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Analysis of energy and greenhouse gas balance as indexes for environmental assessment of wheat and maize farming: a case study

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ABSTRACT

In this study, the net balance of greenhouse gas (GHG) emission and energy of wheat and maize production systems in two farms in Khuzestan province of Iran was assessed. The results showed that totally wheat farming is more efficient than maize farming in terms of energy and CO2-eq indexes. The total energy requirement for maize and wheat farming was 92560.24 MJ ha^{-1} and 39624.15 MJ ha^{-1}, which caused the emission of 20191.47 and 7541.04 kg CO_2-equivalent per hectare in maize and wheat farms respectively. Electricity, fertilizers and fuel were the most important pollutants of environment in terms of energy and gas emission in both farms. Theses inputs consumed 55.52, 22.62 and 6.44 % of total energy of maize and 47.32, 21.19 and 9.01 % of total energy of wheat farm and were responsible for the 88.60, 8.79 and 2.03 % of CO_2-equivalent in maize and 86.54, 9.54 and 3.24 % of CO_2-equivalent in wheat farms respectively. The results of this study also showed that the enhancement of 60.74 and 27.02 % in energy ratio and 46.06 and 27.87 % in CO2-eq index in maize and wheat farming can be expected using simple improving scenarios.

Key words: energy indexes, GHG emission, maize, wheat

IZVLEČEK

ANALIZA ENERGETSKE BILANCE IN BILANCE TOPLOGREDNIH PLINOV KOT OCENA OKOLJSKIH KAZALNIKOV PRIDELAVE PŠENICE IN KORUZE NA PRIMERU DVEH KMETIJ

V raziskavi sta bili ocenjeni letna energetska bilanca in bilanca toplogrednih plinov pri pridelavi pšenice in koruze na dveh kmetijah, v provinci Khuzestan, Iran. Rezultati so pokazali, da je pridelovanje pšenice učinkovitejše kot pridelovanje koruze glede na energetsko bilanco in bilanco CO_2. Celokupna poraba energije je za pridelavo koruze in pšenice znašala 92560,24 MJ ha^{-1} in 39624,15 MJ ha^{-1}, kar je povzročilo emisijo 20191,47 in 7541,04 kg CO_2 ha^{-1} pri koruzi, oziroma pšenici. Elektrika, gnojila in goriva so bili najvažnejši povzročitelji onesnaževanja okolja in emisije toplogrednih plinov na obeh kmetijah. Ti vložki so porabili 55,52; 22,62 MJ ha^{-1}, kar je 6,44 % celokupne energije koruze in 47,32; 21,19 MJ ha^{-1}, kar je 9,01 % celokupne energije energije pšenice. Pridelavi sta bili odgovorni za emisiji 88,60; 8,79 kg CO_2 ha^{-1}, kar znaša 2,03 % ekvivalenta CO_2 pri koruzi in 86,54; 9,54 kg CO_2 ha^{-1} in 3,24 % ekvivalenta CO_2 pri pšenici. Rezultati te študije so tudi pokazali izboljšanje ob uporabi izboljšanega scenarija na 60,74 and 27,02 % v energetski bilanci in 46,06 in 27,87 % v bilanci CO_2 pri koruzi in pšenici.

Ključne besede: energetski indeksi, GHG emisije, koruza, pšenica

1 INTRODUCTION

Both scientists and policy makers increasingly recognize that the impact of agriculture on our environment cannot be ignored. However, the issue is complex, because of the many different agricultural activities and actors, the range of environmental pollutants involved, and as a result

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of that, the various environmental effects (Havlikova and Kroeze, 2007). Energy and greenhouse gage (GHG) balance are from most prevalent factors in environmental assessment of agricultural activities. Kok *et al.* (2006) introduced energy as indicator of environmental load because of two main reasons. Firstly, energy use has impact on three environmental issues: resource depletion, local/regional environmental impact (acid rain) and global impact (greenhouse effect). Secondly, the energy statistics are the best available environmental data and provide the possibility to calculate energy requirements in relation to consumption. The rising atmospheric GHG concentration, believed to be the primary cause of global climate change, has encouraged proposals to reduce human-induced GHG emissions. The increasing use of agricultural inputs in modern farming has resulted in an increase in the energy inputs and consequently incensement of agriculture sector share in production of GHG (Pimentel, 1980).

Fossil energy use by agriculture is about 3.0–4.5 % of the total consumption in the developed countries of the world (Enquete Commission, 1995). Agriculture accounts for around 10-12 % of total global GHG emissions but is the main source of non CO_2 GHGs, emitting nearly 60 % of nitrous oxide (N_2O) and nearly 50 % of methane (CH_4) (Smith *et al*., 2007). Bellarby *et al*. (2008) estimate that the production of fertilizers emits between 284 and 575 Tg CO_2-eq yr^{-1}, representing 0.6-1.2 % of total global GHG emissions from all sources. If agricultural production is going to significantly increase while also minimizing its impact on future climate change, it is important to understand both its current contribution to energy and GHG budgets and how agricultural management practices can influence them.

There are many studies that evaluated the environmental effects of agricultural systems using energy in different areas of agriculture including, farming (Asakereh *et al*., 2011; Lorzadeh *et al*., 2011; Abdi *et al*., 2012b), orchards (Sami *et al*., 2011; Loghmanpour *et al*., 2013; Kizilaslan, 2009) animal husbandry (Naghibzadeh *et al.,* 2011; Barber *et al.,* 1989) and etc. Nevertheless, gas emission as result of agricultural in-farm and off-farm activities has not been sufficiently evaluated. Shortages of information about gas emission of agricultural inputs in the production processes may be one of the most important reasons of this ignorance. However, there are some studies that tried to evaluate and analyze the gas emission of agricultural activities (e.g. Eshun *et al*., 2013; Taki *et al*., 2012; Lal, 2004).

Energy and GHG analysis in agricultural production operations results in determining overuse sectors and may act as a platform to improve production processes. The aim of this paper was to analyze and compare the energy and GHG balance in maize and wheat farming in the field level as two most relevant cereals in the world. According to FAO (2012) report, wheat and maize had the biggest shares of cereals production in the world during 2008-2010 with a share of 29.7 % and 36.7 % respectively. Wheat is also the dominant cereal crop in Iran accounting for almost 71.2 % of the aggregate cereal production. Maize is the other dominant cereal in Iran after barley and rice (FAO, 2012).

2 MATERIALS AND METHODS

2.1 Studied farms

The region of study is located in southwest of Iran, in northeast of Khuzestan province (within 29º 58' and 32º58' North latitude and 47º42' and 50º39' East longitude). The region represents semiarid and subtropical climatic conditions with very hot summers and fairly cool winters. Data were collected from two large mechanized farms producing wheat and maize, respectively. Wheat was cultivated in a 500 ha farm during November 2008 – May 2009, and maize was cultivated in a 220 ha farm during July – October 2009. The farms reflected typical large mechanized arable farming systems in the studied region. The both farms had the similar status, and similar management practices were implemented in both of them. Farms soils were mostly silty-clay loam structured from alluvial materials, with less than 1 % soil organic carbon. Topographically, the farms were flat with a slope less than 2% and the average elevation of 25 m above the sea level.

Stubble working was made via disc harrow with a medium working depth and sowing was done using drills. Nitrogen, phosphorous, potassium and other fertilizers were applied at different rates according to crops nutrient need. Irrigation water was scattered in defined periods through flood irrigation system. Weeds were controlled using mechanical distribution of herbicides.

2.2 Energy calculation

Farm inputs and outputs can be expressed in terms of energy equivalent. The total energy use per unit of activity can be expressed in terms of MJ ha^{-1}, indicating overall energy consumption. In this study energy budget was calculated based on a mix of actual on field data from the farms and the energy coefficients. The energy equivalents for different inputs and outputs used in energy budget calculation are shown in Table 1. The energy cost of inputs and practices were adapted from different sources of estimations that best fit Iran conditions. Based on the energy equivalents of the inputs and outputs, the energy balance (MJ output minus MJ input), the energy ratio (MJ output/MJ input), and energy intensity (MJ input per kg of product) were calculated as indexes of energy use efficiency (Singh, 2002; Stout, 1990).

The input energy is also classified into direct and indirect; and renewable and non-renewable forms. The indirect energy included energy embodied in chemicals, manure, machine and equipment; while the direct energy includes human power, fuel and electricity in the production process. On the other hand, non-renewable energy includes diesel, electricity, pesticides, and fertilisers; while renewable energy consists of human and manure fertilisers (Demircan *et al.*, 2006).

Table 1. The energy equivalent of farm inputs and outputs

Item	Unit	Energy equivalent (MJ $unit^{-1}$)	
		Maize	Wheat
Human labor	h	2.2	2.2
Machinery	kg (Average)	132.6	130.8
Fertilizers			
Nitrogen	kg	78.4	78.4
Phosphate	kg	17.4	17.4
Potassium	kg	13.7	13.7
Others	kg	8.8	8.8
Manure	ton	303.0	-
Herbicides	kg or l (Average)	202.9	166.1
Electricity for irrigation	kWh	12.0	12.0
Diesel	l	47.8	47.8
Gasoline	l	46.3	46.3
Seed	kg	14.0	13.0

2.3 GHG emission

Production, storage and application of inputs in agricultural farms invoke combustion of fuels, which results in CO_2 and other GHGs emissions. CO_2 equivalent is an index calculating emission levels of inputs according to their Global Warming Potentials (GWP), assuming a 100-year time horizon. The GWP is expressed in kg CO_2-eq, which is taken to be 1 for CO_2, 296 for N_2O and 23 for CH_4 (IPCC, 2006). Conversion coefficients CO_2-eq are calculated for each farm input based on its GHG emission during its production or/and consumption and can be expressed in kg CO_2-eq per weight of input. In agriculture, GHGs are released by direct use of fuels in farm equipments, (e.g. tillage, sowing, harvesting, water pumping, grain drying), production, transportation and application of farm inputs, burning or other oxidation of biomass and decomposition of crop residues. CO_2-eq index is calculated by the sum of CO_2-eq of all farms inputs in the term of kg ha^{-1}.

In this study, we calculated the GHG balances of wheat and maize production in the field-level. The conversion coefficients used here are presented in Table 2. Using data published by PEPD (2010), we calculated conversion coefficients for different fuels in Iran and expressed them in terms of kg of CO_2 equivalent. GHG emissions attributable to electricity consumption are based on the fuels used in power generation. Considering the proportion of different fuels in electricity generation, we calculated conversion coefficient for electricity for Iran according to PEPD (2010). N fertilizer has two sources of GHG emission; off-farm emission which involves GHG emission from production, packaging and transporting of fertilizer and on-farm emission which involves emission from soil denitrification and nitrification processes in the field after distribution of fertilizer. Precise measurement of N_2O emission from soil denitrification and nitrification processes is difficult since it depends on many complex interactions taking place in the soil, and can considerably vary depending on temperature, moisture, available N, organic matter, soil aeration, pH and so on (Flynn and Smith, 2010). Nevertheless, direct N_2O emissions have been shown to relate to N inputs. Therefore, amounts of N_2O emissions are often calculated using an emission factor that represents the percentage of any N applied that emit in the form of N_2O (Flynn and Smith, 2010). We used a simple emission factor (percentage of applied N emitted as N_2O) reported by IPCC (2006). The fossil energy and fossil CO_2 contents of manure are considered to be zero. Therefore, we only used an emission factor for GHG emission of manure fertilizer decomposing in the soil. According to IPCC (2006), the amount of C lost via harvested crops is considered to be replaced by C uptake in the following crop and there is no significant long-term accumulation of C in crops or crop products. Therefore, we did not take into account this carbon cycle. For other farm inputs (pesticides and fertilisers), we did not find local reliable data regarding CO_2 equivalent conversion coefficients; therefore we used international consolidated conversion coefficients.

Table 2: The CO2-eq coefficient of farms inputs

Item	Unit ha^{-1}	CO_2-eq coefficient (kg $unit^{-1}$)	References
N fertilizer	kg	6.93 (= 3.97 off-farm + 2.96 on-farm)	Adopted from: Macedo et al. (2008) and IPCC (2006)
P fertilizer	kg	1.30	Macedo et al. (2008)
K fertilizer	kg	0.71	Macedo et al. (2008)
Other fertilizers	kg	0.66	Macedo et al. (2008)
Manure	ton	27.50	Lal, 2004
Gasoline	l	2.94	Calculated according: Macedo et al. (2008) and PEPD (2010)
Diesel	l	3.28	Calculated according: Macedo et al. (2008) and PEPD (2010)
Electricity	kWh	4.18	Calculated according: PEPD (2010)
Human labour	h	0.00	-
Machinery	kg yr^{-1}	0.56	Adopted from: Biswas et al. (2008)
Herbicides	kg or l	29.67	Adopted from: Audsley et al. (2009)

3 RESULTS AND DISCUSSION

3.1 Energy analyses

The amount of physical inputs and outputs and their energy equivalents used per hectare of wheat and maize production are presented in Table 3. Other than seed and gasoline that are higher in wheat production, the amount of other inputs in the maize farm per hectare is higher. Based on the energy equivalents of the inputs and outputs given in Table 1, the average total energy consumed per farms per year were calculated as 92560.24 and 39624.15 MJ ha^{-1} for maize and wheat farming respectively. The energy input of maize farm is higher than most energy reports of maize farming in Iran (e.g. 29307, 26917, 39232 and 34649 MJ ha^{-1} by Lorzadeh *et al*., 2011; Abdi *et al*., 2012a; Taki *et al*., 2012; Lorzadeh *et al*., 2012) and is higher than many reports in other parts of the world (e.g. 12638, 57476, 33976 and 21671 MJ ha^{-1} by Chamsing *et al*., 2006; Shapouri *et al*., 2002; Pimentel and Patzek, 2005 and Lorenz and Morris, 1995). This high energy consumption is due to much higher consumption of water in the studied case and the use of pumping system with high suction head. Water rate consumption in the studied maize farm is 24562 m^3 ha^{-1} that is again much higher than average water consumption reported by similar studies. For example, Lorzadeh *et al*. (2011), Abdi *et al*., (2012a) and Lorzadeh *et al*. (2012) have reported water usage rates of 7327.13, 5400.00 and 4336.87 m^3 ha^{-1} in maize farms. The total energy input in wheat farm is in the range of energy reports of wheat in Iran (e.g. 37482, 38589 and 43900 MJ ha^{-1} by Shahin *et al*., 2008, Houshyar *et al*., 2010 and Zooleh *et al*., 2011). However higher or smaller numbers have also been reported (e.g. 69373, 83454, 21261 MJ ha^{-1} by Abdi *et al*., 2012b; Beheshtitabar and Keihani, 2007; Sedaghathoseini and Moghaddasi, 2010). This range of energy consumption is also much higher than energy reports of non-mechanized and traditional wheat farming systems such as 12200-15260 MJ ha^{-1} that was reported by Nassiri and Singh (2008) and 4030 MJ ha^{-1} that were reported by Nahatkar and Sharma (2006).

Comparison between the energy patterns of farms reveals that the investigated farms have relatively similar energy consumption pattern, however maize production has the higher operational energy input compared to the wheat production. Irrigation has the highest contribution from total input energy in maize and wheat and contributes to the total energy 55.5 % and 47.3 % for the respective crops. The second highest energy consumer in both farms are fertilizers that consume 22.6 and 21.2 % of total input energy followed by diesel fuel, which consumes 6.4 and 8.7 % of total input energy in the maize and wheat respectively. Other inputs have a relatively small share of input energy. In most of the past studies, electricity, fertilizer and fuel were also reported as the main energy consumers of farming systems (e.g. Taki *et al*., 2012; Lorzadeh *et al*., 2012; Sedaghathoseini and Moghaddasi, 2010; Abdi *et al*., 2012b; Nassiri and Singh, 2008; Lorenz and Morris, 1995). Human labour includes the lowest energy of total input energy in two farms (0.08 and 0.06 % in maize and wheat respectively). Used human labour is considered 32.15 and 11.34 h ha^{-1} for maize and wheat, respectively. This small employment of human labour was expected, since all operations, other than irrigation, were done using mechanical power. The comparatively higher use of human labour for maize production is mainly due to more labour requirement for irrigation operation and greater use of mechanical power, which invokes more operator effort in maize farming (22.1 kg ha^{-1} employment of equipment in maize compared to 14.6 kg ha^{-1} employment of equipment in wheat). The higher employment of machinery in maize also caused higher consumption of diesel fuel in maize farm (5961.4 l ha^{-1}) in comparison to wheat farm (3461.3 l ha^{-1}). The human labour employment per hectare in two farms is relatively smaller than that of semi-mechanized farms of wheat and maize in Iran. For example average human labour employment of 45.9, 99.3, 81.5 and 84.9 h ha^{-1} were reported by Taki *et al*. (2012), Lorzadeh *et al*. (2012) , Abdi *et al*. (2012a) and Lorzadeh *et al*. (2011) in maize and 147.3, 192.0, 42.0 and 94.2 h ha^{-1} were reported by Shahin *et al*. (2008), Abdi *et al*. (2012b), Houshyar *et al*. (2010), Attar (2011) and Beheshtitabar and Keihani (2007) in wheat.

The distribution of inputs used in the production of crops according to the direct, indirect, renewable and non-renewable energy groups, are given in Table 4. In both farms, the share of direct and indirect energy of total input energy is closely similar (62.0 and 63.9 % of direct and 37.9 and 36.0 % of indirect energy in maize and wheat farms respectively). It is also seen that the ratios of renewable energy in both farms are very low. However, this share in the wheat production (7.6 %) is relatively higher than that of maize production (0.8 %) and the rate of renewable energy consumption in wheat farm is higher (715.38 MJ ha^{-1} in maize in comparison to 3013.49 MJ ha^{-1} in wheat). This is mostly because of the high consumption of seed for planting in the wheat farm. Replacing of non-renewable energy whit renewable energy offers a varied range of benefits, including: a decrease in external energy dependence; a boost to local and regional component manufacturing industries; promotion of regional engineering; increased research and development, decrease in impact of electricity production and transformation; increase in the level of services for the rural population; creation of employment, etc. (Míguez *et al.*, 2006).

From Table 3 it is also seen that the total output yield (grain) of maize farm (5294.0 kg ha^{-1}) is higher than wheat farm (3985.0 kg ha^{-1}). Accordingly, the overall energy output of maize farm (74116.0 MJ ha^{-1}) is higher than that of the wheat (51805.0 MJ ha^{-1}). These results are in the range of average yield of maize and wheat in the Iran (e.g. Abdi *et al.*, 2012b; Abdi *et al.*, 2012a; Taki *et al.*, 2012; Shahin *et al.*, 2008; Lorzadeh *et al.*, 2012). However, obtained results are generally smaller than the average yields of maize and wheat in mechanized production systems in the world. For example the yields of 6988.7, 7105.2 and 8655.0 kg ha^{-1} were reported by Lorenz and Morris (1995), Shapouri *et al.* (1995) and Pimentel and Patzek (2005), for maize and 4868.0 kg ha^{-1} was reported by Khan *et al.* (2010) for wheat. In addition, some studies in Iran reported higher yields (e.g. 5968.1 - 7272.8 kg ha^{-1} by Sedaghathoseini and Moghaddasi (2010) and 5613.4 kg ha^{-1} by Zooleh *et al.* (2011) for wheat).

Accordingly, the energy indexes of energy ratio, energy balance and energy intensity were estimated 0.80, -18444.24 MJ ha^{-1} and 17.48 MJ kg^{-1} in maize and 1.31, 12180.85 MJ ha^{-1} and 9.94 MJ kg^{-1} in wheat farm respectively (Table 4). These indexes show that mechanized wheat production in the investigated region is more efficient in terms of energy. Energy ratio of maize farm is relatively smaller than that of the other part of Iran. For example, Lorzadeh *et al.* (2011), Abdi *et al.* (2012a), Taki *et al.* (2012) and Lorzadeh *et al.* (2012) reported energy ratios of 1.86, 3.50, 2.60, 2.97 for Iran.

This low energy ratio is mainly because of high energy input, especially water and fertilizer energy, in the maize case study system whereas the energy ratio of wheat is in agreement with the average range of energy ratio index in Iran. Energy ratio in some wheat productions in Iran were reported as 2.72, 2.60, 1.13 - 1.42 and 1.56 by Shahin *et al.* (2008), Houshyar *et al.* (2010), Zooleh *et al.* (2011) and Attar (2011).

Table 3: Input and outputs of farms and their related indexes in the term of energy

Item	Unit	Maize			Wheat		
		Amount of input used per hectare	Input energy (MJ ha^{-1})	%	Amount of input used per hectare	Input energy (MJ ha^{-1})	%
Human labor	h	32.15	70.74	0.08	11.34	24.95	0.06
Machinery	kg	22.12	2932.79	3.17	14.60	1910.15	4.82
Fertilizers			20941.40	22.62		8395.85	21.19
Nitrogen (N)	kg	240.31	18840.43	20.35	96.86	7593.94	19.16
Phosphate (P_2O_5)	kg	20.43	355.45	0.38	11.01	191.51	0.48
Potassium (K_2O)	kg	95.40	1306.98	1.41	36.34	497.90	1.26
Others	kg	22.64	199.26	0.22	12.78	112.50	0.28
Manure	ton	0.79	239.29	0.26	0.00	0.00	0.00
Herbicide	kg or l	2.85	577.29	0.62	1.43	237.92	0.60
Irrigation indirect		-	10278.54	11.10	-	3749.77	9.46
Electricity for irrigation	kWh	4282.72	51392.68	55.52	1562.41	18748.87	47.32
Diesel	l	124.72	5961.45	6.44	72.41	3461.34	8.74
Gasoline	l	0.00	0.00	0.00	2.31	106.76	0.27
Seed	kg	28.95	405.35	0.44	229.89	2988.54	7.54
Total input	-	-	92560.24	100.00	-	39624.15	100.00
Total output	kg	5294.00	74116.00	-	3985.00	51805.00	-

Table 4: Energy indexes of the farms

Energy index	Unit	Maize		Wheat	
		Amount	%	Amount	%
Total output	MJ ha^{-1}	74116.00	-	51805.00	-
Total input	MJ ha^{-1}	92560.24	100.00	39624.15	100.00
Indirect energy	MJ ha^{-1}	35135.37	37.96	14293.69	36.07
Direct energy	MJ ha^{-1}	57424.87	62.04	25330.46	63.93
Renewable energy	MJ ha^{-1}	715.38	0.77	3013.49	7.61
Non renewable energy	MJ ha^{-1}	91844.86	99.23	36610.66	92.39
Energy ratio	-	0.80	-	1.31	-
Energy balance	MJ ha^{-1}	-18444.24	-	12180.85	-
Energy intensity	MJ ha^{-1}	17.48	-	9.94	-

3.2 GHG emission evaluation

Table 5 shows the share and amount of GHG emitted by each input in the farms. Totally, the GHG emission of maize production (20191.47 kg ha^{-1}) is about three times higher than that of wheat production (7541.04 kg ha^{-1}). Considering the share of inputs in the total GHG emission in two farms, the main reason of this difference is about three times higher consumption of electricity (4282.72 compared to 1562.41 kWh ha^{-1}) and N fertiliser (240.31 compared to 96.86 kg ha^{-1}) in maize farm compared to wheat farm (Table 3). Other than electricity, fertilizer and fuel, other inputs have ignorable share of total GHG emission in two farming systems. Electricity in the farms is the dominant source of GHG emissions (88.60 % in maize and 86.54 % in wheat farm). Fertilizers emitted 8.79 % and 9.54 % of CO_2-eq in the maize and wheat farms respectively and are the second important source of Co_2-eq. Nitrogen is the dominant source of GHG emissions among the fertilizers and almost 93.85 and 93.26 % of the total Co_2-eq emissions from fertilizer use and 8.25 % and 8.90 % of total GHG-eq emissions from farming systems associate with nitrogen fertilizers in maize and wheat respectively.

Table 5: The share of inputs from GHG emission of the farms

Item	CO_2-eq			
	Maize		Wheat	
	kg ha^{-1}	%	kg ha^{-1}	%
Human labor	0.00	0.00	0.00	0.00
Machinery	12.39	0.06	8.18	0.11
Fertilizers	1774.54	8.79	719.77	9.54
Nitrogen (N)	1665.36	8.25	671.25	8.90
Phosphate (P_2O5)	26.56	0.13	14.31	0.19
Potassium (K_2O)	67.73	0.34	25.80	0.34
Others	14.89	0.07	8.41	0.11
Manure	21.72	0.11	0.00	0.00
Herbicides	84.42	0.42	42.50	0.56
Irrigation indirect	0.00	0.00	0.00	0.00
Electricity for irrigation	17889.42	88.60	6526.35	86.54
Diesel	408.99	2.03	237.47	3.15
Gasoline	0.00	0.00	6.78	0.09
Seed	0.00	0.00	0.00	0.00
Total	20191.47	100.00	7541.04	100.00

3.3 Opportunities for optimizing greenhouse gases and energy impacts

As it was seen, electricity, fertilizers and fuel are the most important environmental pollutant in the studied farms. Fuel is used in machinery equipments which are inseparable parts of today mechanized agriculture. Nevertheless, employment of certain less fuel consuming systems such as conservation tillage can efficiently help to improve the environmental indexes (Coxworth *et al*., 1999; Entz *et al*., 1995; West and Marland, 2002). In the studied farms, two applicable strategies can be suggested to enhance the environmental impact of farming systems. In the first scenario, using more efficient application of water in the farms, water rate consumption could fall to 12281 m^3 ha^{-1} (50 %) in maize and 6243 m^3 ha^{-1} (30 %) in wheat farms. This is a reasonable scenario since the average water consumption of maize and wheat have been reported 5000-13000 m^3 ha^{-1} and 6000-7000 m^3 ha^{-1} in Iran conditions (Keshavarz and Heidari, 2004). In the second scenario, fertilizer consumption of farms could be decreased up to 20 %. More efficient application of fertilizers such as use of slow and controlled release fertilisers and/or stabilized fertilisers can successfully reduce the application rate of fertilizer without any reduction in the farms yield (Carreres *et al*., 2003; Kochaki *et al*., 2012). The first scenario will enhance the energy ratio of farms by 1.20 and 1.58, and reduce the CO_2-eq by 11246.86 and 5583.13 kg ha^{-1} in maize and wheat farms respectively. The second scenario will enhance the energy ratio of maize and wheat farms by 0.84 and 1.37 and decrease CO_2-eq of farms by 19836.76 and 7397.08 kg ha^{-1} respectively. In addition, if we combine both scenarios, the enhancement of 60.74 and 27.02 % in energy ratio and 46.06 and 27.87 % in CO_2-eq index of maize and wheat farms can be expected (Table 6).

Table 6: The effects of change in some factors on the energy and GHG emission indexes

Item (unit)	Changed factor					
	Water		Fertilizers		Water and fertilizers	
	Maize	Wheat	Maize	Wheat	Maize	Wheat
Factor change (%)	-50 %	-30 %	-20 %	-20 %	-	-
Total input (MJ ha^{-1})	61724.98	32874.56	88420.51	37944.98	57584.56	31195.39
Total input change (%)	-33.31	-17.03	-4.47	-4.24	-37.79	-21.27
Energy balance (MJ ha^{-1})	12391.02	18930.44	-14304.51	13860.02	16531.44	20609.61
Energy balance change (%)	-167.18	55.41	-22.45	13.79	-189.63	69.20
Energy ratio	1.20	1.58	0.84	1.37	1.29	1.66
Energy ratio change (%)	49.96	20.53	4.68	4.43	60.74	27.02
CO_2-eq (kg ha^{-1})	11246.86	5583.13	19836.76	7397.08	10891.95	5439.18
CO_2-eq change (%)	-44.30	-25.96	-1.76	-1.91	-46.06	-27.87

4 CONCLUSION

The present study analyzed the energy and GHG balance as integrative environmental indexes in two production systems of maize and wheat. Although total output and related energy were higher in maize crop than wheat, the indexes showed less environmental impact of wheat farming compared to maize farming. This resulted from the significantly higher inputs entered in maize farming. Electricity used mainly for irrigation pumps was the major energy input among all energy inputs for growing both two crops. Fertilizers played the second dominant role followed by fuel. These three parameters also were the most responsible for GHG emission of the farming systems. The share of renewable energy in two farming systems was negligible. Comparing to semi and non mechanized farming systems, mechanized wheat and maize farming in the studied region were less efficient in terms of energy. The study results also showed that implementation of some reductions in water and fertilizer consumption are able to considerably reduce the environmental effects of both farming systems.

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