RESEARCH

Regression modeling of field emissions in wheat production using a life cycle assessment (LCA) approach

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ABSTRACT Field emissions of Irianian wheat production were investigated. Data were collected from 260 farms from the city of Fereydonshahr in the Esfahan province. Life cycle assessment (LCA) methodology was developed to assess environmental impacts associated with the production of wheat in the studied region. Global warming potential (*GWP*), eutrophication potential (*EP*), human toxicity potential (*HTP*), terrestrial eco-toxicity potential (*TEP*), oxidant formation potential (*OFP*) and acidification potential (*AP*) were calculated as 2620.86 kg CO_2 eq.t^{-1} (tonne of grain), 14.25 kg PO_4^{-2} eq.t^{-1}, 1111.7 kg 1,4-DCB eq.t^{-1}, 10.59 kg 1,4-DCB eq.t^{-1}, 0.0073 kg ethylene eq.t^{-1} and 19.07 kg SO_2 eq.t^{-1}, respectively. In order to specify a relationship between input materials and field emissions (direct and indirect emission), the Cobb-Douglass production function was applied. The impacts of farm area, N, P_2O_5, K_2O, diesel fuel and biocides were entered as independent variables and different impact categories as dependent variables. RMSE of models for *GWP*, *EP*, *HTP*, *TEP*, *OFP* and *AP* was 0.07, 0.19, 0.17, 0.34, 0.49 and 0.26, respectively. Accordingly with a rise in farm size level, the emissions per tonne of grain produced decreased. Accordingly, large farms are more environmentally friendly due to more yields and less emissions per tonne of grains.

KEYWORDS wheat; emissions; LCA; Cobb-Douglass; sensitivity analysis

Abbreviations	
AP	Acidification potential
d	Precision
D^2	d^2/z^2
e_i	Error term
EP	Eutrophication potential
$GM(X_j)$	Geometric mean of *j*th energy input (the 'j'th root product of 'j' input materials)
GM(Y)	Geometric mean of yield (the 'i'th root product of 'i' yields)
GWP	Global warming potential
HTP	Human toxicity potential
LCA	Life cycle assessment
MPP_{xj}	Marginal physical productivity

N	Required sample size; Number of holdings in target population
N_h	Number of the population in the *h* stratification
OFP	Oxidant formation potential
s	Standard deviation
S_h^2	Variance of *h* stratification
TEP	Terrestrial ecotoxicity potential
Y_i	Yield level of the *i*th farmer
z	Reliability coefficient(1.96 in the case of 95% reliability)
α_i	Coefficients of the exogenous variables

Introduction

The excessive use of energy in developed and developing countries creates environmental, commercial, technical, and even social problems, which requires in depth investigation in order to mitigate ensuing negative impacts. Analyzing relevant information is necessary to reduce energy consumption and its environmental impacts. High available energy along with reducing the known energy resources are the key factors to develop the philosophy of optimum energy consumption. Optimum use of energy helps to achieve increased production and contributes to the economy, profitability and competitiveness of agricultural sustainability of rural communities [Singh et al., 2004]. Agriculture is one of the most important productive sectors, which consumes and supplies energy in the form of bioenergy [Kizilaslan, 2009]. Energy input-output analyses are usually made to measure the energy efficiency and environmental aspects. This analysis determines how efficiently the energy is used. Several studies on energy input and output have been concentrated generally on worldwide production of field crops such as wheat [Singh et al., 1999], cotton [Singh et al., 2000], forage maize [Pishgar et al., 2011], sugarcane [Karimi et al., 2008], tomato [Esengun et al., 2007], canola [Mousavi-Avval et al., 2011], soy bean [Mandal et al., 2002], etc.

Increasing use of energy inputs in agriculture leads to numerous environmental problems like high consumption of non-renewable energy resources, loss of biodiversity, pollution of the aquatic environment by the nutrients nitrogen and phosphorus as well as by pesticides [Nemecek et al., 2011]. Life cycle assessment (LCA) is a methodology for assessing all the environmental impacts associated with a product, process or activity, by identifying, quantifying and evaluating all the resources consumed, and all emissions and wastes released into the environment [Rebitzer et al., 2004]. During the last century, LCA was mainly used in industrial fields, but nowadays, most researchers have used it widely to assess the impacts of products, processes and activities on the environment as well as in agriculture. A great deal of reports are available on its use for analyzing agricultural products i.e. olive [Avraamides and Fatta, 2008], cocoa [Ntiamoah and Afrane, 2008], sugar beet [Brentrup et al., 2001], wheat [Brentrup et al., 2004], and green bean [Romero-Gámez et al., 2012], and cropping systems' impacts on the environment.

The aims of this study were to calculate: (a) the emissions of input materials in wheat production, (b) to find a relationship between input materials and field emissions, and (c) carry out sensitivity analysis of the inputs on global warming potential (*GWP*), human toxicity potential (*HTP*), eutrophication potential (*EP*), ecotoxicity potential (*ETP*), acidification potential (*AP*) and oxidant formation potential (*OFP*) in Esfahan province of Iran.

Materials and methods

Study area and data collection

The Esfahan province (a province in center of Iran) is located within 30-42° and 34-30° north latitude and 49-36° and 55-32° east longitude. Data were collected from 260 wheat farms in rural areas of Fereydonshahr, a city in the west of Esfahan province, using a face-to-face questionnaire method. The sample size was calculated using the Neyman method [Yamane, 1967] as is shown below:

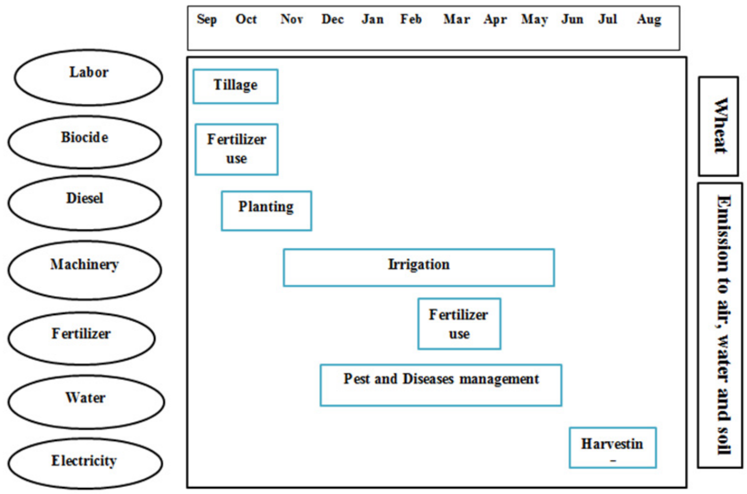

Figure 1 Farm operations and system boundary for wheat production.

$$n = \frac{\sum N_h S_h}{N^2 D^2 + \sum N_h S_h^{\,2}} \qquad \text{Eq. (1)}$$

where 'n' is the required sample size; 'N' is the number of farmers in the target population; 'N_h' is the number of the farmers in the 'h' stratification; 'S^2_h' is the variance of the 'h' stratification; 'd' permitted error ratio deviated from average of population ($\bar{x} = \bar{X}$), 'z' is the reliability coefficient (1.96 which represents 95% confidence); $D^2=d^2/z^2$; the permissible error in the sample population was defined to be 5% within 95% confidence interval. Thus the sample size was calculated to be equal to 260. A selection of 260 wheat producers was randomly carried out.

Input energy sources for the wheat production in the studied region were human labor, electricity, diesel fuel, machinery, chemicals fertilizers, farmyard manure (FMY), water for irrigation and seed; while output energy sources were grains produced. It must be noted that solar energy, either as radiation or heat, was not taken into account, as it is considered as a free subsidy in the energetic or economic analysis of agricultural systems [Slesser, 1973].

Life cycle assessment

Life cycle assessment (LCA) is a tool that can be used to evaluate the environmental effects of a product, process or activity. The LCA methodology has four components: goal definition and scoping, life cycle inventory (LCI), impact assessment and improvement assessment. The goal of this study was the comparative environmental assessment of wheat production in three different farm sizes (<1 ha, 1-3 ha, >3 ha) using LCA methodology. The scope of the present study consisted of agricultural practices, materials and energy inputs employed during the farming season as well as infrastructure process. Biogenic carbon balance, i.e. the equilibrium between net CO_2 uptake by plants (net primary production) and CO_2 released by soil respiration is not taken into account.

The common agricultural practices to yield wheat in the area of which the study was carried out were: field preparation (plowing, disk harrowing and leveling of the soil), incorporating farmyard manure into the soil, seeding, post-seeding agricultural practices, fertilization, irrigation (water extracted from local wells by means of electrical pumps), spray pesticide, plant protection and harvesting. Farm operations of wheat production in the studied region are shown in Fig. 1.

Above-mentioned cultivation processes along with energy and materials consumed during crop treatment were regarded as LCA steps. Life cycle inventory (LCI) data for wheat production is summarized in Table 1.

Data for the production of used inputs were taken

Table 1 Life cycle inventory data for wheat production per ha.

Inputs	Units	Average	Max	Min	SD
Machinery	kg	4675.05	5117	3917	261.6
Labor	h	120	193.12	80	25.64
Diesel fuel	L	74.64	138.5	38	25.67
Electricity	kWh	3297.25	3597	2997.5	174.06
Chemical fertilizers					
Nitrogen (N)	kg	246.68	600	100	67.54
Phosphate (P_2O_5)	kg	146.14	333.5	150	75
Potassium (K_2O)	kg	106.55	320	160	88.5
Farmyard manure	kg	4420	25000	0	6070
Pesticides	kg	1.46	5	0	1.13
Water for irrigation	m^3	6050	6600	5500	319.38
Seed	kg	310.85	366.67	166.67	42.8

from the EcoInvent®2.0 database. These primary data along with calculated direct emissions were imported into and analyzed with the SimaPro7.3 software. The impact categories used in this study are listed in Table 2. The impact-evaluation method used was the CML 2000 baseline developed by the Centre of Environmental Science of Leiden University [Guinée et al., 2002].

GWP was used to express the contribution that gaseous emission from the arable farm production systems make to the environmental problem of climate change. Direct emissions related to *GWP* was calculated using Eq. (2) [Guinée et al., 2002]:

$$\mathrm{GWP} = \sum_i GWP_{a,i} \times m_i \qquad \text{Eq. (2)}$$

The indicator result is expressed in kg of the reference substance, CO_2. '$GWP_{a,i}$' is the *GWP* for substance '*i*' integrated over '*a*' years (we considered 100 years), while '*m*' (kg) is the quantity of substance '*i*' emitted.

Human toxicity (*HT*) covers the impacts of present toxic substances in the environment on human health. Terrestrial ecotoxicity (*TE*) refers to impacts of toxic substances on terrestrial ecosystems. Eutrophication covers all potential impacts of excessively high environmental levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). The indicator result is expressed in kg PO_4^{-3} equivalent. Photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants. These reactive compounds may be injurious to human health and ecosystems and may also damage crops. The indicator result is expressed in kg of the reference substance, ethylene. Acidifying pollutants (*AP*) have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials (buildings). The indicator result is expressed in kg SO_2 equivalents.

System boundaries needed to be defined for correct accounting of emissions associated with inputs, within field/farm activities, and after the product

Table 2 Environmental impact categories and measurement units for each category.

Impact categories	Nomenclature	Measurement units
Global Warming Potential[a]	GWP	kg CO_2 eq.
Eutrophication Potential	EP	kg PO_4^{-2} eq.
Human toxicity Potential[a]	HTP	kg 1,4-DCB eq.[b]
Terrestrial Ecotoxicity Potential[a]	TEP	kg 1,4-DCB eq.[b]
Oxidant Formation Potential	OFP	kg Ethylene eq.
Acidification Potential	AP	kg SO_2 eq.

[a] Considering 100 years.
[b] DCB= Dichlorobenzene

leaves the farm. One tonne of wheat produced and farm gate were determined as the functional unit and system boundaries respectively.

In order to find out whether the calculated values of impact categories for three groups of farm sizes – small (<1 hectare), medium (1–3 hectare) and large (>3 hectare) – are different significantly, the ANOVA test was utilized and in order to compare their means, and Duncan compare mean test was applied.

Emissions

Emissions from wheat cultivation include emissions to air, water and soil from the field. Emissions to water from agricultural soils are determined as substances that leave the root zone of the plants. Thereby, the topsoil is regarded as a part of the techno sphere. E.g. nutrients are added to the soil and most of it is assimilated and harvested by the crops. Emissions are only related to the phosphate, i.e. the difference between inputs to and removals from the field.

Calculating N emission depends on N-balance on the field scale. Known inputs and outputs which are relevant to seed, fertilizer, N changes in soil matter and harvested crops are balanced in order to work out the N surplus. This surplus causes emitting different noxious gases. Nitrogen emissions were computed as elaborated in IPCC [2006]. The guideline estimated that the use of 100 kg of N fertilizer leads to an emission of 1.25 kg of N_2O into the air. IPCC [2006] estimates that 10% of the total nitrogen applied is emitted from the soil as NO_X and NH_3. Furthermore, this breaks down to 2% NO_X and 8% NH_3.

N fertilizer forms ammonium (NH_4^+) and nitrate (NO_3^-) in soil. Ammonium is quickly converted to nitrate in most types of soil. The nitrate form of nitrogen is susceptible to leaching to deeper soil levels where it is not available anymore for plant uptake. According to Erickson et al. [2001], more than 30% of nitrogen applied to ornamental plants leaches deeper down into the soil.

Model development

In order to specify a relationship between input energies and field emissions, a mathematical function needs to be identified. For this purpose Cobb-Douglass production function was chosen as the best function in terms of statistical significance and expected signs of parameters. The Cobb-Douglass production function is expressed as follows [Hatirli et al., 2005]:

$$Y = f(x) \exp(u) \qquad \text{Eq. (3)}$$

Eq. (3) can be expressed in the following form;

$$\text{Ln } Y_i = a + \sum_{j=1}^{n} \alpha_j \text{ h} \left(X_j \right) + e_i \qquad \text{Eq. (4)}$$

$$i = 1, 2, \ldots, n$$

where 'Y_i' denotes the emissions of the *ith* farm, 'X_{ij}' the vector of inputs used in the production process, 'a' the constant term, 'α_i' represent coefficients of inputs which are estimated from the model and 'e_i' is the error term, with assumption that, when the energy input is zero, the emission is also zero, Eq. (4) changed to Eq. (5);

$$\text{Ln } Y_i = \sum_{j=1}^{n} \alpha_j \ln\left(X_j\right) + e_i \quad \text{Eq. (5)}$$

$$i = 1,2,\ldots,n$$

In this study the return to scale index was determined in order to analyze the proportional changes in output due to a proportional change in all the inputs (where all inputs increase by a constant factor). Hence, the return to scale values for the Eqs. (4)-(5) were determined by gathering the elasticities, derived in the form of regression coefficients in the Cobb-Douglas production function. If the sum is more than, equal to, or less than unity, implying that there are increasing, constant, or decreasing returns to scale, respectively. An increasing, constant and decreasing return to scale indicate that when the inputs are increased by *X* value, then the impact categories of wheat production increases by more than, exactly and less than *X* value, respectively.

In the last part of this study, the sensitivity of inputs on emissions of wheat production was analyzed to determine how the output may be affected by the change in each input usage. For this purpose, the marginal physical productivity (MPP) method, based on the response coefficients of the inputs was utilized. The MPP of a factor implies the change in the total output with a unit change in the factor input, assuming all other factors are fixed at their geometric mean level. A positive value of MPP of any input variable identifies that the total output is increasing with an increase in input. The MPP of the various inputs was calculated using the 'α_j' of the various inputs as follows [Mousavi-Avval et al., 2011]:

$$\text{MPP}_{\text{Xj}} = \frac{GM(Y)}{GM(X_j)} \times \alpha_j \quad \text{Eq. (6)}$$

where 'MPP_{Xj}' is the marginal physical productivity of *jth* input, 'α_j' denotes the regression coefficient of *jth* input, '*GM(Y)*' is geometric mean of each emission and '$GM(X_j)$' denotes the geometric mean of *jth* input energies per tonne of grain produced basis.

In order to show the accuracy of our regression model, some quality parameters including, the coefficient of determination (R^2), the mean absolute error (*MAE*) and the root mean square error (*RMSE*) between the predicted and actual values were used and calculated using the following equations [Rahman and Bala, 2010]:

$$R^2 = 1 - \left(\frac{\sum_{i=1}^{n} (t_i - z_i)^2}{\sum_{i=1}^{n} t_i^2} \right) \quad \text{Eq. (7)}$$

$$MAE = \frac{1}{n} \sum_{i=1}^{n} \left| t_i - z_i \right| \quad \text{Eq. (8)}$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (t_i - z_i)^2} \quad \text{Eq. (9)}$$

where '*n*' is the number of the points in the data set, and '*t*' and '*z*' are actual output and predicted output sets, respectively.

Basic information on inputs and output of wheat production and field emissions were entered into Excel 2010 spreadsheets, SPSS 17.0 software and Matlab R2012a and SimaPro software.

Results and discussions

Environmental impact assessment of wheat production

Table 3 summarizes the values of the potential environmental impact of the wheat cultivation. The average *GWP* for wheat production in the studied area was calculated as 2620.86 kg CO_{2eq} t^{-1}. As it can be seen the farm size had an influential effect on the *GWP*. An increase in the farm size led to a reduction trend in *GWP*. Needless to say, such a deduction considerably shrank when the farm size proliferated. It means that the value of *GWP* for large farms fell at 1072 kg CO_2 eq t^{-1} and the value of *GWP* for small farms fell at 4590 kg CO_2 eq t^{-1}. In synthesis, *GWP* for large farms was significantly less than its counterpart

Table 3 Values of the potential environmental impact of the wheat cultivation.

Impact category	Farm size level: Small (<1)	Medium (1-3)	Large (>3)	Average
Global warming potential	4590[a]	1840[b]	1072.6[c]	2620.86
Eutrophication potential	20.78[a]	11.88[b]	10.1[b]	14.25
Human toxicity potential	2263.4[a]	633.7[b]	438.1[b]	1111.7
Terrestrial ecotoxicity potential	12.59[a]	9.35[a]	9.85[a]	10.59
Acidification potential	36.01[a]	12.7[b]	8.5[c]	19.07
Oxidant formation potential	0.0073[ab]	0.0067[a]	0.0081[b]	0.0073
Note: emissions are calculated per tonne (1000 kg) of grain produced				

in small and medium farms due to high value of grains produced in large farm groups.

Based on the evaluations it was revealed that emissions of chemical fertilizers, especially N-based fertilizers, played the most important role on *GWP*, followed by electricity. The share of N_2O emissions of fertilizers for farms less than one hectare was 88% and for two other levels were 87 and 84 percent respectively. Nemecek et al. [2011] in their studies showed that the N_2O and CO_2 emissions of chemical fertilizers played the most important role in *GWP*. Management of using chemical fertilizers can be a good way for reducing the environmental impacts in wheat production. The evaluation of the type of fertilizer illustrates the need to know the composition of the fertilizers and provides explicit possibilities to optimize fertilization practices. In some situations, the type of mineral fertilizer is the main determinant in emissions at the whole farm level and changing the type of fertilizer could significantly reduce the environmental impact [Charles et al., 2006]. The use of chemical fertilizers should happen cautiously due to their permanent effect on environment. Other LCA studies have shown that, for example, the use of urea or organic fertilizers (e.g. slurry) as N sources results in much higher Aps [Küsters and Jenssen, 1998].

The impact category of *EP* was dominated by N-based fertilizers and followed by electricity and P-based fertilizers. As it is illustrated in Table 3 the difference between large and medium farms are not significant from *EP* point of view while its amount in small farms is higher than other farm size groups. The results revealed that in all impact categories except *OFP* the large farms have the lowest environmental impacts per tonne of grain produced due to producing more yields. *OFP* was as a result of diesel combustion in wheat production. Due to an intensive use of machinery in large farms the diesel consumption is higher so *OFP* in large farms has a significant difference with other farm size levels.

The previous study conducted by Khoshnevisan et al. [2013] in this area showed that the difference between three selected farm sizes were not significant from energy consumption point of view while with the same level of energy inputs the output energy from large farms was meaningfully higher than other groups. Moreover, the amount of direct CO_2 emission from large farms was less than small and medium farms. In addition to the results of the present study wheat production in the large farms of the surveyed area is more preferable than small farms.

Damage assessment is a relatively new step in impact assessment. The purpose of damage assessment is to combine a number of impact category indicators

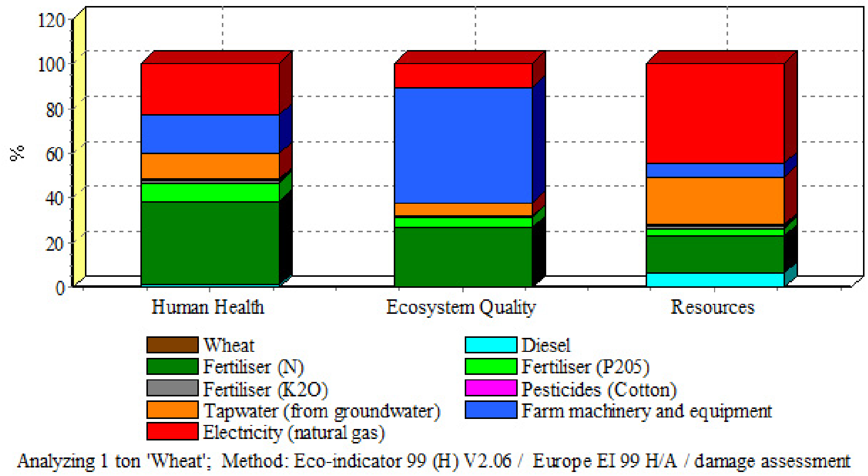

Figure 2 Evaluation of damage assessment of wheat production.

into a damage category (also called area of protection). In the damage assessment step, impact category indicators with a common unit can be added. For example, all impact categories that refer to Human health are expressed in DALY (disability adjusted life years). The results of damage assessment of wheat production are demonstrated in Fig. 2. As can be observed, production and application of chemical fertilizers contribute to all damage categories. The damage category of human health is dominated by fertilizers (more than 40%) while the damage assessment of resources is dominated by electricity.

Econometric model estimation of emissions and sensitivity analysis of inputs on impact categories

It was revealed that the farm size played an important role on environmental burdens and environmental emissions due to significant difference of energy consumptions, so it was considered that the farm size levels indirectly influence each impact category. The relationship between input materials as direct factors together with farm area as indirect factor took into account independent factors for regression modeling. Our model was estimated by CD production function (Eq. 5) and using ordinary least square (OLS) estimation technique. Accordingly, the emissions were assumed to be a function of chemical fertilizers (N, P_2O_5 and K_2O), diesel combustion, chemicals and farm area.

The regression analysis results of Eq. (5) (Table 4) illustrated that in the impact category of *GWP* the contribution of area, chemical fertilizer and diesel fuel energy was significant at 1% level. These results indicated that with an additional use of N fertilizers and diesel fuel energy or area of farms by 1%, the *GWP* will increase 0.711%, 0.046% and 0.738% while 1% additional use of biocides would lead to a decrease by 0.001 in *GWP*. The MPP values of model variables are shown in Table 4. As it can be seen, the MPP values of Area, N, P_2O_5, K_2O, diesel fuel and biocides were 529.7, 0.099, 0.008, 0.019, 0.035 and -0.36, respectively. These values illustrated that with 1 kg increase in each input of N, P_2O_5, K_2O and 1 L diesel fuel additional increase in *GWP* will happen by 0.099, 0.008, 0.019 and 0.035 kg per tonne of grain produced, respectively. On the other hand increasing 1 kg in using biocides can decrease the *GWP* as 0.36 kg per tonne of grain produced. It was shown that with increasing 1 kg biocides consumption the yield would be increased due to better protection of plants and subsequently the emissions per tonne of grain will be increased. The returns to scale (RTS) values for CD model (Eq. 5) were calculated by gathering the regression coefficients. The value of RTS was calculated as 1.51. This revealed that 1% increase in the inputs utilize would lead in 1.51% increase in the emission for this model.

Table 4 Econometric estimation results of inputs.

Independent	GWP Coefficient	GWP t-Ratio	GWP MPP	EP Coefficient	EP t-Ratio	EP MPP	HTP Coefficient	HTP t-Ratio	HTP MPP
1. Area (α_1)	0.738	81.54**	529.7	0.28	11.77**	3.2	-0.15	7.01**	-79.9
2. N (α_2)	0.711	61.9**	0.099	0.004	0.14	0.001	0.36	13.5**	0.038
3. P_2O_5 (α_3)	0.007	0.49	0.008	0.56	15.14**	0.01	0.002	0.07	0.002
4. K_2O (α_4)	0.010	0.66	0.019	0.018	0.45	-0.001	0.15	4.39**	0.22
5. Diesel (α_5)	0.046	3.3**	0.035	-0.19	-5.17**	0.002	0.35	10.75**	0.2
6. Biocides (α_6)	-0.001	-0.42	-0.36	0.001	0.05	0.002	0.001	0.26	0.38
Durbin Watson	1.85			1.83			1.9		
R^2	0.99			0.99			0.99		
RMSE	0.07			0.19			0.17		
MAE	0.04			0.13			0.13		
RTS	1.51			0.68			0.71		

Independent	GWP Coefficient	GWP t-Ratio	GWP MPP	EP Coefficient	EP t-Ratio	EP MPP	HTP Coefficient	HTP t-Ratio	HTP MPP
1. Area (α_1)	-0.14	-3.3**	-0.003	-0.69	-11.6**	0.01	0.078	2.4**	0.61
2. N (α_2)	-0.57	-10.4**	-0.001	-0.96	-12.7**	-0.001	0.471	11.5**	0.001
3. P_2O_5 (α_3)	-0.18	-2.6**	-0.002	0.56	0.03	0.002	0.002	0.04	0.0001
4. K_2O (α_4)	0.22	0.3.07**	0.001	0.003	0.47	0.001	0.025	0.47	0.001
5. Diesel (α_5)	0.18	2.7**	0.002	0.46	5.01**	0.002	-0.291	-5.86**	-0.002
6. Biocides (α_6)	0.56	130.6**	0.02	-0.002	-0.3	0.001	-0.001	-0.28	-0.01
Durbin Watson	1.87			1.81			1.81		
R^2	0.99			0.99			0.98		
RMSE	0.34			0.49			0.26		
MAE	0.24			0.32			0.17		
RTS	0.067			-1.15			0.28		

** Significant at 1% level. * Significant at 5% level

Durbin-Watson statistic test results (Table 4) showed the value of 1.85 for Eq. (5) and there is no auto-correlation in the estimated model. The corresponding R^2 value for this model was 0.99.

The results of regression analysis for area, N, P_2O_5, K_2O, diesel fuel and biocides inputs with *EP*, *HTP*, *TEP*, *OFP* and *AP* of wheat production are given in Table 4 too. As shown, *RTS* for *EP*, *HTP*, *TEP*, *OFP* and *AP* was 0.68, 0.71, 0.067, -1.15 and 0.28, respectively. The results illustrated that there were not any auto-correlations in the estimated models.

Conclusions

Iranian wheat cultivation was investigated using LCA methodology. Initial data were collected using face-to-face questionnaire method and the rest of required information was picked using some databases such as EcoInvent®2.0 database. Direct emissions were calculated along with the amount of input materials used during production season, and were entered SimaPro software to evaluate the environmental emissions of wheat cultivation. Global warming potential (*GWP*), eutrophication potential (*EP*), human toxicity potential (*HTP*), terrestrial ecotoxicity potential (*TEP*), oxidant formation potential (*OFP*) and acidification potential (*AP*) were calculated as 2620.86 kg CO_2 eq.t^{-1} (tonne of grain), 14.25 kg PO_4^{-2} eq.t^{-1}, 1111.7 kg 1,4-DCB eq.t^{-1}, 10.59 kg 1,4-DCB eq.t^{-1}, 0.0073 kg Ethylene eq.t^{-1} and 19.07 kg SO_2 eq.t^{-1}, respectively. The evaluations disclosed that on the basis of a mass-based functional unit (one tonne of grains produced) the large farms were more environmentally preferable than other farm size groups due to more produced yields. It should be highlighted that these results are true for selected environmental impacts and it is likely not true for others. To specify a mathematical relationship between inputs and environmental emissions, the Cobb-Douglass production function was chosen. Based on the results of this study, it is concluded that the evaluated model can estimate selected environmental indices with high accuracy and minimum error.

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References

Avraamides, M. and Fatta, D. (2008). Resource consumption and emissions from olive oil production: a life cycle inventory case study in Cyprus. Journal of Cleaner Production. vol. 16, nº 7, 809-821.

Brentrup, F., Küsters, J., Kuhlmann, H. and Lammel, J. (2001). Application of the life cycle assessment methodology to agricultural production: an example of sugar beet production with different forms of nitrogen fertilisers. European Journal of Agronomy. vol. 14, nº 3, 221-233.

Brentrup, F., Küsters, J., Kuhlmann, H. and Lammel, J. (2004). Environmental impact assessment of agricultural production systems using the life cycle assessment methodology: I. Theoretical concept of a LCA method tailored to crop production. European Journal of Agronomy. vol. 20, nº 3, 247-264.

Charles, R., Jolliet, O., Gillard, G. and Pellet, D. (2006). Environmental analysis of intensity level in wheat production using life cycle assessment. Agriculture, Ecosystem and Environment. vol. 113, 216-225.

Erickson, J.E., Cisar, J.L., Volin, J. and Snyder, G.H. (2001). Comparing nitrogen runoff and leaching between alternative residential landscapes. Crop Science. vol. 41, 1889–95.

Esengun, K., Erdal, G., Gündüz, O. and Erdal, H. (2007). An economic analysis and energy use in stake-tomato production in Tokat province of Turkey. Renewable Energy. vol. 32, nº 11, 1873-1881.

Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., de Koning, K.R.A., Wegener Sleeswijk, A., Suh, S., Udo de Haes, H., Bruijn, H., v. Duin, R. and Huijbregts, M.A.J. (2002). Handbook on life cycle assessment. Operational guide to the ISO standards: Kluwer, Dordrecht, The Netherlands.

Hatirli, S.A., Ozkan, B. and Fert, C. (2005). An econometric analysis of energy input–output in Turkish agriculture. Renewable and Sustainable Energy Reviews. vol. 9, 608–623.

IPCC. (2006). IPCC guidelines for national greenhouse gas inventories. In: Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. Prepared by the national greenhouse gas inventories programme. Japan: IGES.

Karimi, M., RajabiPour, A.R., Tabatabaeefar, A. and Borghei, A. (2008). Energy analysis of sugarcane production in plant farms a case study in Debel Khazaia agro-industry in Iran. American-Eurasian Journal of Agricultural & Environmental Science. vol. 4, 165-71.

Khoshnevisan, B., Rafiee, S., Omid, M., Yousefi, M. and Movahedi, M. (2013). Modeling of energy consumption and GHG (greenhouse gas) emissions in wheat production in Esfahan province of Iran using artificial neural networks. Energy. vol. 52, nº 0, 333-338.

Kizilaslan, H. (2009). Input-output energy analysis of cherries production in Tokat Province of Turkey. Applied Energy. vol. 86, 1354-8.

Küsters, J. and Jenssen, T. (1998). Selecting the right fertilizer from an environmental life cycle perspective. In Technical Conference, 290–296: IFA (International Fertilizer Industry Association).

Mandal, K.G., Saha, K.P., Ghosh, P.K., Hati, K.M. and Bandyopadhyay, K.K. (2002). Bioenergy and economic analysis of soybean-based crop production systems in central India. Biomass and Bioenergy. vol. 23, nº 5, 337-345.

Mousavi-Avval, S.H., Rafiee, S., Jafari, A. and Mohammadi, A. (2011). Energy flow modeling and sensitivity analysis of inputs for canola production in Iran. Journal of Cleaner Production. vol. 19, nº 13, 1464-1470.

Nemecek, T., Dubois, D., Huguenin-Elie, O. and Gaillard, G. (2011). Life cycle assessment of Swiss farming systems: I. Integerated and organic farming. Agriculture Systems. vol. 104, 217-232.

Ntiamoah, A. and Afrane, G. (2008). Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach. Journal of Cleaner Production. vol. 16, nº 16, 1735-1740.

Pishgar, S.H., Keyhani, A., Rafiee, S. and Sefeedpary, P. (2011). Energy use and economic analysis of corn silage production under three cultivated area levels in Tehran province of Iran. Energy. vol. 36, nº 5, 3335-3341.

Rahman, M.M. and Bala, B.K. (2010). Modelling of jute production using artificial neural networks. Biosystems Engineering. vol. 105, nº 3, 350-356.

Rebitzer, G., Ekvall, T. and Frischknecht, R. (2004). Life cycle assessment part I: framework, goal and scope definition, inventory analysis, and applications. Environment International. vol. 30, 701-720.

Romero-Gámez, M., Suárez-Rey, E.M., Antón, A., Castilla, N. and Soriano, T. (2012). Environmental impact of screenhouse and open-field cultivation using a life cycle analysis: the case study of green bean production. Journal of Cleaner Production. vol. 28, nº 0, 63-69.

Singh, G., Singh, S. and Singh, J. (2004). Optimization of energy inputs for wheat crop in Punjab. Energy Convers Management. vol. 45, nº 3, 453-65.

Singh, S., Singh, S., Pannu, C.J. and Singh, J. (1999). Energy input and yield relations for wheat in different agro-climatic zones of the Punjab. Applied Energy. vol. 63, 287-98.

Singh, S., Singh, S., Pannu, C.J.S. and Singh, J. (2000). Optimization of energy input for raising cotton crop in Punjab. Energy Conversion and Management. vol. 41, 1851-61.

Slesser, M. (1973). Energy subsidy as a criterion in food policy planning. Journal Science Food Agric Ecosystem Environment. vol. 24, 1193-207.

Yamane, T. (1967). Elementary Sampling Theory. Engle wood Cliffs, NJ, USA: Prentice Hall Inc.