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Environmental Life Cycle Assessment (LCA) Of Wheat Cultivation In Agro industry company Of Iranian Novin(Aq-Qala)

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ABSTRACT

The unique and systematic solution to the problems existing in the energy and environmental sectors of Iran is to improveenergy productivity (EP) in various fields.. Despite the extensive researches on the energy consumption and optimization of crops in Iran and other countries, the direct study of pollution and greenhouse gas emissions has received less attention from researchers. The study of crop production from the viewpoint of environmental issues and emissions will be a solution tothe environmental protection and achievement of sustainable agriculture. In this study, environmental pollution and energy input/output were investigated in Agroindustry Company of Iranian Novin Farms,Golestan province. According to the results, the average of energy output to input ratio was 1.04,with average EP of 0.07 kg/MJ, in wheat production. The average energy intensity and net energy gain were 14.1 MJ/kg and 1298.3 MJ/ha, respectively. Nursing and tillage operations accounted for 57 and 24% of total energy input, respectively. The results of wheat LCAusingSIMAPRO software revealedthat the open water poisoning indexwas55845.08 kg 1.4-DCB eq. for the production of one ton of wheat.The global warming potentialwas 841 kg CO_2 due to diesel fuel consumption. Despite the negligibleshare of chemical pesticides from total energy consumption, a value of 257.3 kg was obtained for the human toxicity index per ton of the produced crop.

Keywords: Diesel Fuel, Energy, Life Cycle Assessment, Pollution, Wheat

INTRODUCTION

Environmental issues have received increasing attention in recent years. With increasing environmental awareness, various economic sectors have focused on evaluating the environmental impact of their activities. High use of energy by human causes many problems for the environment and human health.The increase in greenhouse gases raises global temperature and climate change problems.An accurate and comprehensive assessment that can simultaneously encompass all environmental impacts requires the use of integrated criteria. Life cycle assessment or analysis (LCA) is a method in which all environmental impacts related to a product (including goods and services) are evaluated in the whole life cycle of that product from the extraction and/or collection of raw materials to the consumption stage and then recycling or removing the resultant wastes. Environmental assessment is a systematic and multistage process consisting of four stages, viz. goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO 14040, 2016). Given the effectiveness of LCA, it is introduced as the most appropriate method for the sustainability assessment of various activities, including agriculture.

Agriculture is one of the important economic sectors that has important effects on the environment. Agriculture is responsive to food security, therefore, the increasing world population requires more agricultural activity. In the past decades, this sector is associated with the dramatically increased use of agricultural mechanization, widespread application of fertilizers and pesticides, and advances in animal husbandry, resulting in elevated energy input to farms (Roder et al., 2014). Agriculture is the main source of several important environmental issues such as eutrophication open waters poisoning and etc. (Zhu et al, 2018, Dijkman et al., 2018).

Optimal use of energy in the agricultural systems can reduce input energy in food production and pave the way towards sustainable agricultural production (Fernanda et al., 2016).Any agricultural activity will be ecologically sustainable when the amount of depleted resources and emitted pollutions from this activity could be compensated by nature. The environmental impacts of agricultural activities should be initially evaluated by considering their sustainability in the long term (Kaab et al, 2019, Borghino et al., 2021).

Borghino et al., (2021)investigated environmental problems caused by the use of different levels of nitrogen fertilizers in wheat production in Germany.They found thateutrophication was increased with rising nitrogen fertilizer use, which is one of the most important environmental impacts of wheat production. Their results indicated that acidity and global warming indices are other major environmental impactsin wheat production.Wowra et al. (2020)reported that changing the tillage method to which led to less carbon decomposition in agricultural soils, would reduce greenhouse gas emissions. In many studies, fossil fuel consumption has been reported as the most important factor for greenhouse gas emissions (Wang et al., 2020).

The use of pesticides and chemical fertilizers in agriculture is also the cause of emissions in the environment. Modification of pest control methods, calibration of sprayers, biological control against pests, and the use of integrated methods are effective ways in the reduction of pesticides consumption. Optimal use of chemical fertilizers and the use of biological fertilizers are effective in the reduction of emissions. According to data collected from farmers in the study of Singh et al.

(2021), only 25% of farmers used the integrated method (combined chemical and biological control) in their farms management.

Due to scare studies on environmental effects of wheat production in Iran, this study intended to investigate theenergy consumption in wheat cultivation stagesand evaluate several environmental factors on wheat production in the farms of Iranian Novin Co.

MATERIALS AND METHODS

The geographical range of this research was wheat farmsof Agroindustry Company of Iranian Novin (Aq-Qala in Golestan province, Iran). The statistics and information were obtained from Company's registered data for output-inputs and machinery operations in wheat crop cultivation. Overall data for climatic conditions, farms area, and land plots specifications were obtained by consulting with company's staffs.

Due to the large area under the cultivation bycompany, for better management the total farms area has been divided into four units.Each unitwas with a somewhat different cropping method. Therefore, the data for this study were collected separately from each unit.

According to the ISO 14040 standard definition, LCAdeals with environmental and potential environmental aspects throughout the life cycle of a crop production. Therefore, all input and output data in the form of consumed materials, direct energy consumption and machinery use were collected. Below, the four stages of LCA for this study is described.

Goal and scope definition: This study aimed to investigate the environmental impact groups affecting the depletion of water and fossil fuel resources, global warming, and acidification inwheat production.Thefunctional unit was the production of one ton of wheat in IranianNovinCo.Farms.

Inventory analysis:

The inputs were fuels, chemical pesticides, and fertilizersconsumptionsin wheat production farms.The calculation of energy input through main inputs was as below:

The actual capacity of the machinery operations is the area covered in one hour of machinery work. In some studies, an average coefficient is considered for all machines, which presents energy intensity in terms of machinery working hours (Moradi, 2018). This coefficient was used to obtain the amount of energy input from machines,knowing their working hours in each hectare. An average amount of fuel consumption was used to calculate the energy input fromfuel consumption in different machinery operations. The production of chemical fertilizers is associated with the use of high energy levels. To calculate the energy input from chemical fertilizers, the used amount of different types of fertilizersconsumed in different periods of wheat growth, was multiplied by their energy equivalents. The same method was applied to calculate the energy input from animal manures and pesticides. The energy equivalents of these inputs in this study was according to the mentioned values by Fabiani(2020).

Emissionlevels emitted from wheat production farmsare different depending on soil, climate, and farm management system, making it difficult to measure directly them in the farms. Hence, the estimations for emissions, such as the variety of nitrogen compounds emitted from the farms, were made according to the introduced factors in LCA studies (Borghino et al., (2021)).

Ammonia emission: Urea has the highest ammonia sublimation among mineral fertilizers. Ammonia sublimation level varies depending on climatic conditions and soil properties. Due to the lack of necessary studies in Iran in this study, the ammonia emission factor from urea was considered equal to the European and American averages.The sublimated NH_3-N is about 17% of the total nitrogen consumed in the form of mineral fertilizersas well as urea (Borghino et al., (2021)).

N_2O emission: emitted N_2O into the atmosphere is affected bytwo microbial phenomena,viz. nitrification and denitrification. However, this issue is also influenced by different soil conditions, climate, and crop management. The factor presented by the International Panel on Climate Change (IPCC) was used in this study. According to the IPCC (2006), 1% of total consumed nitrogen is released as N_2O-N (Ingramet al.,2018).

NOx emissions: As reported by some investigations, emitted NOx to the atmosphere was considered as10% of N_2O levels.

Emissions from gasoline consumption: The most important types of greenhouse gases emissions, including CO_2, N_2O, and CH_4, from each liter gasoline combustion was calculated as follows (naderiet al., 2020):

Impact assessment:

The stage of impact assessment aimed to further interpret the inputs and outputs in thewheat production system. Environmental profile was analyzed by LCA methodology toolsusingSimaPro 7.1 software (Pre ́ Consultants, 2006), following the CML-2 baseline V3.01/EU25 method developed by the Institute of Environmental Sciences (CML) from Leiden University of the Netherlands.This model is commonly used in LCA studies of agricultural production.Finally, environmental indicators (global warming potential, acidification, eutrophication, toxicity, etc.) were identified. The calculated energy indices in crop production was as follow:

Energy output-inputratio (OIR) = Output Energy/Input Energy (1)

By definition, this indicator shows the status of energy outputs in relation to the input amounts.

Net Energy Gain (NEG) = Output Energy − InputEnergy (2)

By definition, this is the total amount of generated (output) energy minus the energyinput (GJ/ha).

Energy Productivity (EP)=Product yield/Energy input (3)

This is defined asthe produced crop unitper energy input unit (kg/MJ). Energyproductivity is considered as an important evaluation criterion in thecomparison of energy efficiency of different production systems.

Energy Intensity (EI=the amount of consumed energy / thecrop yield (11)

This index is defined as the energy amount consumed per unit of production (MJ/kg). It is the main indicator for comparison of energy efficiency of different cropping systems.

RESULTS AND DISCUSSION

LCA analyses

The calculated levels for environmental indicators in the studied wheat production are shown in Table 1. According to this table, for the production of one ton of wheat, 55845.1 kg of 1.4-DCB eq. was emmited, resultingthe open water toxicity index (OWTI) as the main impact category.It is due to high CO_2 emissions from diesel fuel consumption. The second main impact was global warming potential (GWP) with 841 kg of CO_2eq. emitted from N fertilizers in the form of N_2O.The human toxicity index (HTI) resulted from pesticides consumption was 257.3 kg of PO_4^{3-}eq. as the third main impact.

Table 1. Environmental impact indices in the wheat production

Effect section	Unit	Wheat
Depletion of organic resources	kg Sb eq.	3.4791
Acidification potential	kg SO_2 eq.	5.1911
Eutrophication potential	kg $PO^4{}_{-2}$ eq.	0.9557
Global warming potential (GWP)	kg CO_2 eq.	841.807
Ozone layer depletion	kg CFC-11 eq.	0.0003
Human toxicity potential	kg 1,4-DCB eq.	257.294
Surface water poisoning	kg 1,4-DCB eq.	21.0199
Open water poisoning	kg 1,4-DCB eq.	55845.08
Soil **poisoning**	kg 1,4-DCB eq.	0.3152
Photochemical oxidation potential	kg C_2H_4 eq.	0.1349

The effects of chemical fertilizers, diesel fuel, and consumed pesticide are shown as a normalized diagram in Figure 1.Diesel fuel and consumed pesticides, with percentage s of 60% and 39.8%, respectively, affected Surface water poisoning index. Among the substances emitted from diesel fuel, CO2with 80% had the greatest impact on the index.

All inputs had the same effect on the eutrophication index. Ammonium emitted from chemical fertilizers with a proportion of 72% had the highest effect on this index compared to N_2O and NOx. Sulfur dioxide (SO_2) emitted from diesel fuel had the greatest impact on this indexwith 55% in comparison to other pollutants.

Diesel fuel and pesticides, with 61% and 38.5%, respectively,influencedsoil toxicity index. Among the substances emitted from diesel fuel, $CO_2$with 60% had the greatest effect on this index.

The most effective factorsin thedepletion of organic resources index were the use of diesel fuel and N fertilizers with 41% and 36%, respectively. Ammonium emitted from chemical fertilizers, with a proportion of 65%, had the greatest impact on this index compared to N_2O and NOx. Among the substances emitted from diesel fuel, $CO_2$with a proportionof 80% had the utmostimpact on the index.

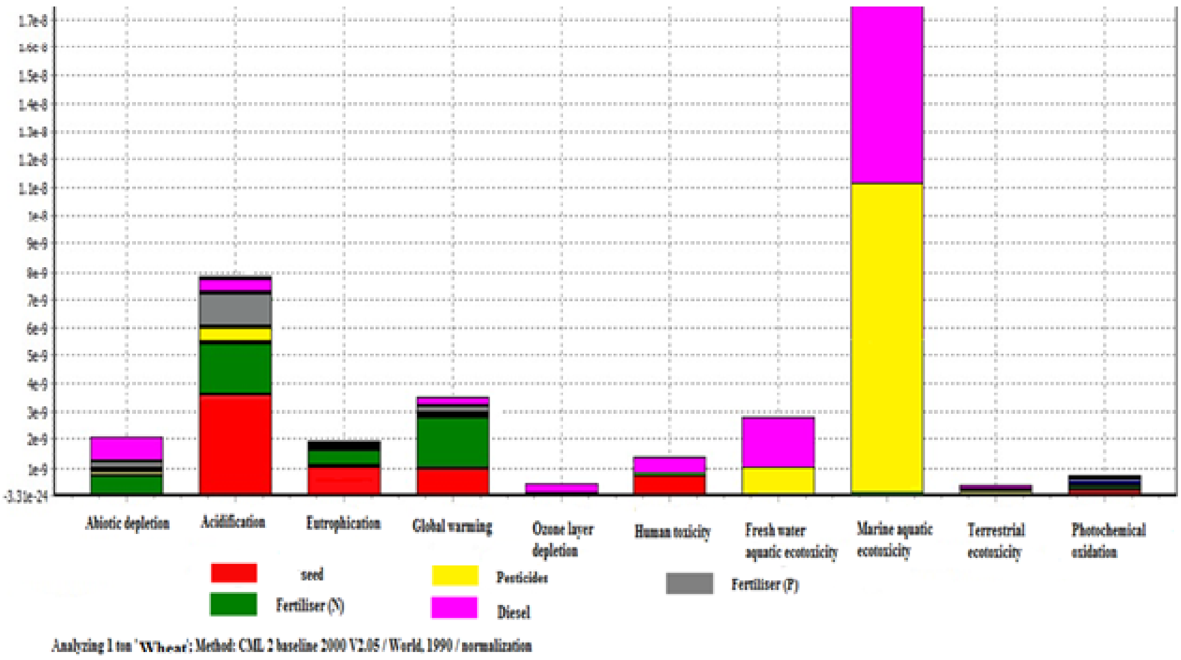

Figure 1.Levels of the environmental indices in the wheat production

The use of chemical fertilizers had no effect on the ozone depletion indexwhile diesel fuel with 81% had a very strong effect on this index.$CO_2$and CO emissions fromthe combustion of diesel fuel, each with a proportion of 40%, had the highest impact on this index.

Nitrate and phosphate fertilizers, with a share of 47% and 32%, respectively, had the greatest effect on theacidification potential (AP). N_2O emitted from chemical fertilizers with 85% had the uppermost effect on this index. Among the materials emitted from diesel fuel, $CO_2$with 75% had the greatest effect on AP.

The consumed inputs of pesticides and diesel fuel, with proportions of 51% and 46%,respectively, had the highest effect on the human toxicity index (HTI). Chromium with a 60% proportion had the greatest impact on this index compared to other diesel fuel emissions.

Chemical fertilizers, in particular nitrate fertilizer with a proportion of 76%, were the most effective factor on global warming potential (GWP) among the consumed inputs.N_2O emitted from chemical fertilizers, with 82%, had the highest impact on GWP compared to ammonium and NOx. With a share of 90%, CO_2emitted from diesel fuel had the uppermost effect on this index compared to CH_4, CO_2, N_2O, NOx,and Non-methane volatile organic compounds (NMVOC).

Energy analyses

The total energy input to the system and the share of each input are determined given the energy equivalents to the construction and depreciation of used machinery andconsumption of fuel, seeds, fertilizers, and chemical pesticides.

As shown in Table 3, a total energy of 30.8 GJ/ha was obtained for the wheat production in the company's farms. The highest energy consumption belongs to seed, fertilizers, and chemical pesticides, accounting for 60.01% of the total energy consumption. Chemical fertilizers are energy intensive, therefore, their higher consumption increases the energy input. According to this table, fuel energy input lies in the next category.

Table 3. The proportion of the inputs from total energy inwheat production (MJ/ha)

Machine	Energy	Percentage of total	Rank
Machinery	4637.7	15.1	3
Fuel	7677.5	24.9	2
Seed, fertilizers, and pesticides	18483.8	60.0	1
Total	30799.1	100.0	

According to Table 4, the output energy was 33.0 GJ/ha for wheat grain as the mean value for all farms. The farms in unit C had the highest yield compared to other units.

Khanaliet al. (2018) reported the energy input and output of 19.3 and 19.4 GJ/hafor rain-fed wheat growing,where the output and input values were 33.0 and 31.7 GJ/ha in the present study. As reported by other study, in Golestan province energy input and output forthe irrigated wheat production were 32.0and 94.0GJ/ha, representing higher crop yield in irrigated farms

(KazemiandZare, 2014). In the studied company the famrs were rain-fed butthe wheat yield was higher than other rain-fed systems in Iran 2887 kg/ha). However, it was lower than that forirrigated wheat cropping systems. In another energy study forrain-fed wheat in Mazandaran province, the energy input and outputwere 22.0and 29.0GJ/ha (Gholinejad and Hassanzadeh 2012).

Table 4. The energyoutput in the farm units for wheat production

Farm Unit	Yield (kg)	Energy contetnt (MJ/kg)	Energyequivalent (MJ)	Rank
A	2150	14.7	31605	3
B	1904	14.7	27988.8	4
C	2327	14.7	34206.9	1
D	2137	14.7	31413.9	2
Weighted average	2244.4	14.7	32993.3	

Energy indices

According to the results of input and output energies (Table 3 and 4), energy indicators in wheat cultivation were calculated using the definitions provided for these indices.

According to Table 5,the energy output to input ratio (OIR) was 1.04 for all farms as the weighted average of the company units. Due to the higher yieldof unit C, it can be observed that this unit has a betterOIR (> 1), whereas this ratio is less than 1 for unit B due to lower yields,resulting innegative NEG for unit B. However, a positive net energy gain (NEG) index (1.3 GJ/ha) was calculated by weighted averagingin the whole company.

The OIR obtained for wheat in this study is lower than those of 3.13, 3.17, and 1.64 MJ/MJ reported byAfzalinia and Karimi (2020), Shahin et al. (2008) in Ardabil, Mashhoori Azar et al. (2007) in Maragheh, and Sadeghi (2008) in Mahyar plain of Shahreza, respectively. In the mentioned studies the farms were irrigatedresulting higher yields than this study. Compared to some rainfed cultivations,with theratios of 1.03, 0.68, 0.81, and 0.99 reported respectively forShahrekord, West Azarbaijan, Kermanshah, and Saveh(Kazemi et al. 2016),the OIR in this study is somewhat higher.

In this study, the average energy productivity EPindex (0.07 kg/MJ)is lowerthan that (0.096 kg/MJ) reported in irrigated wheat growing in Ardabil region (Shahin et al. 2008). A similar EP of 0.07was obtained in rainfed wheat growing in Shahrekordregion (Kazemi et al. 2016). The mean weighted energy energy intensity (EI)index was 14.12 MJ/kg for all farms,which is close tothat of 15.67 for rainfed wheat growing in Shahrekord. The calculatedEI in this study ismuch higher thanthat of 8.21 for rainfed wheat in Kermanshah region (Fathi et al. 2018). In fact, it can be re-concluded many inputs were consumed to achieve a high rainfed yield in the Iranian Novin Co.farms.A review ona yield of over two tons per hectare indicates that it is much higher than the yields reported for rainfed farms, which are usually in the range of 1 t/ha in Iran.

Table 5. Energy indices in the wheat production units

	Unit	A	B	C	D	Total
OIR	MJ/MJ	1.01	0.87	1.01	1.09	1.04
EP	kg/MJ	0.07	0.07	0.07	0.07	0.07
EI	MJ/kg	14.60	16.92	14.61	13.51	14.12
NEG	MJ	225.00	−4229.20	207.90	2546.90	1298.27

Table 6 represents the energy consumed in the farms in individual stages of the crop cultivation. Accordingly, the highest amount of energy consumption (57%) belongs to the growing stage due to the high consumption of nitrogen fertilizers at this stage. If fertilizer use is saved at the growing stage, the amount of energy consumed will be reduced in this stage. The harvesting stageaccounts for the lowest amount of energy consumption, which is less than 6% of the total input energy. Although the tillage stage usually has the highest energy consumption, it is in the second place in this company with 24% of energy consumption.The use of no-tillage or low-tillage methods will also decrease the energy consumption at this stage.

Table 6. The energy consumptionin different stages of wheat cultivation

	Energy consumption (MJ/ha)	Energy consumption (%)
Tillage	7568.5	23.9
Cropping	4256.8	13.4
Growing	18041.5	56.9
Harvesting	1835.1	5.8

CONCLUSIONS

This study aimed to investigate the amount of in-farm emissions in wheat cultivation. Direct and indirect emissions from farms is due to the consumption of several inputs as seed, fertilizers, and fuels consumed in agricultural operations.

According to the results of LCA of wheat crop in the farms of Iranian Novin Agroindustry Co., marine aquatic eco-toxicity, acidification and global warming are three main environmental impact categories in the wheat production. Pesticides, fertilizers and diesel fuel arethe main resources of the pollutants resulting in these impact categories.Given the energy input and output analysis of the farms, EI in wheat grain production was 14.12 MJ/kg (without considering straw as abyproduct). A comparison with other studies indicates that this value is much higher than that for irrigated wheat production but similar or less than that for other studies around rainfedwheat.The highest energy inputin this study with 40%belongs to the fuel consumption followed by nitrogen fertilizers with 40%. To reduce the total energy input,alternative methods should be considered as well as using lower pesticides and fertilizers or application of reduced machinery operations without a significant reduction in wheat yield. Also, increasing the crop yield by irrigation program would reduce the energy intensity in wheat production and break down the emitted pollutions. The use of straw as a byproduct would also break down the energy input between product and byproduct.

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