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Energy analysis and life cycle assessment of wheat production in Iran

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This study was done to evaluate the energy balance between the inputs and output per unit area and to examine the effect of different farm sizes on total energy inputs and output of wheat production in Esfahan province of Iran. For this purpose data were collected by using a face-to-face questionnaire. The total energy input and output are calculated as 31.5 and 44.6 GJ ha⁻¹, respectively. The highest energy consumer was chemical fertilizer and followed by diesel fuel and seed energy with share of 64, 14 and 8%, respectively. Total green house gas emission was 756.11 kgCO₂eq ha⁻¹ where chemical fertilizer and diesel fuel had the highest contribution. The energy ratio, energy productivity and net energy values are 1.49, 9.82 kg MJ⁻¹ and 13.1 GJ ha⁻¹, respectively. The forms of direct, indirect, renewable and non-renewable energies of wheat production are calculated as 6.5, 25, 5.3 and 26.2 GJ ha⁻¹ at 21, 79, 17 and 83% of the total energy input, respectively. The results of regression analysis which is applied to find the relationship between energy inputs and wheat yield indicate the significant effect of water for irrigation, seed, chemical fertilizer and machinery energy input on wheat yield. It is concluded that use of 10 MJ in forms of direct, indirect, renewable and nonrenewable energy, leads to 3.0, 0.4, 2.8 and 0.6 kg ha⁻¹ growth in wheat yield, respectively. The results of farm size analysis show very large farms have better energy use efficiency due to better energy management.

Keywords: Energy balance, life cycle assessment, green house gases (GHG) emission, sensitivity analysis, farm size, wheat, Iran.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the top three most produced cereals in the world, ranks third after corn and rice (paddy) and it provides financial savings, fossil resources preservation and most extensively grown of all crops (Shahin et al., 2008). It is a worldwide cultivated grain for its highly nutritious and useful grain (Houshyar et al., 2010a). Wheat is grown under irrigated as well as rain-fed conditions worldwide. Under rain-fed conditions the developing grains are frequently exposed to mild to severe stress at different stages of grain development (Shahin et al., 2008; Singh et al., 2008). The annual wheat world production for 2008 was 683 million ton with 11% increase in comparison with 2007. China is the highest wheat producer with production of 112 million ton and followed by India, United States of America, Russian federation and France. Based on Ministry of Jihad-e-agriculture of Iran statistics, Iran produced about 13 million ton wheat for 2008. The whole country cultivated

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area was 6.65 million hectare where, Kurdistan province had the highest wheat cultivated area in Iran (8.27%). Esfahan is one of the important Iranian provinces in agricultural production. Wheat with share of 36% of total farming area is the single most important agricultural commodity in this province (Anonymous, 2010, 2011).

Agriculture has become an increasingly energy intensive sector in the last half century with much of it attributable to the needed inputs. For example, chemical fertilizers and pesticides require much greater energy to manufacture than to apply on-farm (Dyer and Desjardins, 2006). Agriculture is both a producer and a consumer of energy (Kizilaslan, 2009). Through photosynthesis, crops convert solar energy to biomass, thus providing food, feed and fiber (Alam et al., 2005; Ozkan et al., 2004a, b). Energy use in agriculture has become more intensive in response to increasing population, limited supply of arable land, and a desire for higher standards of living (Rafiee et al., 2010). The continual increase in the production of food requires an intensive use of machinery, fertilizers, pesticides and other natural resources. Intensive use of energy brings about problems threatening human health and the environment (global warming and climate change) (Urban et al., 2007). Productive use of energy in agriculture will minimize the environmental problems, prevent degradation of natural resources, and improve sustainable agricultural activities with an economical system of production (Esengun et al., 2007). The challenge for energy policy is that of reducing the environmental costs of energy production and use, while extending access to basic energy services in developing countries, and preserving energy security (Karbassi et al., 2007). If the increase in the energy use in the agricultural industry continues, the only chance of producers to increase total output will be using more input as there is no chance to expand the size of arable lands. Under these circumstances, an input to output analysis provides planners and policy makers the opportunity to evaluate economic interactions of energy use (Ozkan et al., 2004). An input to output energy analysis is used to determine the effects of production systems on environment and the efficiency of the uses of energy.

Several researches have conducted on energy use in different agricultural crops such as cotton (Singh et al., 2002, 2000), sugarcane (Karimi et al., 2008), forage maize (Pishgar et al., 2011; Phipps et al., 1976), kiwifruit (Mohammadi and Omid, 2010), strawberry (Banaeian et al., 2011), apricot (Gezer et al., 2003), grape (Ozkan et al., 2007), tomato (Hatirli et al., 2006; Esengun et al., 2007), potato (Znganeh et al., 2010), greenhouse cucumber (Mohammadi et al., 2010), citrus (Özkan et al., 2004a, b), canola (Unakitan et al., 2010) soy bean (Mandal et al., 2002; Chamsing et al., 2006) and etc.

In literature review, Singh et al. (2004) studied the sensitivity of a particular energy input on wheat production in Punjab. Kuesters and Lammel (1999) investigated the energy efficiency of the production of winter wheat and sugar beet in Europe and found a linear relationship between increasing energy input into the total system and increasing N fertilizer application. Shyam and Gite (1990) analyzed the energy balance of soybean-wheat crop rotation under the rain fed conditions of central India worked out and compared with the traditional practice. Marakoğlu and Çarman (2010) studied the energy balance of direct seeding applications used in wheat production in middle Anatolia and found that direct seeding application in comparison with conventional application can improve the energy ratio. Khan et al. (2010) studied the energy and economic analysis of wheat, rice and barley production in Australia and found that wheat is the most energy efficient crop compared to rice and barley. The benefit-cost ratio of rice farms (3.33) was the highest incomparison with wheat (2.82) and Barley (2.50) production.

One of the most important issues in recent century is the global warming and green house gas emission is the main factor of this change in weather conditions. There is scientific consensus that global warming poses one of the major environmental challenges in the future. While the bulk of the so called green house gases (GHG) originate from fossil fuel consumption (Pathak and Wassmann, 2007). Green house gas (GHG) emissions from agriculture account for 10 to 12% of all manmade GHG emissions and are the main source of anthropogenic N₂O (60%) and CH₄ (50%) (Browne et al., 2011). Production, formulation, storage, distribution of the inputs and application with machinery lead to combustion of fossil fuel and use of energy from alternate sources, which also emits CO₂ and other green house gases in to the atmosphere. Thus, an understanding of the emissions expressed in kilograms of carbon equivalent (kg CE) for different tillage operations, fertilizers and pesticides use, supplemental irrigation practices, harvesting and residue management is essential to identifying C-efficient alternatives such as biofuels and renewable energy sources for seed bed preparation, soil fertility management, pest control and other farm operations (Lal, 2004).

Life cycle analysis (LCA) is a tool used to assess the amount of green house gas of a product throughout its whole life cycle. The life cycle of wheat includes production, use of machinery and application of agricultural chemicals such as pesticides and fertilizers.

Ho (2011) calculated the amount of GHG emissions in wheat production and found 2,963 MgCO₂ ha⁻¹ where, fertilizer production was responsible 89% of GHG emissions in this crop production. Biswas et al. (2008) presented a greenhouse gas (GHG) life cycle assessment of 1 tons of wheat transported to portin south-western Australia, including emissions from pre-farm, on-farm and post-farm stages. The results indicated that fertilizer production in the pre-farm stage contributed significantly (35%) to GHG, followed by on-farm CO₂.
emissions (27%) and emissions from transportation of inputs and wheat (12%).

DeFigueiredo et al. (2010) studied the association of greenhouse gas emissions with sugar production in southern Brazil. According to their calculations, 241 kg of carbon dioxide equivalent were released to the atmosphere per a ton of sugar produced (2,406 kg of carbon dioxide equivalent per a hectare of the cropped area). The major part of the total emission (44%) resulted from residues burning; about 20% resulted from the use of fertilizers, and about 18% from fossil fuel combustion.

The aim of the present study is to determine the input to output energy use in wheat production in Esfahan Province of Iran to find the energy efficiency of this production. Also, the Cobb–Douglas production function is applied to study the relationship and the sensitivity between energy inputs and wheat yield. Also the effect of farm size on energy use is evaluated.

MATERIALS AND METHODS

Esfahan province covers an area of approximately 1 million hectare and is located in the center of Iran within 30° 43 and 34° 27’ N latitude and 49° 36 and 55° 31’ E longitude (Asakerereh et al., 2010a). Data were collected from 400 farmers growing wheat by using a face to face questionnaire. The stratified random sampling technique was used to select farms randomly in the study region. The sample size was calculated using the Neyman method as, (Yamane, 1967).

\[ n = \frac{\sum N_n S_n}{N^2 D^2 + \sum N_n S_n} \]  

where ‘n’ is the required sample size; ‘N’ is the number of farmers in the ‘h’ stratification; ‘S_n’ the variance of the ‘h’ stratification; ‘d’ permitted error ratio deviated from average of population (\(\bar{x} - \bar{X}\)), ‘z’ the reliability coefficient (1.96 which represents 95% confidence) and \(D^2 = d^2 / z^2\) is the permissible error in the sample population was defined to be 5% within 95% confidence interval. The calculated sample size in this study was found to be 211. Thus, 320 potato producers from the population were selected randomly.

In order to specify the inputs and output energy of wheat production, the amounts of each input (diesel fuel, human labor, machinery, seed, chemical fertilizer, water for irrigation, biocide and manure) and output (wheat yield) were determined. The wheat straw is not used in study region and this output is removed from energy analysis. To calculate the amount of energy value for inputs and output, the energy equivalent values are applied and by multiplying the inputs amount by equivalents the energy values were calculated (Table 1). The machinery energy is calculated by the following formula that is taken from Ozkan et al. (2004a, b) and Hatirli et al. (2005) with some change:

\[ ME = \frac{ELG}{TC_a} \]  

Where ‘\(ME\)’ is the machine energy (MJ ha\(^{-1}\)); ‘G’ the weight of machine (kg); ‘E’ the production energy equivalent (MJ kg\(^{-1}\) yr\(^{-1}\)) that is shown in Table 1, ‘L’ the useful life of machine (year), ‘T’ the economic life of machine (h) and ‘C_a’ the effective field capacity (ha h\(^{-1}\)). To calculate ‘\(C_a\)’, the following equation is used (Hatirli et al., 2005; Ozkan et al., 2004a, b):

\[ C_a = \frac{SWE}{10} \]  

Where ‘\(C_a\)’, the effective field capacity (ha h\(^{-1}\)); ‘W’ working width (m); ‘S’ working speed (kmh\(^{-1}\)) and ‘E’ is the field efficiency.

Based on the energy equivalents of the inputs and outputs (Table 2), the output to input ratio (energy use efficiency), specific energy, energy productivity and net energy for wheat production were calculated using the following equations as suggested by (Mandal et al., 2002; Singh et al., 1997).

\[ \text{Energy Ratio} = \frac{\text{Energy Output (MJ ha}^{-1}\)}{\text{Energy Input (MJ ha}^{-1}\)} \]  

\[ \text{Energy Productivity} = \frac{\text{Wheat Output (kg ha}^{-1}\)}{\text{Energy Input (MJ ha}^{-1}\)} \]  

\[ \text{Specific Energy} = \frac{\text{Energy Input (MJ ha}^{-1}\)}{\text{Wheat Output (kg ha}^{-1}\)} \]  

\[ \text{Net Energy} = \text{Energy Output (MJ ha}^{-1}\) \cdot \text{Energy Input (MJ ha}^{-1}\) \]  

Agriculture sector uses energy directly and indirectly (Pervanchon et al., 2002). The input energy is also classified into direct and indirect and renewable and non-renewable forms (Singh, 2002; Mandal et al., 2002; Singh et al., 2003; Uhlin, 1998). The indirect energy consists of machinery, pesticide and fertilizer while the direct energy includes human power, diesel fuel, water for irrigation and electricity energy used in the production process. On the other hand, non-renewable energy includes petrol, diesel, electricity, chemical fertilizers, biocide, machinery and renewable energy consists of human, animal, farmyard manure (FYM) and water for irrigation (Pervanchon et al., 2002; Singh et al., 2003).

In order to evaluate the effect of farms size on energy analysis and calculate the best wheat farm size, farms classified into four levels (small <1 ha), medium (between 1 and 4 hectare), large (between 4 and 10 hectare) and very large (> 10 ha) due to the frequency of farm size in the sample population. In order to find the significant difference between wheat farm levels, ANOVA and Duncan compare mean test were applied like Pishgar et al. (2011) study.

To find the amount of GHG emission of inputs in wheat production per unit area (hectare), CO\(_2\) emission coefficient was applied (Table 2). For every GHG producers (diesel fuel, chemical fertilizer, biocide and water for irrigation) the amount of produced CO\(_2\) was calculated by multiplying the input application rate by emission coefficient that is shown in Table 2.

For water irrigation, the energy consumption was converted to the diesel fuel amount and calculated by multiplying the diesel fuel by coefficient emission the total CO\(_2\) emission in water for irrigation input was calculated. Dvoskin et al. (1976) assessed fuel consumption for lifting irrigation water in several regions of the western US. The CO\(_2\) emission ranged from 7.2 to 425.1 kg CO\(_2\) eq ha\(^{-1}\) (128.9 ± 97.6 kg CO\(_2\) eq ha\(^{-1}\)).

A mathematical function can be used to investigate the relationship between input energies and wheat yield. For this purpose, Cobb-Douglas production function is used. The Cobb-Douglas function helps to estimate the relationship between input energies and crop yield (Hatirli et al., 2006; Momammad and Omid, 2010; Singh et al., 2004) and is expressed as follow (Mohammad and Omid, 2010; Hatirli et al., 2005):

\[ Y_0 = (\bar{X}) \exp (\bar{U}) \]  

This last expression can be expressed explicitly in the following form;
Table 1. Energy equivalents of inputs and output.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Input</th>
<th>Unit</th>
<th>Energy equivalent (MJ unit⁻¹)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inputs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Tractor and self-propelled</td>
<td>Kg yr⁻¹</td>
<td>9-10</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td></td>
<td>Stationary equipment</td>
<td>Kg yr⁻¹</td>
<td>8-10</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td></td>
<td>Implement and machinery</td>
<td>Kg yr⁻¹</td>
<td>6-8</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td>2</td>
<td>Human labor</td>
<td>h</td>
<td>1.96</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td>3</td>
<td>Diesel fuel</td>
<td>l</td>
<td>47.8</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td></td>
<td>Bioicide</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Herbicide</td>
<td>kg</td>
<td>85</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td></td>
<td>Insecticide</td>
<td>kg</td>
<td>115</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td></td>
<td>Fungicide</td>
<td>kg</td>
<td>295</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td>5</td>
<td>Nitrogen (N)</td>
<td>kg</td>
<td>78.1</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td></td>
<td>Phosphate (P₂O₅)</td>
<td>kg</td>
<td>17.4</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td></td>
<td>Potassium (K₂O)</td>
<td>kg</td>
<td>13.7</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td>6</td>
<td>Farmyard manure (FYM)</td>
<td>kg</td>
<td>0.30</td>
<td>Demircan et al. (2006) and Ozkan et al. (2004a, b)</td>
</tr>
<tr>
<td>7</td>
<td>Water for irrigation</td>
<td>m³</td>
<td>1.02</td>
<td>Acaroglu (1998), and Acaroglu and Aksoy (2005)</td>
</tr>
<tr>
<td>8</td>
<td>Seed</td>
<td>kg</td>
<td>13</td>
<td>Kitani (1999)</td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Wheat (grain)</td>
<td>kg</td>
<td>13</td>
<td>Kitani (1999)</td>
</tr>
</tbody>
</table>

yr⁻¹: The economic life of machine (year)

\[
\ln Y_i = \alpha + \sum_{j=1}^{n} \alpha_j \ln(X_{ij}) + e_i \quad i=1,2,\ldots, n \tag{9}
\]

Where 'Y_i' denotes the yield of the ith farmer, 'X_{ij}' the vector of inputs used in the production process, 'α' the constant term, 'α_j' represent coefficients of inputs, which are estimated from the model and 'e_i' is the error term. When the energy input is zero, the crop production is also zero (Hatirli et al., 2006; Singh et al., 2003), and hence Equation 9 can be rewritten as:

\[
\ln Y_i = \beta_1 \ln(DE) + \beta_2 \ln(IDE) + e_i \tag{12}
\]

\[
\ln Y_i = \gamma_1 \ln(RE) + \gamma_2 \ln(NRE) + e_i \tag{13}
\]

With assumptions that yield is a function of inputs energy, Equation 10 can be expanded to the following form:

\[
\ln Y_i = a_1 \ln(X_1) + a_2 \ln(X_2) + a_3 \ln(X_3) + a_4 \ln(X_4) + a_5 \ln(X_5) + a_6 \ln(X_6) + a_7 \ln(X_7) + a_8 \ln(X_8) + e_i \tag{11}
\]

Where 'X_i' is machinery, 'X_2' human labor, 'X_3' diesel fuel, 'X_4' chemical fertilizer, 'X_5' water for irrigation, 'X_6' seed, 'X_7' biocide and 'X_8' farmyard manure are energy inputs. By using Equation 11, the impact of the energy inputs on the yield was studied.

In order to analyze the relationship between the forms of energy and wheat yield, Cobb–Douglas function was utilized to evaluate the impact of direct, indirect, renewable and non-renewable energy as a following forms (Pishgar et al., 2011):

Where 'Y_i' denotes the yield of the ith farmer, 'DE', 'IDE', 'RE' and 'NRE' are direct, indirect, renewable and non-renewable energy that used for wheat production respectively, 'β_1' and 'γ_i' are the coefficients of variables and 'e_i' is the error term. By using ordinary least square (OLS) technique, Equations 11 to 13 are estimated
Table 2. Greenhouse gas (GHG) emission coefficient of inputs.

<table>
<thead>
<tr>
<th>Input</th>
<th>Unit</th>
<th>GHG coefficient (kgCO₂eq unit⁻¹)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machinery</td>
<td>MJ</td>
<td>0.071</td>
<td>Dyer and Desjardins (2006)</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>L</td>
<td>2.76</td>
<td>Dyer and Desjardins (2003)</td>
</tr>
<tr>
<td>Chemical fertilizers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphorus (P₂O₅)</td>
<td>kg</td>
<td>0.2</td>
<td>Lal (2004) and Pathak and Wassmann (2007)</td>
</tr>
<tr>
<td>Potassium (K₂O)</td>
<td>kg</td>
<td>0.2</td>
<td>Lal (2004) and Pathak and Wassmann (2007)</td>
</tr>
<tr>
<td>Biocide</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insecticide</td>
<td>kg</td>
<td>5.1</td>
<td>Lal (2004) and Pathak and Wassmann (2007)</td>
</tr>
</tbody>
</table>

(Pishgar et al., 2011).

The marginal physical productivity (MPP) technique based on the response coefficients of the inputs is applied to find the sensitivity of a particular energy input on wheat production. The MPP value indicates the change in the output with a unit change in the input factor (when all other factors are constant at their geometric mean level) (Pishgar et al., 2011).

The MPP value of the various inputs was calculated by using the ‘αj’ of the various energy inputs as (Pishgar et al., 2011; Singh et al., 2004):

\[
MPP_{xj} = \frac{GM(Y)}{GM(X_j)} \times \alpha_j = \frac{GM(Y)}{GM(X_j)} \times \alpha_j
\]

(14)

Where ‘MPP_{xj}' is marginal physical productivity of jth input, ‘αj', the regression coefficient of jth input, GM (Y), geometric mean of yield, and GM (X_j), geometric mean of jth input energy per hectare.

In order to suggest optimal adjustments in the existing resource use patterns and to determine the proportionate change, it is necessary to know the nature of the return to scale, which is indicated by the sum of the elasticities \( (\varepsilon \equiv \frac{m}{n}) \) derived in the form of regression coefficients in the Cobb-Douglas production function (Ghasemi et al., 2010). If the sum is less than or equal to or greater than one, the decreasing, constant, or increasing returns to scale are indicated, respectively. An increasing, constant and decreasing return to scale indicates that with x value increasing in the energy inputs, the yield of wheat increases by more than, exactly and less than x value, respectively (Singh et al., 2004). For this purpose the return to scale of Equations 11 to 13 were calculated.

Durbin-Watson statistic test is used to examine the presence of autocorrelation in the residuals of regression analysis and in order to measure of how well future outcomes are likely to be predicted by the model the coefficient of determination \( (R^2) \) was applied (Ghasemi et al., 2010).

All collected data on energy inputs and wheat yield were entered into Excel spread-sheets and all calculations and estimations were carried out using the Excel 2010, Shazam8.0 and SPSS 18 software.

RESULTS AND DISCUSSION

Energy inputs and output of wheat production in different levels of farms

The results of energy inputs and output in different farm levels are shown in Table 3. The total energy use in wheat production and energy output are calculated as 31,482 and 44,589 MJ ha⁻¹, respectively. et al., (2010b) found the energy use of 38,985 MJ ha⁻¹ for wheat production in Australia. The difference related to level of mechanization (farms with high level of mechanization use more energy in production). As it can be seen in Table 3, chemical fertilizer is the highest energy consumer with share of 64% of all energy inputs and followed by diesel fuel, seed and water energy with portion of 14, 8 and 5%, respectively. Between chemical fertilizers, nitrogen (43%) had first rank in energy use and followed by phosphate (12%) and potassium (9%) fertilizer in wheat production. There are several reasons for high energy consumption of chemical fertilizer such as subsidies price. Subsidies (government financial assistant) in agricultural sector leads to reduction of chemical fertilizer price and with low surveillance, farmers consume the high amount of chemical fertilizer especially nitrogen. Wrong belief between Iranian farmers is another reason causing increase in fertilizer use. They believe by using more chemical fertilizer the amount of crop production will increase. Most of Iranian farmers are illiterate or with low level of literacy so changing their wrong belief is not accessible. Soil erosion is another problem that increases the amount of chemical usage. The result is similar to Asakereh et al. (2010), Houshyar et al. (2010), Shahin et al. (2008) and Khan et al. (2010) and they found chemical fertilizer (especially nitrogen) as one of the most energy consumers in wheat production in Iran. Diesel fuel energy as the second important input in wheat production is mainly consumed for land preparation, planting, spraying, harvesting and transportation. Using tractors and machinery in their highest field capacity, not applying worn out tractors and using conservation tillage systems in wheat production can reduce the amount of diesel fuel energy use (Pishgar et al., 2011). The human labor energy is the least energy consumer (1% of total energy) due to high mechanization level and low amount of energy equivalent for human
The energy consumption calculation for different farm levels showed that total energy consumption was least in very large farms (more than 10 ha) significantly due to high level of management in using inputs. As shown in Table 3, small farms (less than 1 ha) use more human labor, chemical fertilizer and seed energy significantly in comparison to other farm levels. The results revealed that the irrigation energy use in small farms is least significantly. In small farms irrigation management is better and the water loss is less than larger farms. The comparison of wheat yield based on the farm levels indicated that by increasing the farms size, the wheat yield will increase respectively. In large farms, larger and precision machinery are applied and all farm operations are done accurately. Moreover doing operations accurately decreases the amount of inputs (fertilizer, seed, diesel fuel, labor and machinery). The results are similar to Shahin et al. (2008) study that found large farms in wheat production have more energy efficiency.

Table 4 shows the values of energy indices and the distribution of energy input according to the energy forms (direct, indirect, renewable and non-renewable energies) for different farm levels in wheat production. The energy ratio, energy productivity, specific energy and net energy average value were 1.49, 9.82 kg MJ⁻¹, 0.11 MJ kg⁻¹ and 13 GJ ha⁻¹ respectively. The energy ratio value in this study is lower than Shahin et al. (2008) and Houshyar et al. (2010a) studies.

The lower value of energy ratio in this study region can be explained by lower wheat yield, removing wheat straw from output energy (straw had no usage in the research region) and lower energy use management in research region. As it can be seen in Table 4, increasing the farms size lead to increase energy ratio, specific and net energy values accordingly, reaching to 2.18, 0.17 MJ ha⁻¹ and 30 GJ ha⁻¹, respectively in very large farms. Energy ratio (energy use efficiency) can be increased by decreasing total energy input or by increasing the total energy output and by applying both specified actions at the same time. As it is expressed in previous paragraph, in larger wheat farms the consumption of inputs is less (based on the plant need so the yield is in highest value) therefore, these situations lead to more energy ratio value (energy use efficiency) for very large farms.

The distribution of energy inputs in wheat production according to direct, indirect, renewable and non-renewable energy forms are displayed in Table 4. The results revealed that the average share of indirect (79%) energy form was greater than the direct one (21%) and also the portion of non-renewable (83%) form was higher than renewable (17%) form. It can be concluded that wheat production is mostly depending on non-renewable resources (fossil energy resources) that lead to environment pollution and global warming. The results were similar to Shahin et al. (2008) study. They represented that 36, 64, 90 and 10% of total energy consume in form of direct, indirect, non-renewable and renewable, respectively. Some other research found similar results in other crops (Mohammadi and Omid, 2010; Ozkan et al., 2007). It is clear from Table 4 that as farms size increase, the amount of all forms of energy input becomes higher.
resources decreases due to use energy inputs efficiently.

Greenhouse gas (GHG) emission

The results of life cycle assessment of wheat production are shown in Table 5. As it can be seen total global warming potential (GWP) in wheat production is 756.11 kgCO$_{2eq}$ ha$^{-1}$. Emissions were much lower for pea (250 kgCO$_{2eq}$ ha$^{-1}$) than wheat (1,086 kgCO$_{2eq}$ ha$^{-1}$) as less fertilizer was applied to pea (Khakbazan et al., 2009). The estimate of total GHG emission in this investigation is lower that reported by Pathak and Wassmann (2007) for wheat production (total GWP in the various districts was between 1,038 and 1,624 kgCO$_{2eq}$ ha$^{-1}$). Burning of wheat straw was the difference between this study and Pathak and Wassmann (2007) research which increased the amount of GHG emissions to highest values (1,624 kgCO$_{2eq}$ ha$^{-1}$) for various districts. Our estimate of GHG intensity is very similar to that reported by Khakbazan et al. (2009) that greenhouse gas emissions from wheat production can be ranged from 410 kgCO$_{2eq}$ ha$^{-1}$ to 1,30 kgCO$_{2eq}$ ha$^{-1}$ depending on fertilizer rate, location and seeding system.

It is revealed that chemical fertilizer is the major source contributing 41% of total GHG emission and followed by diesel fuel, water for irrigation, machinery and biocide contributing 35, 12, 9 and 3% of GWP, respectively (Figure 1).

Between chemical fertilizers, nitrogen had the first rank in GHG emission and next ranks belonged to phosphorus and potassium with portion of 30, 6 and 5%, respectively (Table 5). Using fertilizer (especially nitrogen) more than plant need is the most reason for high amount of GHG emission. Beside GHG emission, soil and water pollutions are the results of using more chemical fertilizer in wheat production in research area which can make agriculture environment unfriendly. Unfortunately, increasing fertilizer application and other natural nitrification processes have resulted in elevated levels of nitrous oxide emissions from soils (Neitzert et al., 1999).

Diesel fuel is one of the most important inputs in total GHG emission of wheat production (with production of 260 kgCO$_{2eq}$ ha$^{-1}$) (Table 5). Applying worn out tractors in operations, improper matching of equipment to tractors and performing high energy intensity tillage operation are the most reasons for the high GHG emissions in wheat production (Dyer and Desjardins, 2003). After diesel fuel input, irrigation input causes 94 kgCO$_{2eq}$ ha$^{-1}$ emissions by using diesel fuel to pump the water for irrigation. Using more ground water in irrigation is a solution to decrease the amount of diesel fuel consumption and relatively the GHG emissions. Machinery manufacture after water for irrigation produces 70 kgCO$_{2eq}$ ha$^{-1}$ in wheat production. Decreasing machinery operations by applying zero or no tillage systems and direct seeding leads to reduce this amount of GHG emissions. The least amount of GHG emissions in wheat production belongs to biocide with amount of 20 kgCO$_{2eq}$ ha$^{-1}$ that shares 3% of total GHG emissions.

Econometric model and sensitivity analysis for wheat production

By assuming that the wheat yield is a function of energy inputs the Cobb-Douglas production function is applied to find the relationship between energy inputs (human labor, diesel fuel, biocide, chemical fertilizer, machinery, seed, water for irrigation and farmyard manure energy) and yield. The results of Table 6 indicate that machinery and water for irrigation energy have significant impact (p < 0.01) on wheat yield and also the impact of chemical fertilizer and seed are significant on 5% probability level.

Table 4. Energy indices in wheat production.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Farms level (ha)</th>
<th>Average (unit)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small (&lt;1)</td>
<td>Medium (1-4)</td>
<td>Large (4-10)</td>
</tr>
<tr>
<td>Energy ratio</td>
<td></td>
<td>0.86$^{a}$</td>
<td>1.28$^{a}$</td>
<td>1.62$^{a}$</td>
</tr>
<tr>
<td>Energy productivity</td>
<td>Kg MJ$^{-1}$</td>
<td>15.17$^{b}$</td>
<td>10.14$^{b}$</td>
<td>8.01$^{b}$</td>
</tr>
<tr>
<td>Specific energy</td>
<td>MJ kg$^{-1}$</td>
<td>0.07$^{a}$</td>
<td>0.10$^{a}$</td>
<td>0.12$^{a}$</td>
</tr>
<tr>
<td>Net energy</td>
<td>MJ ha$^{-1}$</td>
<td>-5479.56$^{a}$</td>
<td>8994.38$^{b}$</td>
<td>18912.07$^{c}$</td>
</tr>
<tr>
<td>Direct energy$^{d}$</td>
<td>MJ ha$^{-1}$</td>
<td>8241.10$^{a}$</td>
<td>6605.98$^{b}$</td>
<td>5637.36$^{b}$</td>
</tr>
<tr>
<td>Indirect energy$^{e}$</td>
<td>MJ ha$^{-1}$</td>
<td>30039.46$^{a}$</td>
<td>25294.64$^{b}$</td>
<td>24705.57$^{b}$</td>
</tr>
<tr>
<td>Renewable energy$^{f}$</td>
<td>MJ ha$^{-1}$</td>
<td>5799.29$^{a}$</td>
<td>5098.97$^{b}$</td>
<td>5006.06$^{b}$</td>
</tr>
<tr>
<td>Non-renewable energy$^{g}$</td>
<td>MJ ha$^{-1}$</td>
<td>32481.27$^{a}$</td>
<td>26801.85$^{b}$</td>
<td>25336.87$^{b}$</td>
</tr>
<tr>
<td>Total energy$^{h}$</td>
<td>MJ ha$^{-1}$</td>
<td>38280.56$^{a}$</td>
<td>31900.62$^{b}$</td>
<td>30342.93$^{b}$</td>
</tr>
</tbody>
</table>

$^{a}$ Include human labor, diesel fuel and water for irrigation; $^{b}$ Include machinery, seed, biocide and manure and chemical fertilizer; $^{c}$ Include seed, human labor, manure and water for irrigation; $^{d}$ Include machinery, chemical fertilizer, biocide and diesel fuel; Note: Different letters (a, b and c) show significant difference of means.
Figure 1. The contribution of GHG emissions in wheat production.

Table 5. Greenhouse gas emissions of inputs in wheat production.

<table>
<thead>
<tr>
<th>Input</th>
<th>GHG emissions (kgCO₂eq ha⁻¹)</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machinery</td>
<td>70.31</td>
<td>9.30</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>260.94</td>
<td>34.51</td>
</tr>
<tr>
<td>Chemical fertilizer</td>
<td>310.05</td>
<td>41.01</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>226.37</td>
<td>29.94</td>
</tr>
<tr>
<td>Phosphorus (P₂O₅)</td>
<td>43.15</td>
<td>5.71</td>
</tr>
<tr>
<td>Potassium (K₂O)</td>
<td>40.53</td>
<td>5.36</td>
</tr>
<tr>
<td>Biocide</td>
<td>20.51</td>
<td>2.71</td>
</tr>
<tr>
<td>Herbicide</td>
<td>10.01</td>
<td>1.32</td>
</tr>
<tr>
<td>Insecticide</td>
<td>6.61</td>
<td>0.87</td>
</tr>
<tr>
<td>Fungicide</td>
<td>3.90</td>
<td>0.52</td>
</tr>
<tr>
<td>Water for irrigation</td>
<td>94.29</td>
<td>12.47</td>
</tr>
<tr>
<td>Total</td>
<td>756.11</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 6. Econometric estimation and sensitivity analysis of wheat production.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Independent variable</th>
<th>Coefficient</th>
<th>t-Ratio</th>
<th>MPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Machinery</td>
<td>0.12</td>
<td>3.36⁸</td>
<td>0.90</td>
</tr>
<tr>
<td>2</td>
<td>Human labor</td>
<td>0.02</td>
<td>0.66</td>
<td>0.12</td>
</tr>
<tr>
<td>3</td>
<td>Diesel fuel</td>
<td>-0.09</td>
<td>0.78</td>
<td>-0.04</td>
</tr>
<tr>
<td>4</td>
<td>Chemical fertilizer</td>
<td>-0.12</td>
<td>2.64⁵</td>
<td>-0.01</td>
</tr>
<tr>
<td>5</td>
<td>Water for irrigation</td>
<td>0.37</td>
<td>3.03⁸</td>
<td>0.05</td>
</tr>
<tr>
<td>6</td>
<td>Seed</td>
<td>0.22</td>
<td>2.35⁶</td>
<td>0.15</td>
</tr>
<tr>
<td>7</td>
<td>Biocide</td>
<td>0.08</td>
<td>0.45</td>
<td>0.08</td>
</tr>
<tr>
<td>8</td>
<td>FYM</td>
<td>0.03</td>
<td>0.31</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Durbin Watson 1.78
R² 0.84
Return to scale 0.6

⁸ Significant at 1% level; ⁵ significant at 5% level.
The highest coefficient value belongs to water for irrigation (0.37) and followed by seed (0.22), machinery (0.12) and biocide (0.08). Based on these results it can be concluded that 10% growth in using water for irrigation, seed, machinery and biocide energy for wheat production leads to 3.7, 2.2, 1.2 and 0.8% increase in wheat yield. Among all inputs, chemical fertilizer and diesel fuel had negative coefficient values (-0.12 and -0.09, respectively) that indicate by 10% increasing in energy use of specified inputs the wheat yield will decrease 1.2 and 0.9%, respectively. In order to examine the autocorrelation, Durbin-Watson test is done and the value was 1.78, which indicates that there is no auto correlation at the 5% significant level for estimated model. The $R^2$ value is calculated as 0.84 for model 1. The last column belongs to MPP value to study the sensitivity of energy inputs. The MPP values for human labor, diesel fuel, biocide, chemical fertilizer, machinery, seed, water for irrigation energy and manure inputs calculated to be 0.12, -0.04, 0.08, -0.01, 0.90, 0.15, 0.05 and 0.11, respectively. These values indicate that additional use of 1 MJ for each energy inputs (except diesel fuel and chemical fertilizer energy) is resulted to increase of 0.12, 0.08, 0.90, 0.15, 0.05 and 0.1 kg ha$^{-1}$in wheat yield, respectively. For diesel fuel and chemical fertilizer inputs, 1 MJ additional use leads to decrease in wheat yield (-0.04 and -0.01 kg ha$^{-1}$, respectively).

The regression results for different forms of energy in wheat production are shown in Table 7. The results of model 2 and 3 reveals the significant (at 1% level) impacts of direct, indirect, renewable and non-renewable forms of energy on wheat yield. Using more amounts (10%) of direct, indirect, renewable and non-renewable energies increases the wheat yield 5.6, 3.3, 5.1 and 4.7%, respectively. The MPP values illustrated, 1 MJ additional use in direct, indirect, renewable and non-renewable energies can increase the yield 0.30, 0.04, 0.28 and 0.06 kg ha$^{-1}$. The $R^2$ and Durbin Watson values for models 1 and 2 calculated 81, 1.94 and 79, 2.11%, respectively.

### Conclusions

This study analyzed the energy balance of wheat production in different farm levels. For this purpose, the farms divided in four groups (small (<1 ha), medium (between 1 and 4 hectare), large (between 4 and 10 ha) and very large (>10 ha). In order to find the relationship between inputs energy and wheat yield, sensitivity analysis was done. Based on the results, the following conclusions are drawn:

1) Total energy usage of wheat production was calculated to be 31.5 GJ ha$^{-1}$ where chemical fertilizer and diesel fuel energy had the highest energy usage in all inputs. The output energy was 44.6 GJ ha$^{-1}$. The comparison energy input and output in different farm levels shows that total energy consumption in very large farms was least while the output energy in this category was the highest value. So, joining small farms into one farm to use inputs efficiently is recommended. GHG analysis indicated the total greenhouse emission of 756.11 kg CO$_2eq$ ha$^{-1}$. Chemical fertilizer with share of 41% of total GHG emission was in first rank and followed by diesel fuel (35%) and water for irrigation (12%), respectively. Using fertilizer based on plant needs and applying soil analysis to specify the soil needs are recommended to decrease high chemical fertilizer energy consumption and GHG emission. Fuel efficiency and

### Table 7. Econometric estimation and sensitivity analysis of energy forms for wheat production

<table>
<thead>
<tr>
<th>S/N</th>
<th>Independent variable</th>
<th>Coefficient</th>
<th>t-Ratio</th>
<th>MPP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 2:</strong> $\ln Y_i = \beta_1 \ln (DE) + \beta_2 \ln (IDE) + e_i$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Direct</td>
<td>0.56</td>
<td>5.71$^a$</td>
<td>0.30</td>
</tr>
<tr>
<td>2</td>
<td>Indirect</td>
<td>0.33</td>
<td>6.43$^a$</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Durbin Watson</td>
<td>1.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R^2$</td>
<td>0.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Return to scale</td>
<td>0.89</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **Model 3:** $\ln Y_i = \gamma_1 \ln (RE) + \gamma_2 \ln (NRE) + e_i$ |
| 1   | 1. Renewable         | 0.51        | 7.98$^a$| 0.28 |
| 2   | 2. Nonrenewable      | 0.47        | 12.25$^a$| 0.06 |
|     | Durbin Watson        | 2.11        |         |      |
|     | $R^2$                | 0.79        |         |      |
|     | Return to scale      | 0.98        |         |      |

$^a$significant at 1% level.
proper matching of equipment to tractors are the important factors in reduction of diesel fuel consumption. Moreover, applying minimum or zero tillage can emit considerably less diesel fuel GHG emission per hectare than conventional tillage (by moldboard plow) in the study region.

2) The average value of energy ratio, energy productivity, specific energy and net energy calculated 1.49, 9.82 kgMJ⁻¹, 0.11 MJkg⁻¹ and 13.1 GJha⁻¹, respectively. Very large farms had better results in energy indices in comparison with other size of farms. The amount of direct, indirect, renewable and non-renewable forms of energy were 6.5, 25, 5.3 and 26.2 GJ ha⁻¹ that they were 21, 79, 17 and 83% of total energy consumption in wheat production. Consumption of all forms of energy in wheat production was the least in very large farms due to high level of energy use management. The high share of nonrenewable source of energies in wheat production in study area leads to more environment pollution and to make agriculture environment friendly applying more manure and green fertilizer is recommended.

3) The regression analysis indicated that machinery, chemical fertilizer, water for irrigation and seed had significant effect on wheat yield with coefficient value of 0.12, -0.12, 0.37 and 0.22, respectively. The highest positive MPP value belonged to machinery (0.90) and followed by seed (0.15) and human labor (0.12) while the chemical fertilizer and diesel fuel had negative MPP values (-0.01 and -0.04, respectively).

4) The coefficient values of direct, indirect, renewable and non-renewable forms of energy were 0.56, 0.33, 0.51 and 0.47 (significant at 1% level), respectively. The MPP values indicated an additional use (10 MJ) of direct, indirect, renewable and non-renewable forms of energy leads to 3.0, 0.4, 2.8 and 0.6 kg ha⁻¹ increase in wheat yield.

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