Journal of Agricultural Technology 2014 Vol. 10(3): 517-532
Available online http://www.ijat-aatsea.com
ISSN 1686-9141

Modeling and analysis of energy efficiency in grape production of Iran

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Mousa Rasouli, Majid Namdari, Seyed Hashem Mousavi-Avval (2014) Modeling and analysis of energy efficiency in grape production of Iran. Journal of Agricultural Technology 10(3):517-532.

This paper examines the energy use patterns and energy input-output analysis of grape productions in Iran. For this purposes, a face to face questionnaire with 48 grape growers from Hamadan province, Iran was conducted. The results indicated that total energy inputs were 33873.78 MJ ha^{-1}. The energy use efficiency, energy productivity and net energy of grape production were found to be 1.73, 0.15 kg MJ^{-1} and 24748.62 MJ ha^{-1}. Among input energy sources, chemical fertilizers and electricity contained highest energy with 51.64 and 23.95%, respectively. Econometric model evaluation showed that, the impact of human labor for grape was significant at 1% level. The results also showed that, direct, indirect and renewable and non-renewable, energy forms had a positive and statistically significant impact on output level. Also, the marginal physical productivity (MPP) technique was applied to analyze the sensitivity of energy inputs. It was found that, grape production had more sensitivity on chemicals, electricity and water for irrigation energies; so that an additional use of 1 MJ from each of the chemicals, electricity and water for irrigation would lead to an increase in production by 5.68, 2.42 and 1.81 kg, respectively.

Keywords: Energy input; Econometric model; Grape; Sensitivity analysis.

Introduction

Grapevine (*Vitisvinifera* L.) is one of the oldest crops and the only Mediterranean/Western Asiatic representative of the *Vitis* genus. Its domestication created cultivars suited to a wide diversity of climates and tastes. Iran is very rich in grapevine biodiversity and different cultivars cultivated in more than 20 provinces. Qazvin, West-Azerbaijan, Fars, Khorasan and Hamedan provinces are the main centers of grape production in Iran, where it grows on flat and slopping areas (Rasouli *et al.*, 2012).

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Energy, economics, and the environment are mutually dependent. Efficient use of energy is one of the principal requirements of sustainable agriculture. Energy use in agriculture has been increased in response to increasing population, limited supply of arable lands, and a desire for higher standards of living. Energy use patterns and the contribution of energy inputs vary depending on farming systems, crop season and farming conditions.

Tendency towards intensive use of energy in agricultural systems is profoundly due to higher level of mechanization, using chemical fertilizers, high-yielding seeds and synthetic pesticides. On the other hand, dependence of conventional agricultural systems to intensive use of energy is one of the main reasons creating environmental problems such as global warming in the most developing and developed countries (Jonge, 2004). Economically, increased energy inputs in order to obtain maximum yields may not bring maximum profits due to increasing production costs. In addition, both the natural resources are rapidly decreasing and the amount of contaminants on the environment is considerably increasing (Hatirli *et al.,* 2006). Resource and energy use efficiency is one of the principal requirements of eco-efficient and sustainable agriculture (Jonge, 2004). Efficient use of energy in agriculture and improving energy use efficiency will minimize environmental problems, prevent destruction of natural resources, and promote sustainable agriculture as an economical production system (Mobtaker*et al.,* 2010). Therefore, agriculture and energy have a complementary structure, affected by each other (Ghorbani *et al.,* 2011).

The intensity of energy use on grape farms is high and energy analysis of agricultural ecosystems is a commonly applied approach to investigate the energy use efficiency, assess their environmental impacts and to redirect them toward sustainable agriculture (Metzidakis *et al.,* 2008).

Sensitivity analysis (SA) is a fundamental tool in developing, applying and understanding of mathematical models of all forms. Sensitivity analysis provides information regarding the behavior of the simulation model being evaluated. It examines the response of the output(s) by varying input parameters (Confalonieri*et al.,* 2010). SA is a step in the modeling process aimed to rank model parameters, initial values of state variables, sub-models, or even processes according to their impacts on model results (Brugnach, 2005).

Sensitivity analysis of energy and inputs in crop production is important for resources management, environmental regulation, and remediable design (Pan *et al.,* 2011).

Considerable study has been conducted on the use of energy in agriculture with respect to efficient and economic uses of energy for sustainable production. But there are few studies on the energy and economic analysis of grape production. In fact, little attention has been given to the relationships between input energy and yield using functional forms in these research studies where energy use in agriculture was examined.

Most of researches carried about energy consumption and its indicators in Iran and other countries, for example: Rajabi Hamedani *et al.* (2011) examined the energy use patterns and relationship between energy input and yield for grape production in Malayer region of Hamadan province. In their study, energy consumption and energy ratio were calculated as 45213.66 $MJha^{-1}$ and 4.95, respectively. Among input energy sources, fertilizers, electricity and farmyard manure contained higher contributions with 37.25%, 19%, and 17.84%, respectively. Sensitivity analysis indicated that among the inputs, chemical has the highest sensitivity value of energy inputs and returns to scale values for grape yield was found to be 2.15. Their study was focused on the special region of Hamadan province (Malayer region) and they didn't study whole of the Hamadan province.

Ozkan *et al.* (2007) investigated the relationship between energy inputs and the yield for greenhouse and open-field grape production in Turkey. The results indicated that total input energy use in greenhouse and open-field production was found to be 24513.0 and 23640.9 MJ/ha, respectively. However, the output energy of greenhouse grapes was lower than open-field grapes. The output–input ratio for greenhouse and open-field grape production was found to be 2.99 and 5.10, respectively.

Mohammadi *et al.* (2010) surveyed energy use of kiwifruit in Iran. Determination of the efficient allocation of energy resources was modeled by Cobb-Douglas production function. The results indicated that energy inputs of human labor, water for irrigation, total fertilizer and machinery contributed significantly to the yield. The impact of human labor energy was found the highest among the other inputs in kiwifruit production.

Banaeian *et al.* (2011) examined the relationship between energy inputs and the yield using Cobb-Douglas function and energy input-output analysis of strawberry production in Tehran province of Iran. The elasticity estimates indicated that among the cost inputs, transportation is the most important input that influences total cost of production, followed by labor, fertilizers and installation of equipments.

Namdari *et al.* (2011) investigated energy inputs and the yield relationship for mandarin production to develop and estimate an econometric model. Results showed that human labor is the most important variable that influences the yield followed by chemical fertilizers with an elasticity of 0.37 and 0.31, respectively.

The aims of the present research were to develop an econometric model on energy inputs and crop yield and to analyze the sensitivity of energy inputs for grape production in Hamadan province, Iran. Prior to the model development the energy use pattern and the main energy use indicators for grape production were also investigated.

Materials and methods

This study was done in Hamadan province, Iran. Hamadan province has 1.2% of total area of the country and is located in the west of Iran, within 59° 33' and 49° 35' north latitude and 34° 47' and 34° 49' east longitude (Namdari, 2011). The surveyed region had a homogenous condition (climatic conditions, topography, soil type, etc). Data were collected from 48 grape orchards using a face to face questionnaire. A simple random sampling method was used to determine survey volume and the orchards were chosen randomly from study region. The size of each sample was determined from Neyman technique (Pahlavan*et al.*, 2012). The input energy (MJ ha^{-1}) used from various input sources including human labor, diesel fuel, chemical fertilizers, farmyard manure (FYM), chemicals, irrigation water and electricity. Energy equivalents' coefficients were calculated based on previous studies. Table 1 showed energy equivalents used for estimating inputs and output energies in grape production.

Table 1. Energy coefficients of different inputs and outputs used in grape production

Inputs/Output	**Units**	**Energy coefficients (MJ $unit^{-1}$)**	**Reference**
Inputs			
Human labor	Hr	1.96	(Pahlavan*et al*., 2012)
Diesel fuel	L	56.31	(Pahlavan*et al*., 2012)
Electricity	KW	11.93	(Pahlavan*et al*., 2012)
Chemical fertilizers	Kg		
Nitrogen (N)		66.14	(Pahlavan *et al*., 2012)
Phosphate (P_2O_5)		12.44	(Pahlavan *et al*., 2012)
Potassium (K_2O)		11.15	(Pahlavan *et al*., 2012)
FYM	Kg	0.3	(Pahlavan *et al*., 2012)
Chemicals	Kg	120	(Pahlavan *et al*., 2012)
Water for irrigation	m^3	1.02	(Namdari *et al*., 2011)
Output			(Pahlavan *et al*., 2012)
Grape	Kg	11.8	(Koctürk and Engindeniz, 2009) (Ozkan *et al*., 2007)

The energy equivalences of inputs are given in Mega Joule (MJ) unit by multiplying inputs with the coefficient of energy equivalent. An overview of the key characteristics of the data is presented in Table 2 in the form of mean, standard deviation (SD), maximum (Max) and minimum (Min) values.

Table 2. Summary of inputs (source wise energy use, MJ ha^{-1}) and output (yield, kg ha^{-1})

Particular	Human labor	Diesel fuel	Electricity	Chemical fertilizers	FYM	Chemicals	Water for irrigation	Yield
Max	2500	28	1320	7500	60000	12	6480	24000
Min	150	0	255	0	0	0	54	1000
Average	853	14	680	506	15873	1.42	860	4968
SD	432	10	385	1330	15315	2.68	1030	4683

Based on the energy equivalents of the inputs and output (Table 1), the energy ratio (energy use efficiency), energy productivity and net energy were calculated by Eqs. (1), (2), and (3), respectively:

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

$$\text{Energy productivity} = \text{Grape output (kg ha}^{-1}) \Big/ \text{Input energy (MJ ha}^{-1}) \tag{2}$$

$$\text{Net energy} = \text{Output Energy (MJ ha}^{-1}) - \text{Input energy (MJ ha}^{-1}) \tag{3}$$

In energy balances the energy ratio is often used as an index to examine the energy efficiency in crop production (Mohammadi *et al.*, 2010). The input energy is also classified into direct and indirect and renewable and non-renewable forms. The indirect energy consists of chemical fertilizers, FYM, chemicals and machinery while the direct energy includes human labor, diesel fuel, water for irrigation and electric energy used in the production process. On the other hand, non-renewable energy includes diesel fuel, electricity, chemicals, chemical fertilizers, machinery and renewable energy consists of human labor, FYM and water for irrigation (Namdari *et al.*, 2011).

In order to analyze the relationship between energy inputs and yield, several mathematical functions were tried. Cobb-Douglas function yielded better estimates in terms of statistical significance and expected signs of parameters among linear, linear-logarithmic, logarithmic-linear and second degree polynomial functions (Hamedani *et al.*, 2011). Several authors used Cobb-Douglas function (Hatirli *et al.*, 2006; Mohammadi *et al.*, 2010; Rafiee *et al.*, 2010; Banaeian & Zangeneh, 2011; Namdari, 2011). The production function is expressed as:

$$Y = f(x)\exp(u) \tag{4}$$

This function can further be expressed in the following form:

$$\ln Y_i = a + \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \qquad i=1,2,3,\ldots,n \tag{5}$$

where Y_i denotes the yield of the *i*th farmer; X_{ij}, the vector of inputs used in the production process; a, the constant term; α_j, represent coefficients of inputs which are estimated from the model and e_i, the error term (Rafiee *et al.*, 2010).
In this study, it is assumed that, if there is no input energy, the output energy is also zero. The same assumption also was made by other authors (Hatirli *et al.*, 2006; Mohammadi *et al.*, 2010; Rafiee *et al.*, 2010). So, Eq. (5) is reformed to:

$$\ln Y_i = \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \qquad i=1,2,3,\ldots,n \tag{6}$$

In the present case, n=7; therefore Eq. (6) can be expressed in the following form:

$$\ln Y_i = \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + e_i \tag{7}$$

where; X_i stands for corresponding energies as X_1, human labor; X_2, diesel fuel; X_3, electricity; X_4, chemical fertilizers; X_5, farmyard manure; X_6, chemicals; and X_7, water for irrigation. With respect to this pattern, by using Eq. (7), the impact of each input energy on output energy was studied.
Similarly, the effect of direct, indirect, renewable and nonrenewable energies on production was modeled by using the following equations (Mohammadi *et al.*, 2010):

$$\ln Y_i = \beta_1 \ln DE + \beta_2 \ln IDE + e_i \tag{8}$$

$$\ln Y_i = \gamma_1 \ln RE + \gamma_2 \ln NRE + e_i \tag{9}$$

where; Y_i is the i^{th} grower's yield, β_i and γ_i are coefficient of exogenous variables, DE and IDE are direct and indirect energies, respectively; RE is renewable energy; and NRE is non-renewable energy.

In the Cobb-Douglas production function, if the sum of the coefficients (returns to scale) is greater than unity, it means that the increasing returns to scale, and if the latter parameter is less than unity, it means that the decreasing returns to scale is applied; and, if the result is unity, it shows the constant returns to scale assumption (Singh *et al.,* 2004).

In the last part of the study the Marginal Physical Product (MPP) method, was used to analyze the sensitivity of energy inputs on grape yield. The MPP factor indicates the changes in the output with a unit change in the input factor in question, keeping all other factors constant at their geometric mean level (Mobtaker *et al.,* 2010). A positive value of MPP of any factor indicates that, with an increase in input, production is increased; and a negative value of MPP of any factor input indicates that, additional units of inputs contribute negatively to production; hence, it is better to keep the variable resource in surplus rather than utilizing it as a fixed resource (Banaeian & Zangeneh, 2011). The MPP of the various inputs was calculated using the α_j of the various energy inputs as follows (Singh *et al.*, 2004):

$$MPP_{xj} = \frac{GM(Y)}{GM(X_j)} \times \alpha_j \qquad (10)$$

Where; MPP_{xj} is MPP of j^{th} input; α_j, regression coefficient of j^{th} input; GM(Y), geometric mean of yield; and $GM(X_j)$, geometric mean of j^{th} input energy on per hectare basis.

Basic information on energy inputs and grape yields were entered into Excel's spreadsheet and SPSS 17.0 software. Modeling carried out using linear regression technique.

Results and discussions

Table 3 shows the inputs used and output in grape orchards in the surveyed area, and their energy equivalents. The last column in Table 3 gives the percentage of each input of the total energy input.The results revealed that total energy used in various farm operations during grape production was 33873.78 MJ ha^{-1}. The highest average energy consumption of inputs was for chemical fertilizers (17491.66 MJ ha^{-1}) which was accounted for about 51.64% of the total energy input (Table 3), followed by electricity (8112.40 MJ ha^{-1}, 23.95%). Similar results were reported by RajabiHamedani*et al.* (2011) for grape production in Malayer region. Ozakan*et al.* (2007) reported that the highest energy consumption of inputs in grape production in Turkey was for electricity, followed by chemical fertilizers. The results of this study are also close to their research results.

Table 3. Inputs and output with their equivalent energy in grape production

Inputs/Output	Total energy Equivalent (MJ ha^{-1})	Share (%)
Inputs		
Human labor	1671.88	4.93
Diesel fuel	788.34	2.33
Electricity	8112.40	23.95
Chemical fertilizers	17491.66	51.64
Nitrogen (N)	13095.72	38.66
Phosphate (P_2O_5)	2500.44	7.38
Potassium (K_2O)	1895.50	5.60
FYM	4761.90	14.06
Chemicals	170.40	0.50
Water for irrigation	877.20	2.59
Total energy input	33873.78	100
Output		
Grape	58622.4	100

Of all chemical fertilizers, share of nitrogen, phosphate, and potassium were 74.87%, 14.29% and 10.84%, respectively. Nitrogen had the highest portion among the fertilizers, owing to its high energy values (Table 3).

Similarly, Ozkan *et al.* (2007) found that nitrogen constituted 15.33% of the total energy input in grape production in Turkey. Their results revealed that the highest energy input is provided by chemical fertilizers. The determination of the exact grape nutrients needs through soil, then applying fertilizers accordingly is a good way for reducing chemical fertilizers. The decline in soil organic matter leads to the use of greater amounts of chemical fertilizers than normal. Green manuring is another area that should be explored (Karimi *et al.*, 2008).

The second highest share in energy consumption belongs to the electricity energy because vineyards are irrigated by electric pumps. Having deep wells in the region and not using modern efficient irrigation methods are among the reasons of high consumption of electrical energy in the studied region. In order to reduce the electricity consumption, using the modern methods of irrigation with high efficiency can be suggested (Mobtaker *et al.*, 2012). Furrow irrigation, plus drip irrigation and micro-irrigation and other new water-saving irrigation technologies should also be considered (Karimi *et al.*, 2008).

From Table 3 it is shown that, from the total energy input for grape production, the consumption of human labor, diesel fuel, FYM, chemicals and water for irrigation were 4.93%, 2.33%, 14.06%, 0.5% and 2.59%, respectively.

From Table 3 it is shown that, chemicals are the least demanding energy input for grape production with 170.40 MJ ha^{-1} (only 0.50% of the total sequestered energy) follow by diesel fuel (788.34 MJ ha^{-1}, 2.33%). Diesel energy was mainly utilized for operating tractors to perform various farm operations.

Similarly, Ozkan *et al.* (2007) reported that chemicals are the least demanding energy input for both open-field and greenhouse grape production in Turkey. Similar results have been reported in the literature implying that, the energy input of chemicals has a little share of total energy input in agricultural productions (Erdal *et al.*, 2007; Kizilaslan *et al.*, 2009; Mohammadi *et al.*, 2010).

Table 4 shows the distribution of total energy input as direct, indirect, renewable and non-renewable forms. The total consumed energy input could be classified as direct energy (11449.82 MJ ha^{-1}), and indirect energy (22423.96 MJ ha^{-1}) or renewable energy (7310.98 MJ ha^{-1}) and non-renewable energy (26562.8 MJ ha^{-1}). The shares of energy input as direct, indirect, renewable and nonrenewable forms are illustrated in Fig. 1. As it can be seen from the figure, 78.42% of total energy input resulted from non-renewable (NRE), 21.58% from renewable energy (RE), 33.80% from direct energy (DE) and 66.20% indirect energy (IDE). This indicates that grape production depends mainly on non-renewable energy (diesel fuel, electricity, chemicals and chemical fertilizers) in the studied area.Intensity of non-renewable energy consumption resulted from electricity and chemical fertilizer use in the region. These results are in agreement with the literatures for different crops (Erdal *et al.*, 2007; Kizilaslan, 2009; Mobtaker *et al.*, 2010; Mohammadi *et al.*, 2010).

Table 4. Some energy parameters in grape production

Items	Unit	Quantity
Total energy input	MJha^{-1}	33873.78
Total energy output	MJha^{-1}	58622.40
Energy ratio	-	1.73
Productivity	kgMJ^{-1}	0.15
Net energy	MJha^{-1}	24748.62
Direct energy [a]	MJha^{-1}	11449.82
Indirect energy [b]	MJha^{-1}	22423.96
Renewable energy [c]	MJha^{-1}	7310.98
Non-renewable energy [d]	MJha^{-1}	26562.80

[a] Includes electricity, human labor, diesel fuel, water for irrigation
[b] Includes, fertilizers, chemicals, farmyard manure
[c] Includes farmyard manure, human labor, water for irrigation
[d] Includes diesel fuel, electricity, chemicals, fertilizers

The mean yield of grape was 4.968 ton ha^{-1} (Table 2). Energy output of grape production was 58622.4 MJ ha^{-1} (Table 3). The energy use efficiency (energy ratio), energy productivity and net energy gain of grape production in the Hamadan province are listed in Table 4. The energy use efficiency of 1.73 observed in the present study indicates that 1.73 times energy was produced per unit of energy used in grape production. This means energy consumption in grape production in surveyed region is efficient, i.e. energy production was greater than energy utilization. In previous investigations, Ozkan *et al.* (2007) calculated energy ratio as 2.99 and 5.10 for greenhouse and open-field grape, respectively, in Turkey. From the literature, energy ratio was investigated for different crops in Iran such as 1.54 for kiwifruit (Mohammadi *et al.*, 2010), 1.16 for apple (Rafiee *et al.*, 2010), 2.9 for walnut (Banaeian&Zangeneh) and 1.1 for potato (Hamedani *et al.*, 2011).

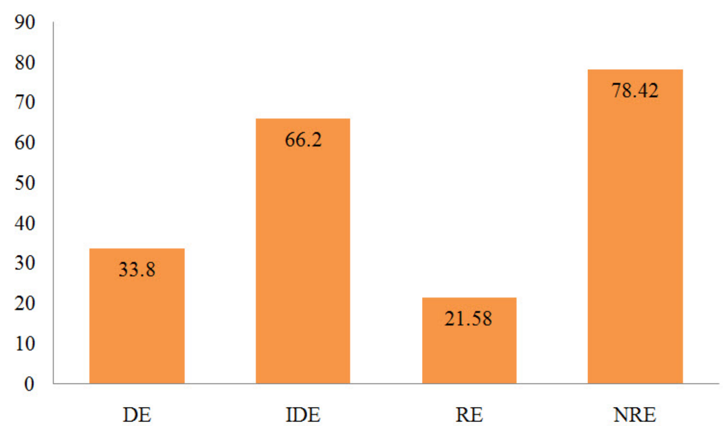

Fig. 1. Percentage of total energy input in the form of direct (DE), indirect (IDE), renewable (RE) and non-renewable (NRE) for grape production

The energy productivity of grape production was 0.15 kg MJ^{-1}. This means in grape production 0.15 kg output was obtained per unit energy (MJ). Calculation of energy productivity rate is well documented in the literature such as cotton (0.06) (Yilmaz *et al.*, 2005), apple (0.49) (Rafiee *et al.*, 2010) and potato (0.32 and 0.27) (Zangeneh*et al.*, 2010). Koctürk and Engindeniz (2009) and RajabiHamedani *et al*. (2011) reported the energy productivity as 0.73 and 0.42 kg MJ^{-1} for grape production in Turkey and Iran, respectively.

For investigating the relationship between the energy inputs and yield of grape production, the Cobb-Douglas production function was specified and estimated using Ordinary Least Square (OLS) estimation technique. It was assumed that the grape yield (endogenous variable) is a function of human labor, diesel fuel, FYM, chemical fertilizers, electricity and chemicals (exogenous variables). For the data used in this study, autocorrelation was tested using Durbin-Watson method (Heidari and Omid, 2011).

The results of regression model estimation are shown in Table 5. The Durbin–Watson value was found to be 1.79 for Eq. (7) which indicates that there was no autocorrelation at the 5% significance level in the estimated model. Therefore, grape yield (endogenous variable) was assumed to be a function of human labor, diesel fuel, chemicals, chemical fertilizers, water for irrigation, FYM and electricity energies (exogenous variables). Similar results were reported by Rajabi Hamedani *et al.* (2011). The coefficient of determination (R^2) was 0.97 for this model, implying that around 0.97 of the variability in the energy inputs was explained by this model. RajabiHamedani*et al.* (2011) calculated R^2 as 0.91 for model I. The estimated regression coefficients for the model (I) are presented in the second column of Table 5.

The results revealed that the impact of energy inputs could have positive effect on yield (except for diesel fuel). The contribution of human labor, water for irrigation and farmyard manure energies are significant at the 1% level (Table 5). This indicates that, an additional use of 1% for each of these inputs would lead, respectively, to 0.38, 0.31 and 0.21% increase in yield. The impacts of chemical fertilizers, chemicals and electricity were estimated as 0.09, 0.14 and 0.28, respectively (all significant at the 5% level).

Table 5. Econometric estimation results of inputs

Variables	**Coefficient**	***t*-ratio**	**MPP**
Model 1: $\ln Y_i = \alpha_1 \ln X_1 + \alpha_2 \ln X_2 + \alpha_3 \ln X_3 + \alpha_4 \ln X_4 + \alpha_5 \ln X_5 + \alpha_6 \ln X_6 + \alpha_7 \ln X_7 + e_i$			
Endogenous variable			
Yield (kg/ha)	-	-	-
Exogenous variables			
Human labor	0.38	2.304*	1.77
Diesel fuel	-0.12	-0.331	-0.32
Farmyard manure	0.21	2.188*	0.09
Chemical fertilizers	0.09	0.739**	0.29
Chemicals	0.14	0.591**	5.68
Electricity	0.28	1.742**	2.42
Water for irrigation	0.31	1.475*	1.81
Durbin-Watson	1.79		
R^2	0.97		
Return to scale ($\sum_{i=1}^{n} \alpha_i$)	1.29		

*: Significant at 1% level; **: Significant at 5% level

As it can be seen from Table 5, human labor had the highest impact (0.38) among other inputs. This indicates that by increase in the energy obtained from human labor input, the amount of output level improves in present condition. Heidari&Omid (2011) developed an econometric model for greenhouse cucumber and tomato production in Iran and reported that the human labor, chemical fertilizers, chemicals and fuel energy were important inputs, which significantly contributed to yield and human labor energy had the highest elasticity. Similarly, Mohammadi *et al.* (2010) for kiwifruit production in Iran, Namdari *et al.* (2011) for mandarin production in Iran, Banaeian&Zangeneh (2011) for walnut production in Iran, reported that human labor energy had the highest elasticity among the other inputs.

The regression coefficients of direct and indirect energies (Model 2) as well as renewable and nonrenewable energies (Model 3) on yield were investigated through Eq. (8) and (9), respectively; and the results are given in Table 6. Durbin-Watson statistical test revealed that Durbin-Watson values were 1.86 and 1.78 for Eqs. (8) and (9), respectively; indicating that there was no autocorrelation at the 5% significant level in the estimated models; also, the R^2 value was found to be 0.98 and 0.96 for these models respectively. As shown from Table 6, the regression coefficients of direct, indirect, renewable and non-renewable energies were all positive and statistically significant at 1% level. The impacts of direct, indirect, renewable and non-renewable energies were estimated as 0.32, 0.69, 0.71 and 0.39, respectively. It concludes that, the impact of indirect energy was more than that of direct energy on yield. The research results were consistent with finding reported by other authors (Rafiee *et al.,* 2010; Banaeian&Zangeneh).

The return to scale values for models 1 to 3, Eqs. (7)-(9), were calculated by gathering the regression coefficients and shown in Table 5 and Table 6. The return to scale was calculated as 1.29, 1.01 and 1.10 for models 1, 2 and 3, respectively. The return to scale value of higher than unity implies increasing return to scale. For example, this revealed that a 1% increase in the total energy inputs utilize would lead in 1.29% increase in the grape yield for model 1. Similar results have been reported in the literature implying that the return to scale was more than unity (Namdari *et al.,* 2011; Namdari, 2011, Rafiee *et al.,* 2010; Banaeian&Zangeneh; Heidari&Omid, 2011). The sensitivity of energy inputs on production was analyzed by using MPP technique based on response coefficient of inputs and results are shown in Table 5. As can be seen, the major MPP was drown for chemicals energy (5.68), followed by electricity energy (2.42). This implies that an additional use of 1 MJ ha^{-1} of each of the chemicals and electricity energy inputs would lead to additional increase in yield by 5.68 and 2.42 kg ha^{-1}, respectively. Then, these inputs have a strong impact on the yield with large sensitivity coefficients. Rajabi Hamedani *et al.* (2011) for grape production in Malayer reported that the major MPP was due to chemicals energy (21.37) followed by human labor (2.99).

Table 6. Econometric estimation results of direct, indirect, renewable and non-renewable energies

Endogenous variable: yield **Exogenous variables**	**Coefficient**	***t*-ratio**	**MPP**
Model 2: $\ln Y_i = \beta_1 \ln DE + \beta_2 \ln IDE + e_i$			
Direct energy	0.32	2.458*	0.75
Indirect energy	0.69	3.033*	0.29
Durbin-Watson	1.86		
R^2	0.98		
Return to scale ($\sum_{i=1}^{n} \beta_i$)	1.01		
Model 3: $\ln Y_i = \gamma_0 + \gamma_1 \ln RE + \gamma_2 \ln NRE + e_i$			
Renewable energy	0.71	4.017*	0.24
Non-renewable energy	0.39	3.283*	3.23
Durbin-Watson	1.78		
R^2	0.96		
Return to scale ($\sum_{i=1}^{n} \gamma_i$)	1.10		

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

The MPP of diesel fuel energy was found to be -0.32; A negative value of MPP of any variable input indicates that every additional unit of input starts to diminish the total output of previous units. Therefore, the continuous usage of these inputs would lead to energy dissipation as well as impose negative effects to environment and human health.

The MPP values of direct, indirect, renewable and nonrenewable energies are shown in the last column of Table 6. The MPP of direct, indirect, renewable and non-renewable energy were found to be 0.75, 0.29, 0.24 and 3.23, respectively. This indicates that with an additional use of 1MJ of each of the direct, indirect, renewable and non-renewable energy would lead to an additional increase in yield by 0.75, 0.29, 0.24 and 0.3.23 kg ha^{-1}, respectively. It is concluded that impact of non-renewable energy was higher than that of renewable energy in grape production. Similar results were reported by other researches (Rajabi Hamedani *et al.,* 2011; Mobtaker *et al.,* 2012; Heidari and Omid, 2011; Mousavi-Avval *et al.,* 2011). Additional use of non-renewable energy sources to boost agricultural productions in developing countries with low levels of technological knowledge not only results in environmental deterioration, but also confronts us with the dilemma of a rapid rate of depletion of energetic resources (Mousavi-Avval *et al.*, 2011).

Conclusion

The aim of this study was to analyze sensitivity of a particular energy input level on grape yield in Hamadan province, Iran. Based on the results, the following conclusions are drawn:

Energy inputs and output of grape production calculated to be 33873.78 MJ ha^{-1} and 58622.4 MJ ha^{-1}, respectively. The biggest energy consumer was chemical fertilizer (51.64%), followed by electricity (23.95%), FYM (14.06%), and human labor energy (4.93%). Chemicals energy was discovered as the least demanding energy input in all inputs (0.50%). Energy ratio, energy productivity and net energy were 1.73, 0.15 kg MJ^{-1} and 24748.62 MJ ha^{-1}, respectively. Direct, indirect, renewable and non-renewable forms of energy were 11449.82, 22423.96, 7310.98 and 26562.80 MJ ha^{-1}, respectively.

The impact of human labor, farmyard manure, chemical fertilizers, chemicals, electricity, and water for irrigation energy inputs was significantly positive on yield. Regression coefficient values for human labor, diesel fuel, FYM, chemical fertilizers, chemicals, electricity, and water for irrigation were 0.38, -0.12, 0.21, 0.09, 0.14, 0.28 and 0.31, respectively.

The estimated MPP for chemicals energy was the biggest among inputs of energy. As well, MPP of diesel fuel energy was found negative, indicating that diesel fuel energy consumption is high in grape production.

The impact of direct (0.32), indirect (0.69) renewable (0.71) and non-renewable (0.39) energies was significant at 1% level on grape yield.

Optimal consumptions of electricity, chemical fertilizers and other major inputs would be useful not only in reducing negative effects to environment, but also in maintaining sustainability. Lack of soil analysis in the area leads to unconscious usage of chemical fertilizer. In order to reduce the electricity consumption, using of modern methods of irrigation with high efficiency (which leads in saving water consumption) can be suggested.

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(Received 19 February 2014; accepted 30 April 2014)