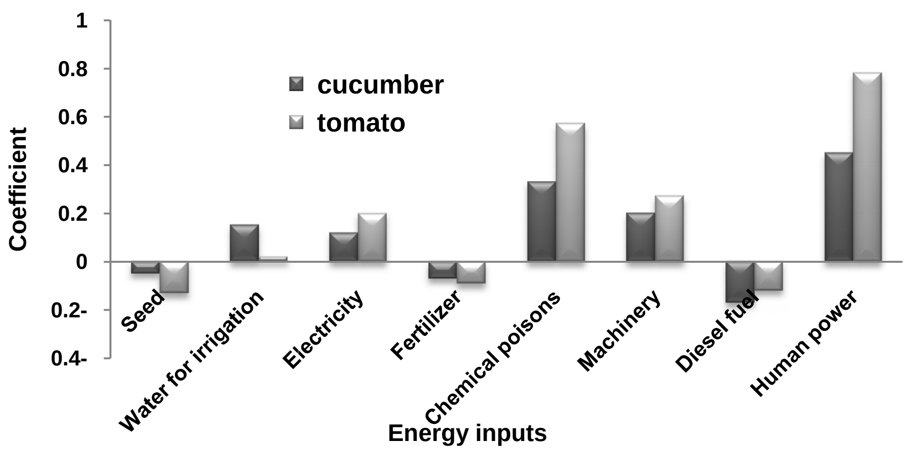

Fig. 3. Sensitivity analysis of energy inputs in cucumber and tomato production

The relationship between the direct and indirect energies, as well as renewable and non–renewable energies on the yield of each greenhouse production was investigated by Eqs 9 and 10, 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 of IDE for cucumber and NRE for tomato were 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 (2011) for greenhouse production of tomato and cucumber in Tehran province of Iran. Statistical tests revealed that DW values were 1.98–2.33 for Eqs. 9 and 10; indicating that there is no autocorrelation at the 5% significance level in the estimated models.

Results indicated that tomato and cucumber production are mostly depending on fossil energy sources. As it can be seen in Table 8, the total amounts of CO_2 for cucumber and tomato production were calculated as 4.930 and 4.622 tons respectively. Diesel fuel had the highest share (65.27% and 58.89%) in both of cucumber and tomato production. Pishgar et al. (2011) reported the amount of CO_2 emission for corn silage production in Tehran province of Iran to be 2792000 tons. Using ethanol and biodiesel as biofuel is essential in the 21st century to reduce the high GHG emissions. Field operations with minimum machinery use (especially tillage operation) and machinery production need to be considered to reduce the amount of CO_2.

Table 7. Econometric estimation of direct vs indirect and renewable vs. non–renewable energy in tomato and cucumber production

Variables	Cucumber yield		Tomato yield	
	Coefficient	**t–Ratio**	**Coefficient**	**t–Ratio**
$LnY_t = \text{¨}_1 LnDE + \text{¨}_2 LnIDE + \text{£}_t$				
DE(φ_1)	0.23	2.96*	0.59	4.50*
IDE(φ_2)	0.17	2.10*	0.51	4.90**
Durbin–Watson	2.33		2.28	
R^2	0.90		0.89	
$LnY_t = \text{«}_1 LnRE + \text{«}_2 LnNRE + \text{£}_t$				
RE(μ_1)	0.78	6.23*	0.37	4.12*
NRE(μ_2)	0.32	3.17**	1.21	6.54*
Durbin–Watson	1.98		2.12	
R^2	93.0		0.95	

*Significance at 1% level; **Significance at 5% level

Table 8. Amount of greenhouse gas emission in cucumber and tomato production

Input	Consumption (MJ)	Equivalent (Tg (CO_2) PJ^{-1})	Amount of CO_2 (ton)	Percentage
Cucumber production				
Diesel fuel	55687	0.0578	3.218	65.27
Machinery	2592	0.071	0.184	3.73
fertilizer	26352	0.058	1.528	31.00
Total	84631	–	4.930	100
Tomato production				
Diesel fuel	47106.9	0.0578	2.722	58.89
Machinery	3389	0.071	0.240	5.20
fertilizer	28627	0.058	1.660	35.91
Total	79122.9	–	4.622	100

3.5. Economic Analysis of Tomato and Cucumber Production

The total cost of tomato and cucumber production and the gross value of this production were calculated and shown in Table 9. The fixed and variable expenditures included in the cost of production were calculated separately. The total expenditure for the tomato and cucumber production were 34939 and 31956$ ha^{-1}, respectively, while the gross production value were found to be 95850 and 57280$ ha^{-1}, respectively. The share of variable costs in total costs of tomato and cucumber production was 66% and 62%, respectively. With respect to results of Table 7, the benefit–cost ratio from tomato and cucumber production in the surveyed farms was calculated to be 2.74 and 1.79, respectively. Other researchers reported similar results, such as 2.53 for sweet cherry (Demirjan et al., 2006), 2.37 for orange

(Chauhan et al., 2006), 1.17 for sugar beet (Erdal et al., 2007), 1.57 for corn silage (Pishgar Komleh et al., 2001), 1.03 for stake-tomato (Esengun et al., 2007), 1.68 for cucumber and 3.28 for tomato (Heidari and Omid, 2011).

Table 9. Economic analysis of tomato and cucumber production

Cost and return components	Unit	Tomato	Cucumber
Yield	$kgha^{-1}$	135000	88123
Sale price	$\$kg^{-1}$	0.71	0.65
Gross value of production	$\$ha^{-1}$	95850	57280
Variable cost of production	$\$ha^{-1}$	23159	19986
Fixed cost of production	$\$ha^{-1}$	11780	11970
Total cost of production	$\$ha^{-1}$	34939	31956
Total cost of production	$\$kg^{-1}$	0.27	0.36
Gross return	$\$ha^{-1}$	72691	37294
Net return	$\$ha^{-1}$	60911	25324
Benefit–cost ratio	–	2.74	1.79
Productivity	$kg\$^{-1}$	3.86	2.76

4. CONCLUSION

In this study, the level of energy consumption for input and output energies in tomato and cucumber production were investigated in Esfahan province of Iran. Data were collected from 60 greenhouses by a face to face questionnaire technique. Greenhouses were selected through a stratified random sampling technique. The following results were obtained:

1. Tomato production consumed a total of 116768.38 $MJha^{-1}$, while the cucumber consumed 124447.5 $MJha^{-1}$.

2. Diesel fuel is the major energy input in both types of production. Output energy, energy ratio and energy productivity of the tomato production were higher than cucumber production.

3. The impact of human power energy input in both of cucumber and tomato production was significantly positive on yield ($p < 1\%$). The regression coefficients of fertilizer and diesel fuel inputs for both productions were found negative, indicating that power consumption of fertilizer and fuel are high in the surveyed greenhouses.

4. The benefit–cost ratio for cucumber and tomato production was found to be 1.79 and 2.74 respectively. The mean net return from cucumber and tomato production were 25324 and 60911 $\$ ha^{-1}$, respectively.

5. Total amounts of CO_2 for cucumber and tomato production were calculated as 4.930 and 4.622 tons respectively. Diesel fuel had the highest share (65.27% and 58.89%) in both of cucumber and tomato production. It is possible to decrease greenhouse gas emission in agricultural production by reduction of non–renewable energy sources that create environmental problems. Therefore, policy makers should take the necessary measurements to ensure more environmentally friendly energy use patterns in the Persian agriculture. Finally, in the research area, greenhouse operators are still increasing the amount of inputs used in vegetable production. However, the timing of

any applications and use of the inputs are not significant issues for the Iranian greenhouse producer. This inevitably leads to problems associated with energy use such as global warming, nutrient loading and pesticide pollution, as indicated above. Therefore, there is a need to develop a new policy to force producers to use all inputs on time and enough undertake more energy–efficient practices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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