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Energy Efficiency Analysis and Modeling the Relationship between Energy Inputs and Wheat Yield in Iran

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Abstract

Wheat is the dominant cereal crop constituting the first staple food in Iran. This paper studies the energy consumption patterns and the relationship between energy inputs and yield for Wheat production in Iranian agriculture during the period 1986 – 2008. The results indicated that total energy inputs in irrigated and dryland wheat production increased from 29.01 and 9.81 GJ ha^{-1} in 1986 to 44.67 and 12.35 GJ ha^{-1} in 2008, respectively. Similarly, total output energy rose from 28.87 and 10.43 GJ ha^{-1} in 1986 to 58.53 and 15.77 GJ ha^{-1} in 2008, in the same period. Energy efficiency indicators, input–output ratio, energy productivity, and net energy have improved over the examined period. The results also revealed that non-renewable, direct, and indirect energy forms had a positive impact on the output level. Moreover, the regression results showed the significant effect of irrigation water and seed energies in irrigated wheat and human labor and fertilizer in dryland wheat on crop yield. Results of this study indicated that improvement of fertilizer efficiency and reduction of fuel consumption by modifying tillage, harvest method, and other agronomic operations can significantly affect the energy efficiency of wheat production in Iran.

Keywords:
Wheat, Energy efficiency, Input-output, Econometric analysis

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INTRODUCTION

Agriculture is an important sector in Iran's economy wherein wheat and barley are the main crops cultivated. Wheat constitutes the primary staple food of the people of Iran after being adopted since ages due to local wisdom, its immense nutritional value as well as low price. Therefore, wheat is the dominant cereal crop including almost 70 % of the aggregate cereal production. Based on statistics of Ministry of Jihad-e-Agriculture of Iran (Anonymous, 2010), wheat production in Iran was about 13.5 million tons in 2010, out of -which 8 million tons was from irrigated and 5.5 million tons was from dryland lands, respectively. According to the statistics of FAO (2013), Iran is the 12^{th} leading producer of wheat in the world, with an average production of 14 million tons in 2011.

Wheat production is a direct function of high-yielding varieties, chemicals, fertilizers, mechanization and other energy inputs. It is produced using energy resources ranging from human and animal power to power of heavy machinery (Singh *et al*., 2007). Energy requirements in agriculture are divided into four groups: direct and indirect, non-renewable and renewable. Direct energy is required to perform various tasks related to crop production processes such as land preparation, irrigation, planting, different crop management operations, harvesting and transportation of agricultural inputs and farm products (Singh, 2000). Direct energy consumption in Iranian agriculture amounts to around 204.37×1015 $J.yr^{-1}$ that constitutes 3.5% of the national consumption of fuel and electricity (MOE, 2006). However, a large part of the energy consumption in agriculture is indirect. Indirect energy consists of the energy used in manufacturing, packaging and transporting agricultural inputs (fertilizers, herbicides, etc.) and farm machinery. Non-renewable energy includes diesel, chemicals, fertilizers and machinery, and renewable energy consists of human labor, seed and manure (Mohammadi *et al*., 2008). Energy consumption in wheat production has been increasing in response to increasing population, limited supply of arable land and most importantly, by supporting government's policies. Intensive use of energy causes problems threatening public health and environment. Efficient use of energy in agriculture will minimize environmental problems, prevent destruction of natural resources, and promote sustainable agriculture as an economical production system (Kizilaslan, 2009). The development of energy- efficient agricultural systems with low input energy compared with the output of food could help reduce the greenhouse gasses emissions in agricultural production (Dalgaard *et al*., 2001).

Given the importance of energy consumption in agriculture sector, numerous works have been conducted on energy efficiency in agricultural systems and showed that, in most countries, Agricultural sector was highly dependent on different sources of energy and intensive use of energy causes some environmental problems such as an increase in global warming,CO_2 emissions, and non-sustainability. These studies revealed that the output of production could increase by ensuring optimal energy inputs in agricultural systems.

In case of Turkey, for example, the study by Canakci *et al*. (2005), Esengun *et al*. (2007), Hatirli *et al*. (2005), Hatirli *et al*. (2006), Kizilaslan (2009), Ozkan *et al*. (2004) showed that the inputs used in agricultural production were not used efficiently and led to many environmental problems. Hence, they suggested that sustainable agriculture should be extended and conscious farming should be provided. Results of Beheshti Tabar *et al*. (2010), Mohammadi and Omid (2010), Shahan *et al*. (2008) revealed that the contribution of energy inputs to crops yields in Iranian agriculture was significant. Also energy use in Iranian agriculture showed an increasing trend during the period 1990-2006 as the total energy input increased from 32.4 GJ ha^{-1} in 1990 to 37.2 GJ ha^{-1} in 2006. At the same period, total output energy increased from 30.85 to 43.68 GJ ha^{-1}. Also, Singh *et al*. (2007) showed that western Rajasthan had the maximum energy consumption in wheat production of India because textured soil was light which required intensive irrigation. The maximum energy ratio was observed at Punjab (5.2) and Ultra Pradesh (4.2) areas. The work of Martin *et al*. (2006) in

USA is another example of the important energy inputs in agricultural systems with different scales and management. According to this study, food production systems with large yields are more dependent on renewable energies.

Regarding the energy scarcity and wheat importance in Iran, this study was carried out to examine energy use pattern for irrigated and dryland wheat production for the period of 1986–2008. Furthermore, this study aims to explore the relationship between energy inputs and wheat yield using various functional forms. In this regard, the relationship is examined for different energy sources as renewable and non-renewable, direct and indirect energy. The results can be used by policy makers or other relevant agents in order to ensure sustainability and more efficient energy use in wheat production in agricultural economics of Iran. Some studies have been conducted on energy use in wheat production (Beheshti Tabar *et al*., 2010; Shahan *et al*., 2008; Taki *et al*., 2012). However, most of these studies have used cross-sectional data rather than time series data. Besides, none of them explored functional relationship between energy inputs and wheat yield. In fact, little attention has been paid to the relationships between input energy and wheat yield using functional forms in these research studies where energy use in agriculture was examined. In this study, we have used time series data and focused on the relationship between energy inputs and wheat yield which differ from the previous researches.

MATERIALS AND METHODS

The data used in this study is based on yearly statistics for the period of 1986 to 2008. Information about energy consumption was obtained from the Ministry of Jihad-e Agriculture of Iran and FAO. The study has also benefited from the previous researches and studies conducted on energy analysis in agriculture. The study starts in 1986 because confident statistics are available only for this period of time. To calculate energy ratio, five major inputs in wheat production were considered including human labor, fertilizer, pesticide, irrigation, seed, and diesel Fuel and yield value. Energy content embodied in the crop was calculated based on review of literature and ASAE standards (Kitani. 1999). Energy equivalents of the inputs and outputs are given in Table 1.

In order to do an energy analysis, it is necessary to consider the use of human and animal power in agricultural processes. The amounts of agricultural labor work required for all of the operations for each crop were collected from the statistical Yearbooks on production cost (Anonymous. 2007). These data were given as labor-day ha^{-1}. Assuming 8 h of work a day and considering 1.96 MJ h^{-1} as human labor energy equivalent (Beheshti Tabar *et al*., 2010; Mohammadi *et al*., 2008) , the labor-day ha^{-1} was converted into GJ ha^{-1}. Considering the negligible share in the total energy input, animal power was omitted. Pesticides (insecticide, fungicide, and herbicide) and fertilizer (N, P, and K) consumption inputs data for irrigated and dryland wheat in each

Table 1. Energy equivalent of inputs and outputs in agricultural production

Item	Unit	Energy equivalent (MJ/unit)	Reference
A. Inputs			
Human labour	h	1.96	[3, 5, 10]
Diesel Fuel	L	47.3	[10]
Chemical fertilizers			
Nitrogen (N)	kg	78.1	[3, 8]
Phosphate (P_2O_5)	kg	17.4	[3, 8]
Potassium (K_2O)	kg	13.7	[3, 8]
Irrigation	m3	1.02	[11]
Insecticides	kg	58	[12, 8]
Fungicides	kg	115	[12, 8]
Herbicides	kg	295	[12, 8]
Seeds	kg	25	[13]
B. Outputs			
Wheat grain yield	kg	14.7	[14]

year were collected. Another essential input for agriculture production is seed. Its amount was obtained based on the data for wheat crop (Anonymous. 2007).

Since there is no data available for diesel fuel consumption for machinery used in agriculture, the total diesel energy input for the last year of the investigation was collected through field investigation using 75 hp tractors, taking into account the differences in the field operations of different crops. The fuel consumption for all the field operations for every year of the study period was estimated based on the differences in mechanization levels of each operation at different years compared with the mechanization level of 2008 (Beheshti Tabar *et al.*, 2010).

Data on electricity consumption in agriculture is not available for wheat crop. Therefore, to calculate the amount of electricity consumed in crop production, the energy required to pump water for irrigating crop was estimated. Average depth of wells used for agricultural purposes in Iran is reported to be 80 m (MOE. 2006). A weighted average of the water requirement of wheat crop sown in different parts of the country was obtained and the energy required to pump the required amount of water was calculated using the following formula:

$$DE = \gamma gHQ/\varepsilon q \qquad (1)$$

Where DE: direct energy (GJ ha^{-1}); g, water density (1000 kg m^{-3}); g, gravity (9.81 m s^{-2}); Q: net water requirement (m^3 ha-1); H: the total head (m); eq: overall efficiency, taken to be 0.18 (Ercolia *et al.*, 1999). Net water requirement was calculated by the CropWat. Based on the energy equivalents of the inputs and output (Table 1), the energy ratio (energy use efficiency), energy productivity and the specific energy were calculated (Demircan *et al.*, 2006; Sartori *et al.*, 2005).

Energy use efficiency= Energy Output (MJ ha⁻¹)/Energy Input (MJ ha⁻¹) (2)

Energy productivity = Grain Output (MJ ha⁻¹)/Energy Input (MJ ha⁻¹) (3)

Specific energy = Energy Input (MJ ha⁻¹)/Grain Output (MJ ha⁻¹) (4)

Net energy = Energy Output (MJ ha⁻¹) – Energy Input (MJ ha⁻¹) (5)

In order to analyze the relationship between energy inputs and yield, several mathematical functions were tried. The Cobb–Douglas function was selected as the suitable function pattern. Several authors used Cobb–Douglas function to evaluate the relationship between energy inputs and production (Hatirli *et al.*, 2005; Hatirli *et al.*, 2006, Mohammadi and Omid, 2010). Cobb–Douglas function is expressed as follows:

$$Y=f(x)\ exp(u) \qquad (6)$$

Eq. (6) can be linearized and be further re-written as:

$$lnYi = a + \sum_{j=1}^{n} \alpha_j \ln(x_{ij}) + e_i \qquad i= 1, 2, \ldots, n$$

(irrigation wheat) (7)

$$lnYi = a + \sum_{j=1}^{n} \alpha_j \ln(x_{ij}) + e_i \qquad i= 1, 2, \ldots, n$$

(dryland wheat) (8)

Where Yi denotes the yield of the i'th farmer, Xij is the vector of inputs used in the production process, a is a constant, aj represents coefficients of inputs which are estimated from the model and ei is the error term. Eq. (7) and (8) can be expressed as follows;

$$lnY_i= \alpha_0+ \alpha_1 lnx_1+ \alpha_2 lnx_2+ \alpha_3 lnx_3+ \alpha_4 lnx_4+ \alpha_5 lnx_5+ \alpha_6 lnx_6+e_i \qquad (9)$$

Where human labour energy is (X_1), diesel fuel energy is (X_2), fertilizer energy is (X_3), pesticide energy is (X_4), water of irrigation energy is (X_5), seed energy is (X_6) in irrigation wheat production.

$$lnY_i= \alpha_0+ \alpha_1 lnx_1+ \alpha_2 lnx_2+ \alpha_3 lnx_3+ \alpha_4 lnx_4+ \alpha_5 lnx_5+e_i \qquad (10)$$

Where human labour energy is (X_1), diesel fuel energy is (X_2), fertilizer energy is (X_3), pesticide energy is (X_4), seed energy is (X_5) in dryland wheat production.

With respect to this pattern, the impact of the energy of each input on the output energy was studied using (9) – (10). Then, the impact of DE and IDE energies, and RE and NRE energies on the output energy was studied. For latter purposes, Cobb–Douglas function was determined as (11) and (12), respectively, in irrigation and dryland wheat production:

$$lnY_i=\beta_0+ \beta_1 inDE+ \beta_2 lnIDE+e_i$$

(11)Where Yi is the i'th farm's yield, DE and IDE are direct and indirect energies used for wheat production, respectively, and β_i is the co-efficient of exogenous variables.

$$lnY_i=\gamma_0+\gamma_1\ inRE+\gamma_2\ lnNRE+e_i \qquad (12)$$

Where Y_i is the i'th farm's yield, RE and NRE are renewable and nonrenewable energies used for wheat production, respectively, and γ_i is the coefficient of exogenous variables.

Eqs. (9)– (12) were estimated using ordinary least square (OLS) technique. Basic information on energy inputs and cucumber yields was entered in Excel's spreadsheet and SHAZAM 9.0.

RESULTS AND DISCUSSION

Energy inputs and output values used in irrigated and dryland wheat production for the period of 1986-2008 are shown in Table 2. The energy amount of various inputs during the studied period showed an increasing trend in wheat production. Among all the various inputs of energy in irrigated wheat production, fertilizers were the highest energy consuming input (33.2%), followed by irrigation (31.1%) and diesel fuel (18.7%). In dryland farms, diesel fuel (41.3%) consisted of the highest energy share of total energy input. followed by fertilizer (30.92%) and seed (24.9%). Among the fertilizer energy inputs, irrigated and dryland wheat production increased by 135% and 68%, respectively over the past 23 years. The percent of N fertilizer of the total fertilizer energy was about 93% in irrigated and 87% in dryland wheat during the same period. Due to use of improper methods for application of fertilizers and lack of sufficient knowledge among farmers, fertilizer energy had an increasing trend during the studied period.

The results in Table 2 show that irrigation energy in irrigated wheat has increased from 9.74 GJ ha^{-1} in 1986 to 13.04 GJ ha^{-1} in 2008. Irrigation energy accounts for 31.1% of the total energy inputs per ha^{-1}. The energy value of irrigation in irrigated wheat production of Iran is higher than that of wheat production systems in Australia (Khan *et al.*, 2010) and Pakistan (Hussain *et al.*, 2010), because irrigation is commonly performed with surface irrigation methods such as furrow irrigation in Iran. The average diesel fuel energy in the study period was 6.91 GJ ha^{-1} for irrigated and 4.53 GJ ha^{-1} for dryland wheat production. Increase of the diesel fuel consumption is due to increase of agricultural mechanization index from 0.28 kW ha^{-1} in 1986 to 0.53 kW ha^{-1} in 2008. Agricultural mechanization index is a ratio of the available

Table 2: Energy input and output values in wheat production for the period 1986-2008.

	Years					Average of Total	% [a]
	1986	1991	1996	2001	2008		
Irrigated wheat							
A. input							
human labor (GJ ha^{-1})	0.61	0.69	0.51	0.40	0.69	0.61	1.65
diesel fuel (GJ ha^{-1})	6.56	6.95	6.90	7.03	7.10	6.91	18.70
fertilizers (GJ ha^{-1})	7.24	10.06	11.21	10.6	17.03	12.26	33.20
pesticide (GJ ha^{-1})	0.06	0.22	0.21	0.21	0.39	0.24	0.67
irrigation (GJ ha^{-1})	9.74	10.88	11.91	11.52	13.04	11.47	31.10
seed (GJ ha^{-1})	4.68	4.72	5.20	5.96	6.23	5.37	14.56
B. outputs							
grain yield (GJ ha-1)	28.86	42.64	46.24	52.75	58.53	45.57	
Dry land wheat							
A. input							
human labor (GJ ha^{-1})	0.20	0.18	0.22	0.39	0.25	0.24	2.23
diesel fuel (GJ ha^{-1})	4.44	4.67	4.63	4.64	4.69	4.53	41.32
fertilizers (GJ ha^{-1})	2.44	3.11	3.03	4.76	4.1	3.39	30.92
pesticide (GJ ha^{-1})	0.02	0.09	0.05	0.06	0.06	0.06	0.62
irrigation (GJ ha^{-1})	-	-	-	-	-	-	-
seed (GJ ha^{-1})	2.7	2.65	2.73	2.51	3.22	2.73	24.9
B. Outputs							
grain yield (GJ ha^{-1})	10.4	11.75	10.59	15.7	15.77	13.06	

[a] Indicate percentage of total energy input.

Table 3: Energy parameters in wheat production for the period 1986-2008

	1986	1991	1996	2001	2008	Average of Total
Irrigated wheat						
Energy input (GJ ha^{-1})	29.01	33.71	36.14	36.01	44.67	36.80
Energy outputs (GJ ha^{-1})	28.87	42.64	46.24	52.76	58.53	45.57
Energy use efficiency	0.99	1.26	1.27	1.46	1.31	1.22
Net energy (GJ ha^{-1})	-0.13	8.93	10.1	16.75	12.9	8.46
Energy productivity(Kg MJ^{-1})	0.06	0.08	0.08	0.09	0.09	0.08
Specific energy (M J Kg^{-1})	14.77	11.62	11.49	10.03	11.22	12.21
Dryland wheat						
Energy input (GJ ha^{-1})	9.81	10.73	10.67	12.12	12.35	10.96
Energy outputs (GJ ha^{-1})	10.43	11.75	11.35	15.7	15.77	13.06
Energy use efficiency	1.06	1.09	0.99	1.29	1.27	1.16
Net energy (GJ ha^{-1})	0.62	1.02	0.67	3.58	3.42	2.05
Energy productivity(Kg MJ^{-1})	0.07	0.07	0.06	0.08	0.08	0.08
Specific energy (MJ Kg^{-1})	13.81	13.42	14.82	11.34	11.51	13.03

mechanical power to the total agricultural land. The inconsistency observed in the increase of diesel energy stems from differences in agricultural practices and the type of machinery used.

The seed energy consumed in irrigated and dryland production increased from 4.68 and 2.7 GJ ha^{-1} in 1986 to 6.23 and 3.22 GJ ha^{-1} in 2008, respectively. In recent years, more applications of board cast seeders instead of grain drills have led to use of more seeds per hectare during this period. Human energy in irrigated and dryland wheat production increased from 0.611 and 0.20 GJ ha^{-1} in 1986 to 0.696 and 0.25 GJ ha^{-1} in 2008, respectively. The shares of these inputs in total energy use per hectare for irrigation and dryland wheat were 1.65% and 2.23%, respectively. Use of cheap foreign labors in the agricultural sector especially in irrigation and harvesting wheat has been reason for the increase of labor energy.

It is clear from Tables 2 that pesticides were the least demanding energy input in wheat production with 0.249 (0.67% of the total energy input) and 0.06 GJ ha^{-1} (only 0.62% of the total energy input) in irrigated and dryland farms, respectively. Pesticide energy consumption in irrigated and dryland wheat production had a growing trend in the study period and increased from 0.066 and 0.02 GJ ha^{-1} in 1986 to 0.392 and 0.06 GJ ha^{-1}, in 2008, respectively. Energy input and output, energy ratio, net energy, productivity energy and specific energy of wheat production for different years of the study period are shown in Table 3. Total input energy in irrigated wheat production increased by approximately 53.9% and in dryland wheat increased by about 25.8% from 1986 to 2008, whereas total output energy in irrigated and dryland farms increased by about 102.7% and 51.1% from 1986 to 2008, respectively. (Table 3). Improvement of seed varieties and application of new technologies have affected the energy output.

Mean energy ratio was calculated as 1.22 for irrigated and 1.16 for dryland wheat production. Energy ratio in irrigated wheat production increased from 0.99 to 1.31 and in dryland wheat from 1.06 to 1.27 during the study period. Thus, energy ratio in wheat production shows an increasing trend from 1986 to 2008. Beheshti Tabar *et al.* (2010) reported an increasing trend in the energy ratio of Iran agriculture from 0.95 in 1990 to 1.17 in 2006. However, in Turkey, Ozkan *et al.* (2004) reported a decreasing energy ratio from 2.23 to 1.18 for the periods of 1975 – 2000. Higher growth rate in energy output (yield) than the input of energy is the main reason for rising trend of energy ratio in this review period.

Energy productivity is the term used to estimate the yield of marketable product per unit of energy consumption. Average energy productivity of irrigation and dryland wheat was 0.08 kg MJ^{-1}. As can be seen in Table 4, energy productivity of irrigated and dryland wheat has shown a significant increase from 0.06 and 0.07 kg MJ^{-1} in 1986 to 0.09 and 0.08 kg MJ^{-1} in 2008,

Table 4: Total energy input in the form of direct, indirect, renewable, Non-renewable energy for wheat (Average of period 1986-2008)

Types of energy	Irrigated wheat		Dryland wheat	
	(GJ ha^{-1})	%[a]	(GJ ha^{-1})	%[a]
Direct energy	18.99	51.6	4.77	43.55
Indirect energy	17.81	48.39	6.18	56.44
Renewable energy	17.38	47.24	2.97	27.13
Non-renewable energy	19.42	52.76	7.98	72.87
Total energy input	36.80		10.96	

[a] Indicate percentage of total energy input.

respectively, generally reflecting improvement of efficiency in wheat production over the years.

During the 23- year period, the net energy in irrigated and dryland wheat in 2008 compared to 1986 has a 93 fold and 5 fold increases, respectively. Also, specific energy showed an increasing trend during this period. Specific energy indicated the amount of energy spent to produce a unit of marketable product. The average amount of energy required to product 1 kg of irrigated and dryland wheat was calculated as 12.21 and 13.03 MJ.

Also, the distribution of inputs used for the production of wheat based on the direct, indirect, renewable and non-renewable energy group is given in Table 4. As can be seen from the Table, wheat production has mainly depended on non-renewable energy sources. Similar results have been reported in several studies (Hatirli *et al*., 2005; Beheshti Tabar *et al*., 2010).

One of the main objectives of this study was to explore the relationship between total output and energy inputs in some detail. For this purpose, Cobb–Douglas production function was specified and estimated using ordinary least square estimation technique. One of the features of this production function is that the estimated coefficients represent elasticity. Furthermore, Cobb–Douglas production function imposes a priori restrictions on patterns of substitution among inputs. In particular, elasticity of substitution among all inputs must be equal to unity.

Since time series data were used in this study, autocorrelation might be a potential concern, and therefore should be tested using the Durbin–Watson test. The computed Durbin–Watson values were calculated as 2.03, 2.15, 2.05, 1.9, 2.01 and 2.08 for Eqs. (9) – (12), showing that there was no autocorrelation at the significance level of 5% in the estimated models.

The impact of energy inputs on yield was also investigated by estimating Eq. (9)-(10). Regression result for this model was shown in Tables 5 and 6. Irrigation water in irrigated wheat and

Table 5: Econometric estimation results of inputs for irrigated wheat production

Endogenous variable: yield / Exogenous variables	Coefficient	t-Ratio
Model1: $\ln Y_i = \alpha_0 + \alpha_1 \ln x_1 + \alpha_2 \ln x_2 + \alpha_3 \ln x_3 + \alpha_4 \ln x_4 + \alpha_5 \ln x_5 + \alpha_6 \ln x_6 + e_i$		
Constant	3.36	0.56
Human labour	-0.24	-1.97
Diesel fuel	-0.87	-0.97
Fertilizer	0.21	1.15
Pesticide	0.14	1.81
Water for irrigation	0.83	2.26**
Seeds	0.71	2.11**
Durbin-Watson	2.03	
R^2	0.89	

*p<0.01, **p<0.05

Table 6: Econometric estimation results of inputs for dryland wheat production

Endogenous variable: yield / Exogenous variables	Coefficient	t-Ratio
Model2: $\ln Y_i = \alpha_0 + \alpha_1 \ln x_1 + \alpha_2 \ln x_2 + \alpha_3 \ln x_3 + \alpha_4 \ln x_4 + \alpha_5 \ln x_5 + e_i$		
Constant	- 9.14	-0.69
Human labour	0.41	2.46**
Diesel fuel	0.38	0.81
Fertilizer	0.58	2.64*
Pesticide	-0.055	-0.51
Water for irrigation	0.11	0.26
Seeds	2.15	
Durbin-Watson	0.52	
R^2		

*p<0.01, **p<0.05

Table 7: Econometric estimation results of direct, indirect, renewable, and non-renewable energies for irrigated wheat production

Endogenous variable: yield / Exogenous variables	Coefficient	t-Ratio
Model 3: $\ln Y_i = \beta_0 + \beta_1 \ln DE + \beta_2 \ln IDE + e_i$		
Constant	9.05	3.41*
Direct energy	- 0.25	- 0.89
Indirect energy	0.43	2.52**
Durbin–Watson	2.05	
R^2	0.86	
Model 4: $\ln Y_i = \gamma_0 + \gamma_1 \ln RE + \gamma_2 \ln NRE + e_i$		
Constant	- 7.2	- 3.47*
Renewable energy	1.32	4.07*
Non-renewable energy	0.51	2.71*
Durbin–Watson	1.9	
R^2	0.83	

*p<0.01, **p<0.05

fertilizer in dryland wheat had the highest impact among the other inputs and with elasticity of 0.83 and 0.58, respectively.

This indicates that additional use of irrigation water by 1% in irrigation wheat and fertilizer in dryland wheat would lead to increase of yield by 0.85% and 0.58%, respectively. Hatrili *et al.* (2006) developed an econometric model for greenhouse tomato production in Antalya Province of Turkey and showed that human labor, chemical fertilizers, biocides, machinery, and water energies were important inputs, which significantly contributed to yield.

The regression coefficients of direct and indirect energies (Models 3 and 5) as well as renewable and non-renewable energies (Models 4 and 6) on yield in irrigated and dryland production were investigated through Eqs. (11) and (12), respectively. The results are given in Tables 7 and 8. As shown, the regression coefficients of indirect, renewable and non-renewable energies were all statistically significant at level of 1%. The impacts of direct, indirect, renewable, and non-renewable energies on irrigation wheat were estimated as 0.25, 0.43, 1.32 and 0.51, respectively, whereas the regression coefficient of direct, indirect, renewable and non-renewable energies in dryland wheat were estimated as 3.38, 1.08, 0.98 and 1.38, respectively. In the literature, similar results have been in line with reported results of irrigation

Table 8: Econometric estimation results of direct, indirect, renewable, and non-renewable energies for dryland wheat production.

Endogenous variable: yield / Exogenous variables	Coefficient	t-Ratio
Model 5: $\ln Y_i = \beta_0 + \beta_1 \ln DE + \beta_2 \ln IDE + e_i$		
Constant	- 28.7	3.41*
Direct energy	3.38	- 0.89
Indirect energy	1.08	2.52**
Durbin–Watson	2.01	
R^2	0. 53	
Model 6: $\ln Y_i = \gamma_0 + \gamma_1 \ln RE + \gamma_2 \ln NRE + e_i$		
Constant	- 10.88	- 2.73*
Renewable energy	0.98	1.81
Non-renewable energy	1.38	2.64*
Durbin–Watson	2.08	
R^2	0.51	

*p<0.01, **p<0.05

wheat. For example, the impact of indirect energy was more significant than the impact of direct energy on yield (Hatrili *et al*., 2006).

CONCLUSIONS

This study analyzed the energy consumption and investigated influences of energy inputs and energy forms on output levels in wheat production of Iran during the period of 1986–2008. For this purpose, total human labor, diesel fuel, fertilizer, pesticide, irrigation, seed, and output energies were estimated and the energy consumption pattern was examined as direct, indirect, renewable, and non-renewable energy classifications.

The results revealed that both input and output energy had grown over the study period. The total input energy value for irrigated and dryland wheat increased from 29.01 and 9.81GJ ha^{-1} in 1986 to 44.67 and 12.35 GJ ha^{-1} in 2008, respectively. Similarly, output energy in irrigated and dryland wheat increased from 28.87 and 10.43 GJ ha^{-1} in 1986 to 58.53 and 15.77 GJ ha^{-1} in 2008, respectively. Fertilizers in irrigated wheat production are high-energy resources and supply 33.2% of total energy input, while diesel fuel (41.32%) in dryland wheat consumed the most energy of total energy input. From an environmental perspective, excessive usage of chemical fertilizers and pesticides has negative effects on sustainable agricultural production. In addition, mechanization that depends on fossil fuel usage is another negative factor. This is significant because use of farm manure, biological control, integrated pest management and saving diesel fuel by improving tillage can be effective on sustainable agricultural production.

The input-output ratio in irrigated and dryland wheat increased from 0.99, 1.06 to 1.31, and 1.27, respectively in the examined period. Similarly, energy productivity and net energy indicators have also increased during this period. Improvement of energy indicators indicates the enhancement of wheat productivity in Iran during past two decades. It seems that application of optimal irrigation methods and policymaking toward proper distribution of fertilizer can lead to an increase in the energy ratio of wheat in Iran. Irrigation water and fertilizer had the highest impact on irrigation and dryland wheat production, respectively among the other inputs. The impacts of direct, indirect, renewable, and non-renewable energies in irrigation wheat were estimated as 0.25, 0.43, 1.32, and 0.51, respectively, whereas the regression coefficients of direct, indirect, renewable, and non-renewable energies in dryland wheat were estimated as 3.38, 1.08, 0.98, and 1.38, respectively.

Future researches should apply energy analysis in various low and high input systems along with long -term economic, environmental, and societal analysis, which further explain the suitability and compatibility of production system for establishing sustainable development.

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