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Research Article

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Management of energy consumption and greenhouse gas emissions using the optimal farm scale: Evidence from wheat production in South Khorasan Province

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ABSTRACT - The need for sustainable resource management is increasingly urgent. A prerequisite for achieving sustainable agriculture is the use of production resources more efficiently. In this study, by combining Data Envelopment Analysis (DEA) using environmental and economic indices, the effect of optimal farm scale on the improvement of these indices was investigated. Data were obtained from 136 farmers using a questionnaire and face-to-face interviews. The mean technical efficiency, pure technical efficiency and scale efficiency were estimated to be 0.76, 0.89 and 0.85; respectively, while the benefit-to-cost ratio was found to be 1.22. Results indicated that if the resources were used efficiently on an optimum scale, the emission and energy use could be reduced to 976.33 kg CO_2eq ha^{-1} and 15391 MJ ha^{-1}. 37.73 % of the energy savings, respectively. Also, 35.6% of greenhouse gas emission reductions were related to the optimal farm scale. Furthermore, the contribution of the optimal scale in improving the benefit-to-cost ratio and energy use efficiency was found to be 12.5 and 16.23%, respectively. The results showed that the optimum scale of agricultural activities was a crucial factor in saving energy and reducing greenhouse gas emissions in wheat production in eastern Iran. Therefore, as local farms in the studied region mostly were small-scale, fragmented and scattered, land integration and promotion of activities at the optimal production scale are recommended as important steps in reducing environmental side-effects and increasing farmers' profitability.

INTRODUCTION

Greenhouse gas (GHG) emissions generated by human activity and causing global warming is one of the most challenging issues of our planet in the recent century (Zhang et al., 2021). Agriculture has been exposed to high risks due to climate change and needs to respond quickly to ensure food security (FAO, 2020). Many current production systems are already under stress through degradation of land and water resources and loss of biodiversity and ecosystem services resulting from unsustainable practices. In line with population growth, rising per capita caloric intake and changing dietary preferences such as increasing meat and dairy products consumption, substantial demand for agricultural products is also anticipated in the coming future (Elsoragaby et al., 2019). In 2018, emissions from agriculture amounted to 11.1 Gt CO_2eq, accounting for about 17 percent of the global GHG emissions from all sectors. The largest contributors from agriculture are non-CO_2 emissions such as methane and nitrous oxide, which are both powerful greenhouse gases emitted by crop and livestock activities within the farm gate. Emissions from energy consumed in agriculture have increased by 23 percent during 2000-2018 (FAO, 2020).

In 2019, the agricultural sector, in Iran accounted for 0.87 percent of the total CH_4 and 29.95 percent of the total N_2O emissions (Amini et al., 2020). In the agricultural sector climate change can affect agricultural prices, regional comparative advantage, and producers and consumers' welfare by impacting crop yields (Li et al., 2011). Energy overuse not only results in higher economical costs but also will contribute to more greenhouses gas emissions, global warming and climate changes (Deshpande, 2019; Sriprapakhan et al., 2021). The energy use can be reduced by improving energy efficiency which eventually leads to the prevention of resource depletion and ecosystem damages (Mobtaker et al., 2012).

Incorporating environmental indices into the Data Envelopment Analysis (DEA) can produce more practical and interpretable results. In the DEA, an inefficient decision-making unit (DMU) can be made efficient either by reducing the input levels while the outputs are being kept constant or symmetrically, by increasing the output levels while the inputs are being kept constant (Ebrahimi and Salehi, 2014).

Imran and Ozcatalbas (2021) estimated energy efficiency and GHG emissions of wheat in Antalya Province, Turkey, Their results revealed that a total of 21.07 GJ ha^{-1} input energy was used in wheat production and GHG emissions was calculated to be 592 kg CO_2 ha^{-1}. Based on their findings, 14% of the input energy could be saved in efficient conditions. Singh et al. (2021) investigated energy use efficiency in wheat cultivation in north-western India by DEA. Their results revealed that the average technical efficiency score was 0.92 and that DEA-based benchmarking helped in reducing energy input in wheat by 1953.4 MJ ha^{-1} (~ 7.2%). Powar et al. (2020) studied energy use efficiency for sugarcane crop production using the DEA technique and reported that the average total input and output energy for sugarcane cultivation were 146.15 and 961.02GJ ha^{-1}, respectively. The scope for energy saving in sugarcane cultivation was observed to be 19.82% as compared with the actual energy required. Mostashari-Rad et al. (2019) used DEA to study energy use and GHG emissions of agricultural and horticultural crops in Guilan Province, Iran. They showed that Kiwifruit orchards had the highest potential for energy saving (8316.29 MJ ha^{-1}) and the mitigation of GHG emissions (520.79 kg $CO_{2\,eq}$. ha^{-1}).

Previous studies on the integration of data envelopment analysis and the indicators of energy and greenhouse gas emissions have only shown the amount of energy savings under optimum production state in pure technical efficiency (Imran et al., 2020; Laso et al., 2018; Singh et al., 2019). Little evidence exists on the effect of the scale of activity on energy savings and the curb of greenhouse gas emissions where both resource use and the scale of activity are optimal. In this study, the effects of the optimal scale of activity on reducing energy consumption and greenhouse gas emissions in wheat production were investigated in eastern Iran by determining the optimum utilization of resources in technical efficiency and pure technical efficiency states.

South Khorasan Province as the easternmost region of Iran is located in the dry, semiarid belt of the earth. This province also has good agricultural potential for some products including saffron, barberry, jujube and cotton. South Khorasan is nationally ranked as the first three provinces in terms of production of some of these products. Wheat is one of the most important crops in South Khorasan Province which makes up a large part of the agricultural production of this area and almost most of the farmers try to plant it. Therefore, its economic and environmental analyses seem to be necessary. In this study, The rate of energy consumption and emission of greenhouse gases in the production of wheat was analyzed under current and optimum conditions using the DEA approach to provide useful information for researchers and policymakers.

MATERIALS AND METHODS

Site description and data collection

This study was conducted in South Khorasan Province. The selection region lay in the East of Iran. It has been reported that the climate of this region is dry and desert, with cold winters and dry summers (Ministry of Agriculture-Jahad, 2020).

Data for the present study were collected using questionnaires and face to face interviews with farmers and agricultural experts in the region during the 2019 growing season as well as reliable library sources. The Cochran formula was used to estimate the sample size (Salehi et al., 2014);

$$n = \frac{Nt^2s^2}{Nd^2 + t^2s^2} \qquad (1)$$

where n is the required sample size;

N is the number of holdings in the target population;

t is reliability coefficient (1.96 which represents 95% reliability);

S^2 is the variance of studied qualification in population; and

d is the precision $(\bar{x} - X)$.

Based on this method 136 farmers were eventually studied. Data were analyzed using MS-Excel and DEAP2.1 software packages.

Data envelopment analyses

In order to measure the efficiency of DMU, the following model has been proposed by Charnes et al. (1978). This model has been known as the CCR model which measures the efficiency of DMU assuming constant returns to scale (Poveda et al., 2019).

$$\begin{aligned} &MaxE = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \qquad (2)\\ &st: \\ &\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1 \\ &u_r \ge 0, v_r \ge 0 \end{aligned}$$

where u_r and v_r are the weight of *r*th output and *i*th input.

Eq. (1) can be converted using Charnes et al.'s transformation into the following *lp* model measuring input-oriented technical efficiency of each DMU (Azizi and Ajirlu, 2010);

$$\begin{aligned} &MinE = \sum_{r=1}^{s} v_i x_{io} \\ &s.t: \\ &\sum u_r y_{rj} - \sum v_i x_{ij} \le 0 \qquad (3)\\ &\sum u_r y_{ro} = 1 \\ &u_r \ge 0, v_i \ge 0 \end{aligned}$$

When there are positive weights for output and input (*u*,*v*) resulting in E=1, DMU is efficient; otherwise, if E<1, DMUs are inefficient. To simplify the solution of the above *lp* model, its dual problem can be solved as follows (Azizi and Wang, 2013);

$$\begin{aligned}&MaxE = {}^{-}\\&s.t:\\&Y^{a} \geq Y_0\\&{}^{-}X_0 - X^{a} \geq 0 \qquad (4)\\&{}^{-}free, {}^{a} \geq 0\end{aligned}$$

Pure technical efficiency (PTE) has been introduced by Banker, et al (1984) that measures efficiency in the mode of variable return to scale. PTE is the efficiency in which the effect of the activity scale is eliminated. The function of input-oriented PTE is like CCR model, but in this model the equation $\sum_{j-1}^{J} \lambda_{j-1}$ is a convexity constraint, which specifies the VRS framework (Hesampour et al., 2021). Without this convexity constraint, the BCC model will be a CCR model (Eq. (4)) describing a CRS situation (Heidari et al., 2012). The scale efficiency is defined in terms of technical efficiency (CCR) and pure technical efficiency (BCC) and their relationship shows the effect of farm size on efficiency (Nabavi-Pelesaraei et al., 2014);

$$SE = \frac{TE_{CCR}}{TE_{BCC}} \qquad (5)$$

Energy analysis

In order to calculate the amount of energy input and output, the amounts of inputs used in the production were measured and then, the energy of each of inputs and outputs was estimated by multiplying in its corresponding energy equivalents derived from previous studies of the agricultural sector (Table 1).

Then net energy, specific energy, energy productivity, energy use efficiency and energy intensiveness were calculated using Eqs.7-11(Taghavifar and Mardani, 2015).

$$N \quad e = o \quad e \quad (M\ /ha) - in \quad e \quad (M\ /ha) \qquad (7)$$

$$\text{specific Energy} = \frac{\text{Energy input (MJ/ha)}}{\text{yield output (kg/ha)}} (\text{MJ /kg}) \qquad (8)$$

$$\text{Energy productivity} = \frac{\text{yield output(Kg/ha)}}{\text{Energy input(MJ/ha)}} (\text{Kg /MJ}) \qquad (9)$$

$$\text{energy use efficiency} = \frac{\text{output energy (MJha} - 1)}{\text{total input energy(MJha} - 1)} \qquad (10)$$

$$\text{energy intensiveness} = \frac{in \quad e \quad (M\ ha^{-1})}{t \quad o \quad c \quad (\$)} \qquad (11)$$

Agricultural input energy can be divided into four groups including direct or indirect and renewable or non-renewable energies. Direct energy includes electricity, labor, fuel, and water. Chemical fertilizer, seed, manure and machinery constitute indirect energy (Samavatean et al., 2011). Fertilizer, fuel, electricity, and machinery are in the group of non-renewable energy and water, manure, seed and manpower in the renewable energy group (Mobtaker et al., 2010).

Economic analysis

In order to obtain a more comprehensive evaluation of wheat production, it is necessary to investigate economic aspects of production as well. In this section, some economic indicators, such as total production value, net return, benefit to cost ratio and productivity were calculated using Eqs. 12-15 (Pishgar Komleh et al., 2011).

$$\text{The production value} = \text{wheat yield (kg /ha)} \times \text{wheat price (\$)} \qquad (12)$$

$$\text{Net return} = \text{total production value (\$)} - \text{total production cost (\$)} \qquad (13)$$

$$\text{Benefit} - \text{cost ratio} = \frac{\text{total production value (\$)}}{\text{total production cost (\$)}} \qquad (14)$$

$$\text{Productivity} = \frac{\text{wheat yield (Kg)}}{\text{total production cost (\$)}} \left(\frac{\text{Kg}}{\$}\right) \qquad (15)$$

Greenhouse gas emissions

CH_4, N_2O and CO_2 are three major greenhouse gases that have unequal effects on global warming potential (GWP). It has been shown that CH_4 and N_2O have a stronger effect than CO_2 (Popp et al., 2010). It has been also shown that GWP is expressed in terms of CO_2 equivalence (Snyder et al., 2009). The amount of greenhouse gases emitted by farm inputs could be estimated by CO_2 emission which has been used in previous empirical works (Table 2).

Table 1. The energy equivalent of input and output in agricultural production

Inputs	unit	Energy equivalent (MJ unit-^{1})	References
A: input			
Labor	h	1.96	(Zangeneh et al., 2010)
Fuel	L	47.8	(Banaeian et al., 2011)
N fertilizer(N)	kg	66.14	(Tabatabaie et al., 2013a)
P fertilizer (P_2O_5)	kg	12.44	(Tabatabaie et al., 2013a)
Farm yard manure	kg	0.3	(Houshyar et al., 2015)
Seed	kg	20.1	(Unakıtan and Aydın, 2018)
Water	M^3	0.63	(Yilmaz et al., 2005)
Electricity	KWh	11.93	(Omid et al., 2011)
Machinery	H	62.70	(Yousefi et al., 2014a)
B: Out put			
Wheat grain yield (kg)	Kg	14.48	(Ziaei et al., 2015)
Wheat straw yield (kg)	Kg	9.25	(Ziaei et al., 2015)

Table 2. Greenhouse gas emission coefficients of agriculture inputs

Inputs	Unit	GHG coefficients (kgCO$_2$ eq. unit1)	References
Off farm emission (emission embodied in input)			
N fertilizer (N)	kg	3	(Nguyen and Hermansen, 2012)
P fertilizer (P_2O_5)	kg	1	(Snyder et al., 2009)
Diesel for farm traction and transportation	L	0.016kgCO$_2$eq.MJ^{-1} diesel*36.4 MJ/L Diesel	(Nguyen and Hermansen, 2012)
Electricity	KW	0.8	(Nguyen and Hermansen, 2012)
On farm emission			
N fertilizer (N)	kg	4.7(0.01kgN2O-N/kg N)	(Nguyen and Hermansen, 2012)
Farmyard manure	kg	0.097kgCO$_2$eq.MJ^{-1} FMY*0.3 MJ/Kg FMY	(Nguyen and Hermansen, 2012)
Diesel for farm traction and transportation	L	0.074kgCO$_2$eq.MJ^{-1} diesel*36.4 M L^{-1} diesel	(Nguyen and Hermansen, 2012)

The carbon efficiency was calculated using equation (17) (Yousefi et al., 2014b). In this regard; the yield should be converted to carbon equivalent. It has been reported that approximately 45% of yield is usually carbon (Yousefi et al., 2014a).

$$\text{Carbon efficiency ratio} = \frac{\text{wheat yield (kg C ha}^{-1}\text{)}}{\text{GWP(kg C ha}^{-1}\text{)}} \qquad (17)$$

In order to estimate the amount of CO$_2$ equivalent to the carbon, CO$_2$ equivalent must be multiplied by the rate of carbon into CO$_2$ (12/44) (Maciel et al., 2015).

RESULT AND DISCUSSION

Descriptive statistics

Table 3 lists sources used in wheat production in South Khorasan. On average, 211 kg ha^{-1} of seeds and 3164 m^{3}ha^{-1} of water were used for wheat production in South Khorasan. The average production of wheat was 3113.27 kg ha^{-1}.

Efficiency estimation

The technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) scores are summarized in Table 4 and Fig. 1. According to Table (4), the means of TE, PTE and SE for DMUs were 0.76, 0.89 and 0.85 (dimensionless quantities), respectively. In CCR models, 24 DMUs out of 136 DMUs and in BCC model 41 DMUs out of the same number of DMUs were efficient. The TE score was between 0.26 and 1 and the PTE score was between 0.48 and 1 while the SE score was between 0.37 and 1 (Table 4). The average TE, PTE, and SE scores of wheat farmers in Kermanshah, Iran were reported to be 0.89, 0.99, and 0.90, respectively (Vahedi, 2020). However, Moradi et al. (2018) reported that the TE, PTE, and SE scores for wheat production in Beyza region in Fars Province, Iran, were to be 0.82, 0.99, and 0.83 respectively. In another study, the efficiency of silage corn production was analyzed and these efficiency indices were reported to be 0.80, 0.93 and 0.86, correspondingly (Esfahani et al., 2017).

The comparison of the results of this study with similar studies on wheat production in Iran, as well as the comparison with silage corn in South Khorasan, showed that the wheat farmers were not efficient enough. BCC and CCR model results are shown in Fig 1. As it can be seen, from all 136 farmers surveyed in this study, 41 farmers using BCC models were efficient, while 17 farmers who their PTE were equal to 1, and whose TE were less than 1, were inefficient, that this could have been due to the inadequate scale and thus their SE was less than 1.

Table 3. Descriptive statistics for inputs and outputs of wheat farms that analyzed in this study

Input/output	Average	Maximum	Minimum	Standard Deviation
Human labor (H)	195.60	817.50	72.50	96.70
Diesel (L)	202.89	356.40	76.64	54.69
N fertilizer (kg)	153.89	333.33	66.67	45.53
p fertilizer (kg)	72.70	166.67	25.00	24.48
Farm yard manure (ton)	6.79	26.67	0.00	5.88
Seed (kg)	211.69	400.00	106.67	55.76
Water (M^3)	3164.17	6220.80	933.12	728.90
Electricity (kw)	1740.29	3421.44	513.22	400.90
Machine (H)	13.67	28.25	2.67	5.29
Wheat grain (kg)	3113.27	5692.31	1057.69	784.3983
Wheat straw (kg)	3549.13	6300.00	1248.70	894.2141

Table 4. Descriptive statistics for efficiency scores of wheat farms that analyzed in this study

	Minimum	Maximum	Mean	Std. Deviation	Efficient DMU(%)
TE	0.26	1.00	0.76	0.18	24 (17.6)
PTE	0.48	1.00	0.89	0.11	41 (30)
SE	0.37	1.00	0.85	0.15	24 (17.64)

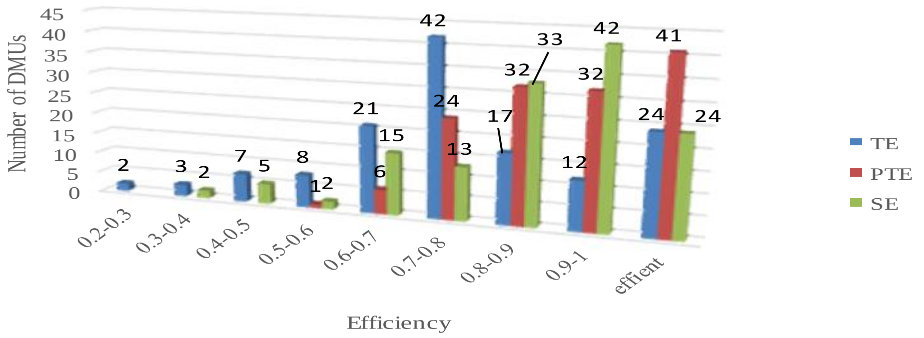

Fig. 1. Efficiency score distribution of wheat producers in eastern Iran as analyzed in this study.

Energy analysis

The energy input for the production of wheat was estimated in this study to be 45372.32 MJ ha^{-1}. The energy to produce wheat in Saravan and Ardabil of Iran was reported to be about 48517 MJ ha^{-1} and 38755 MJ ha^{-1} respectively (Taghinazhad et al., 2019; Ziaei et al., 2015). In India, Turkey and China, the energy to produce wheat was reported to be 26000, 23231 and 37500 MJ ha^{-1}, respectively (Singh et al., 2019; Unakıtan and Aydın, 2018; Yuan et al., 2018). As analyzed in this study, electricity, diesel and chemical fertilizer have the highest shares of total energy consumption with 45.76, 21.37 and 11.3%, in that order (Table 5).

Results of the current study showed that 15391.77MJ ha^{-1} of the total energy input could have been saved without reducing production (Table 6). The savings in the states of PTE, TE and optimal activity scale could have been 9583.94, 15391.77 and 5807.84Mj ha-1 (Table 6), respectively. In fact, 37.7% of the energy saved was related to the optimal scale and 62% to the pure technical efficiency (Table 6).

The inputs' shares of the total energy saving are shown in Fig. 2. According to this Fig., if farmers of the studied region produced wheat optimally, approximately 35 percent of the total energy savings belonged to the reduction of electricity consumption followed by diesel (approximately 29 percent).

Direct and indirect energy under conditions of the current study were 32836.67 and 12535.65 MJ ha^{-1}; respectively (Table 7). Also, 81% of the total energy required for production came from non-renewable energy sources, and only 19 percent of renewable energy was used. It has been reported that shares of direct energy consumed in the production of corn, prune and strawberry in Iran have also been more than those of indirect energy (Banaeian et al., 2011; Tabatabaie et al., 2013a; Yousefi et al., 2014a). Results of other studies on agricultural products reported that shares of renewable energies were less than non-renewable ones (Ordikhani et al., 2021; Samavatean et al., 2011). Data revealed that efficient use of resources could reduce the use of non-renewable energy by 6436.59 MJ ha^{-1}. If in addition to efficient use of resources, the scale of activity is also reformed – i.e. when the technical efficiency is equal to one – the amount of non-renewable energy use can be reduced and equal to

25316.17 MJ ha^{-1}. Also, in optimum conditions, the use of direct energy in wheat production would decrease by 10949.59 MJ ha-1, in which 40.55% of the saving will be contributed by the optimal activity scale(table7)

Table 5. Amounts of inputs and output with their energy equivalent for the production of wheat that determined in this study

Input	Unit	Total energy Equivalent (MJ ha−1)	Percentage (%)
Human labor		383.38	0.84
Diesel		9698.16	21.37
N fertilizer		4681.94	10.32
p fertilizer		416.02	0.92
Farm yard manure		2036.35	4.49
Seed		4254.88	9.38
Water		1993.43	4.39
Electricity		20761.70	45.76
Machine		1146.47	2.53
Total		45372.32	
Output			
Wheat grain yield		45765.11	58.23
Wheat straw yield		32829.46	41.77
Total energy output		78594.57	

Table 6. Energy-saving under optimum conditions for the production of wheat that determined in this study

Input	Energy saving in TE	Energy saving in PTE	Scale effect	Share of PTE	Share of scale
Human labor	127.50	81.77	45.73	64.13%	35.87%
Diesel	4009.37	2761.43	1247.94	68.87%	31.13%
N fertilizer (N)	1412.37	927.23	485.14	65.65%	34.35%
P fertilizer(P_2O_5)	121.95	59.79	62.16	49.03%	50.97%
Farm yard manure	1139.09	1057.00	82.09	92.79%	7.21%
Seed	1243.00	708.03	534.96	56.96%	43.04%
Water	596.82	321.21	275.61	53.82%	46.18%
Electricity	6215.91	3345.38	2870.53	53.82%	46.18%
Machine	525.78	322.11	203.67	61.26%	38.74%
Total	15391.77	9583.94	5807.84	62.27%	37.73%

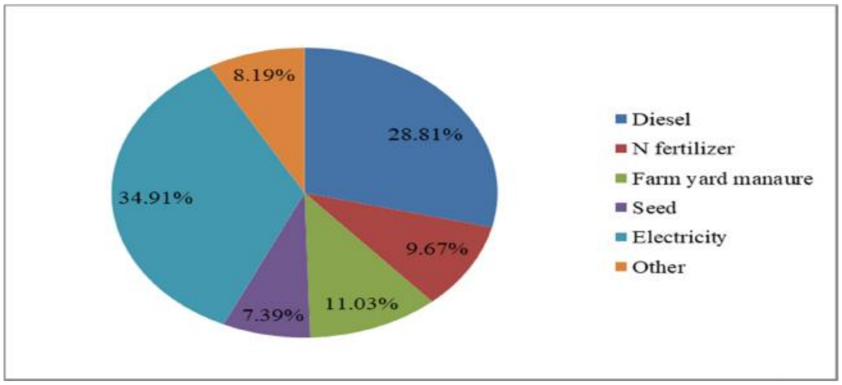

Fig 2. Share of each input in total energy saving for the wheat production that determined in this study

Table 7. The amount of direct, indirect, renewable and non-renewable energy (MJha^{-1}) for the production of wheat that determined in this study

Index	Present condition	reduction in TE	Reduction in PTE	scale effect	share of PTE	Share of scale
Direct energy	32836.67	10949.59	6509.78	4439.81	59.45%	40.55%
Indirect energy	12535.65	4442.18	3074.16	1368.02	69.20%	30.80%
Renewable energy	8668.03	4003.66	3147.35	856.31	78.61%	21.39%
Non-renewable energy	36704.29	11388.12	6436.59	4951.53	56.52%	43.48%

In the current study, it was shown that the efficient use of inputs could increase net energy up to 42806.18 Mj ha^{-1}. Meanwhile, at optimum scale; the farm's net energy will be increased to 48614 Mj ha^{-1} (Table 8). Indeed, 11.95% of this increase is related to the optimal farm scale (Table 8). The net energy for wheat production in the current study was 33222.25 MJ ha^{-1} (Table 8). which was more than net energy for wheat production in Saravan of Iran (Ziaei et al., 2015).

Energy use efficiency for wheat was reported to be 1.49 and 2.97 (dimensionless quantities) in Iran and Turkey, respectively (Gökdoğan and Sevİm, 2016; Ziaei et al., 2015). Yuan et al. (2018) obtained energy use efficiency equal to 4.4-5.2 (dimensionless quantities) for wheat in various managements in china. Under the optimal production conditions, the energy use efficiency reached 2.62 (dimensionless quantity), that 16.23 percent of the improvement was due to the appropriate farm scale. In other words, if the efficient use of resources was considered, the energy use efficiency would be equal to 2.20. The energy productivity was found to be 0.07 and 0.10 kg MJ^{-1} under current and optimum conditions (Table 8), correspondingly. This item was previously reported to be 0.056 and 0.19 kg MJ^{-1} for wheat in Iran and Turkey, in that order (Unakıtan and Aydın, 2018; Ziaei et al., 2015).

The results of this study indicated that the specific energy needed to produce 1 kg of wheat was 14.57 MJ energy (Table 8). However, if the resources are used efficiently, this amount could be reduced to 11.5 MJ kg^{-1} (Table 8). In case the scale of activity is corrected too, the index will be decreased to 9.63 MJ kg^{-1} (Table 8). Specific energy for prune, garlic, pear and corn silage has been reported to be at 5.59, 2.40, 3.72 and 3.76 MJ kg^{-1}, respectively (Pishgar Komleh et al., 2011; Samavatean et al., 2011; Tabatabaie et al., 2013a; Tabatabaie et al., 2013b).

Economic analyses

Economic analysis of wheat production also showed that the total production value and net return were 560.39 or 99.21 \$ ha^{-1}, respectively (Table 9). The net return of wheat production in Turkey was reported to be 273 \$ ha^{-1} (Unakıtan and Aydın, 2018). The benefit-cost ratio for wheat in this study was estimated to be 1.22 under current conditions (Table 9). The benefit-cost ratio was reported to be 1.38 for wheat in Pakistan (Ansari et al., 2018) and 2.1 for wheat in China (Jiang et al., 2021). The analyses of this study indicated that the benefit-cost ratio will be improved up to 1.45 if the resources are used optimally. The improvement of the scale of activity could further improve it by 1.66. Also, it has been found in the current study that the productivity index could rise by 9.22 kg \$$^{-1}$ under optimum conditions, out of which 12.54 percent would be contributed by the optimal activity scale.

The results of the economic analysis indicated that although the economic indices were lower in comparison with some other crops(Šarauskis et al.,2019; Taki et al.,2013; Pishgar Komleh et al.,2011) , the production of wheat was at an acceptable level of profitability as compared to other agricultural products.

Greenhouse gas emissions

The amount of greenhouse gas emissions for wheat cultivation was calculated to be 2832.94 kg CO_2 eq. ha^{-1}, out of which 1076.74 kg CO_2 eq. ha^{-1} was related to on-farm emissions and 1756.20 kg CO_2 eq. ha^{-1} to off-farm emissions (Table 10). Soltani et al. (2013) calculated emissions as 1137 kg CO_2 eq. ha^{-1} for the production of wheat. greenhouse gas emissions were reported to be 9485.47 kg CO_2 eq. ha^{-1} for the production of watermelons and 6075.96 kg CO_2 eq. ha^{-1} for tomatoes in Iran (Houshyar et al., 2015; Khoshnevisan et al., 2015). The results of the current study indicated that in optimum conditions, off-farm and on-farm emissions could be reduced by 539.54 and 436.79 kg CO_2eq ha^{-1} (Table 10), respectively. In the case of the efficient use of resources, greenhouse gas emissions would reach 2204.07 kg CO_2 eq. ha^{-1} by a reduction of 628.87 kg CO_2 eq. ha^{-1} The optimal farm-scale has a 25% share in reducing on-farm emissions and a 43% share in reducing off-farm emissions. If the scale of activity improved as well, greenhouse gas emissions would lower by 976.33 kg CO_2 eq, and reach 1856.61 kg CO_2 eq per ha. The highest decrease in greenhouse gas emissions was related to electricity followed by diesel fuel and chemical fertilizers (see below).

The results of this study indicated that electricity had the largest share in the greenhouse gas emissions followed by fuel and fertilizer with 49, 24 and 20 %, respectively (Fig 3). Mohammadi et al. (2014) obtained similar results reporting electricity and diesel fuel as the main sources of greenhouse gas emissions in the production of silage corn. In another study on the analysis of greenhouse gas emission, it was shown that the highest amount of greenhouse gas emissions at agricultural production was related to electricity (Esfahani et al., 2017; Yousefi et al., 2014b).

The share of electricity in emissions reflects the importance of management and efficiency that is required to reduce emissions. One of the main uses of electricity in agriculture is pumping groundwater for irrigation. In this regard, Karimi et al. (2012) estimated that groundwater pumping for agricultural irrigation in Iran used 20.5 billion kWh electricity annually and 2 billion liters of diesel fuel. It caused 3.6% of total carbon emission, so optimal consumption of water could result in a considerable reduction of the emission.

The output/input carbon ratio in this study were estimated to be 3.88 and 5.92 under current and optimum conditions; respectively, and the share of the optimum scale was 0.93 (45.74%). In the previous research, it has been reported that this ratio was 2.05 for corn (Yousefi et al., 2014a), 10.95 for sugar beet (Yousefi et al., 2014b) in Iran, and 6.3 for small farm and 4.1 for large farm of sugar beet in Morocco (Lal, 2004).

Table 8. Improvement of energy indices consumption of wheat production that analyzed in this study

Index	Unit	Present quantity	Optimum quantity in TE	Optimum quantity in PTE	Scale effect	Share of PTE	Share of scale
Energy use efficiency	Dimensionless quantity	1.73	2.62	2.20	0.43	83.77%	16.23%
Energy productivity	$KgMJ^{-1}$	0.07	0.10	0.09	0.02	83.77%	16.23%
Net energy	MJ	33222.25	48614.02	42806.18	5807.84	88.05%	11.95%
Specific energy	MJ kg^{-1}	14.57	9.63	11.50	1.87	83.77%	16.23%
Energy intensive	MJ $\$^{-1}$	98.38	88.77	92.68	3.91	95.78%	4.22%

Table 9. Economic analysis of wheat production in this study

Item	Unit	Present quantity	Optimum quantity in TE	Optimum quantity in PTE	Scale effect	Share of PTE	Share of scale
The total production value	$ ha^{-1}	560.39	560.39	560.39			
Net return	$ ha^{-1}	99.21	222.66	174.24	48.42	78.25%	21.75%
Benefit-cost ratio	Dimensionless	1.22	1.66	1.45	0.21	87.46%	12.54%
Productivity	Kg $\$^{-1}$	6.75	9.22	8.06	1.16	87.46%	12.54%

Table 10. Greenhouse gas emission of wheat production in different conditions that estimated in this study

Input	Emission (kg CO_2 eq. ha^{-1})							
	Current	Optimum condition PTE	Optimum condition TE	Reduction in TE	Reduction in PTE	Scale effect	Share of PTE	Share of scale
Off farm emission (emission embodied in input)								
N fertilizer	212.36	170.31	148.30	64.06	42.06	22.01	65.65%	34.35%
P fertilizer (p2O5)	33.44	28.64	23.64	9.80	4.81	5.00	49.03%	50.97%
Diesel for farm traction and transportation	118.16	84.52	69.31	48.85	33.65	15.21	68.87%	31.13%
Electricity credit	1392.23	1167.90	975.41	416.83	224.33	192.49	53.82%	46.18%
Total off farm emission	1756.20	1451.36	1216.66	539.54	304.84	234.70	56.50%	43.50%
On farm emission								
N fertilizer	332.70	266.81	232.34	100.36	65.89	34.47	65.65%	34.35%
Farmyard manure	197.53	95.00	87.03	110.49	102.53	7.96	92.79%	7.21%
Diesel for farm traction and transportation	546.51	390.90	320.57	225.93	155.61	70.32	68.87%	31.13%
Total on farm emission	1076.74	752.71	639.95	436.79	324.03	112.76	74.18%	25.82%
Total emission	2832.94	2204.07	1856.61	976.33	628.87	347.46	64.41%	35.59%
output/input carbon ratio	3.88	4.99	5.92	2.04	1.11	0.93	54.26%	45.74%

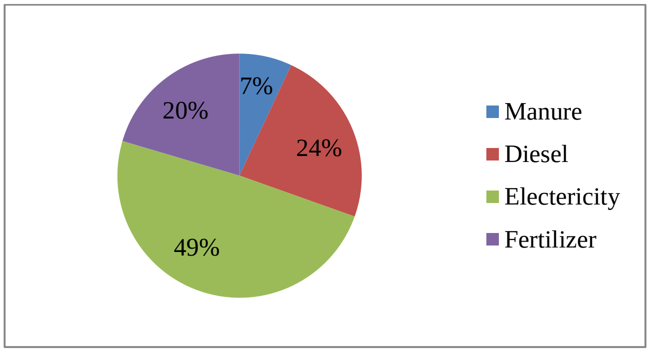

Figure 3. share of each input in GHG for wheat production that estimated in this study

CONCLUSIONS

This study explored the effect of the optimal scale of activity and efficient use of resources separately by estimating both pure technical and technical efficiency. Comparing the results of this study with other similar studies in Iran's agricultural sector, especially wheat production in the north of the country, showed that energy consumption and greenhouse gas emissions of wheat production have been high. Given the relationship between different types of efficiency, it seems that the inappropriate scale of agricultural units was an important factor that could be implicated in low efficiency. The results showed that the optimum scale of agricultural activity was the most crucial factor in saving energy and reducing greenhouse gas emissions in wheat production in eastern Iran. It was found that efficient use of resources partially contributed to energy saving and the reduction of greenhouse gas emissions, while activity on an optimal scale formed an important contribution. It seems that fragmented and scattered agricultural lands are among the most important factors in energy wastage and unsustainable production in the studied region. Therefore, farmers' encouragement to integrate their lands and apply collective farming methods can entail favorable environmental impacts.

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مقاله علمی- پژوهشی

مدیریت مصرف انرژی و انتشار گازهای گلخانه ای با استفاده از مقیاس بهینه مزرعه: شواهدی از تولید گندم در استان خراسان جنوبی

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کارایی مصرف انرژی

کارایی مقیاس

گندم

چکیده - نیاز به مدیریت پایدار منابع یک ضرورت در حال افزایش است. استفاده کارآمدتر از منابع تولید، پیش نیاز دستیابی به کشاورزی پایدار است. در این تحقیق با ترکیب تحلیل پوششی داده ها با استفاده از شاخص های زیست محیطی و اقتصادی، تأثیر مقیاس بهینه مزرعه بر بهبود این شاخص‌ها بررسی شد. داده‌های مورد نیاز از ۱۳۶ کشاورز با استفاده از روش پرسشنامه و مصاحبه چهره‌به‌چهره به دست آمد. نتایج مطالعه نشان داد میانگین کارایی‌فنی، کارایی‌فنی خالص و کارایی-مقیاس به ترتیب ۰/۷۶، ۰/۸۹ و ۰/۸۵، و نسبت فایده به هزینه ۱/۲ بود. نتایج نشان داد که در صورت استفاده کارآمد از منابع در مقیاس بهینه مزرعه، انتشار گازهای گلخانه‌ای و مصرف انرژی را می توان به ترتیب به ۹۷۶ کیلوگرم CO_2eq و ۱۵۳۹۱/۷۷ مگاژول در هکتار کاهش داد؛ ۳۷/۷۳ درصد از صرفه جویی مصرف انرژی و ۳۵/۶ درصد از کاهش انتشار گازهای گلخانه‌ای به مقیاس بهینه مزرعه مربوط بود. علاوه بر این، سهم مقیاس بهینه در بهبود نسبت فایده به هزینه و کارایی مصرف انرژی به ترتیب ۱۲/۵ و ۱۶/۲۳درصد بود. نتایج نشان داد که مقیاس بهینه مزرعه یکی از عوامل مهم در صرفه‌جویی مصرف انرژی و کاهش انتشار گازهای گلخانه‌ای تولید گندم در شرق ایران بود .بنابراین، از آنجا که اکثر مزارع در منطقه مورد مطالعه در مقیاس کوچک و پراکنده بودند، یکپارچه‌سازی اراضی و ترویج فعالیت در مقیاس بهینه تولید به عنوان مهم‌ترین گام در کاهش اثرات جانبی زیست‌محیطی و افزایش سودآوری کشاورزان توصیه می‌شود.