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# Life-Cycle Assessment of Environmental Effects on Rapeseed Production

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In recent years, increasing the awareness on the environmental problems, especially global warming, has increased the concerns about the impact of emissions on the global climate. The current study was conducted to evaluate and analyze the environmental effects of rapeseed production in terms of of life cycle assessment (LCA) using SimaPro software with the aim of concentration on climate changes and impact of acidification. In order to perform the experiments, 1 tone of rapeseed was used as operational unit. The required data was collected from 30 farms in Izeh city. Ten environmental indexes including depletion of groundwater resources, potential to acidification, potential to eutrophication, potential to global warming, ozone depletion potential, human toxicity potential, potential to toxicity of fresh water and marine life, potential to environmental toxicity, potential to photochemical oxidation were investigated in this research. Results showed that the amount of greenhouse emissions for rapeseed was equal to 112.73 kg of carbon dioxide equivalent. It was also revealed that chemical fertilizer have the highest share among the evaluated inputs within the life cycle. Results obtained in this survey indicated that management of nutrients and pesticides can be considered as a local point for optimizing the environmental influences of rapeseed production in the related region.

## 1. INTRODUCTION

Oilseed crops are the world's second largest food reserves. FAO statistics show that rapeseed is the world's third largest source of vegetable oil production in terms of quantity [1, 2] This oilseed is grown in most parts of Iran and its oil content is about 40 to 45 percent of total grain weight [3]. In addition, rapeseed is currently the largest source of biodiesel production in the world. One of the factors affecting human health and the environment is greenhouse gas emissions during the life cycle of agricultural crops. Recognition and product life cycle assessment is one of the methods of measuring greenhouse gas emissions. Global warming is a known issue for everyone. Greenhouse gas emission and its effects on global warming is one of the serious challenges of the developed and developing countries. Under the Kyoto Protocol, countries are obliged to calculate and declare greenhouse gas emissions [4]. According to the repost of National Geographic Journal due to increase in greenhouse gases and global warming, by 2050 more than a million species of flora and fauna will be endangered and geographical distribution of many species will be changed. Now agricultural production systems use limited resources such as fossil fuels, water and other non-renewable inputs and this fact is followed by concerns about the environment such as water, soil and air pollution, decline in soil fertility, soil erosion and reduced associated resources [5].

Pollution from air pollutants and greenhouse gases is a serious problem associated with the majority of vehicles. It seems that widespread use of diesel agricultural tractors, means of transportation and agricultural machinery are endless threats to the ecosystem. Today, with increasing the degree of mechanization and the use of machines in agriculture, the use of fossil fuels has been increased and these fuels are one of the main sources of greenhouse gas emissions and environmental pollution in the present century. On the other hand, soil pollution caused by pouring gasoline and decomposition of burned and unburned diesel engine oils on the ground results in the pollution of groundwater [6]. In addition to fossil fuels following the modern agriculture, the use of nitrogenous fertilizers is being increased rapidly in the world. It seems that this trend will be continued in third world countries to obtain more food thus the level of soil related emission will be increased i.e., about 70% of the emitted $N_2O$ of

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biomass in the atmosphere is caused by agricultural activity that is released through the soil [7, 8].

A necessary condition for reducing emissions in managed ecosystems is to find the sources of emission. One of the new methods in agriculture and industry to determine the amount of greenhouse gas emissions is life cycle assessment. In life cycle assessment, the term cradle to the grave is used. It means that life cycle assessment (LCA) is a tool to measure the environmental aspects of producing during the life cycle of a product, in other words, using this tool all effects acting on the environment from the beginning to the formation of a product or process are assessed and calculated [3]. LCA is mostly used to assess and compare the environmental impact of energy production and economic aspects of producing a product around the world. Meanwhile, life cycle assessment has been introduced as a reliable and practical method for environmental impact evaluation that addresses the practical and potential environmental aspects of the life cycle of a product from the raw material processing to production, consumption, end of life practices, recycling and final disposal [9]. Based on ISO 14040, LCA has four parts of explaining the purpose, determining the inputs and outputs of the system, measuring environmental effects and their interpretation [10]. In order to calculate the environmental impacts in LCA method, a unit of product (operational unit) is considered as the basis for calculation and comparison. Studies have been conducted in this field, for example, Abeliotis et al. have used SimaPro software model 2000 cml to assess the environmental impact of beans. They reported the electricity and manure as the most influential sources of greenhouse gas emission [11]. Rajaiifar et al. (2013) studied the level of carbon dioxide emissions in the life cycle to produce biodiesel from rapeseed as an alternative to fossil fuels. They analyzed the level of greenhouse gas emissions in three main steps including agricultural production, the transportation and industrial conversion. Their research showed that the total greenhouse gas emissions at all stages of the life cycle of biodiesel production was 1054.98 kg $CO_2$ eq $ha^{-1}$ and the agricultural production stage obtained the first rank.

Khoshnevisan et al. (2014) assessed the life cycle of garlic and evaluated its environmental impact by SimaPro software [12]. Sahle and Potting (2013) used SimaPro software to assess cycle of rose cultivation in Ethiopia. They analyzed 9 environmental indicators including the evacuation of underground resources (non-living), acidification potential, global warming potential, ozone depletion potential and human toxicity potential. Their results showed that the highest emissions are associated with chemical fertilizer, especially the nitrogen fertilizers. After those emissions resulting from the use of pesticides, they particularly affected the terrestrial toxicity index, freshwater toxicity and photochemical oxidation. They also stated that pesticides have no visible impact on other environmental indicators and proposed chemical fertilizers and pesticides' management to improve the living conditions [13]. In Mousavi Aval et al. (2011) in order to assess the biological effect of rapeseed production, the model + Impact 2002 is used in SimaPro software and in accordance with the relevant coefficients, the overall index of pollutant emission is calculated to produce rapeseed. On the other hand, using the coefficients all indicators of environmental emissions are calculated and rapeseed production life cycle assessment has been completed. Evaluation of the use of software and the use of coefficients showed that the results of the two methods are the same [14].

The results of Liebig et al. (2005) showed that in agricultural land and pastures in North West America and the West Canada nitrous oxide emission is higher than the Rain fed lands [15].

In this study, detailed and advanced software in determining agricultural destructive factors on the environment and finding effective solutions to mitigate these factors have been used. Moreover, aligning the research methods appropriate to the global scientific community can be a huge step for reducing environmental pollutants to achieve sustainable agriculture, although in small areas. Given the importance of environmental issues in agricultural environmental systems, in this paper it is attempted to use a detailed and specific method to determine the main environmental indicators by life cycle assessment method in rapeseed agricultural production stage. It is also attempted to determine the amount of greenhouse gas emissions and calculate the coefficient of greenhouse gas emissions as well.

## 2. MATERIALS AND METHODS

Since Khuzestan province is one of the top-ten provinces in the cultivation of rapeseed in the country and the largest area under cultivation in Izeh city is dedicated to rapeseed cultivation after wheat and barley, rapeseed is considered as the product under study. The region under study is located at 31°50′03″N 49°52′02″E in the north eastern side of Khuzestan province with a height of 835 meters above sea level. Average precipitation of Izeh city is 650 mm and the average annual temperature is 24 Degrees Celsius. The area has a clay loam soil.

The data used in the crop year 2014-2015 is collected through questionnaires distributed among 30 fields of rapeseed lands in Izeh city (Fig. 1).

Rapeseed production in the region amounts to one hundred hectares in 2014-2015 which reflects the importance of rapeseed production in the region. Inputs applied in the production of rapeseed in under study area included labor, machinery, diesel fuel, chemical fertilizers and seeds.


**Figure 1.** Location map of the study area in the province and the country

On the other hand, the outputs included canola rapeseed. The level of greenhouse gas emissions was calculated for the total fields. One way to manage energy is to analyze the consumed energy and determine the energy consumption indicators; various indicators are considered for an appropriate analysis of the production system with an energy viewpoint. Indicators such as energy rate (ER), energy productivity (EP), net energy gain (NEG) and specific energy (SE) can be considered by which it is possible to compare the energy consumption in different areas and it is also possible to compare several production systems. With the help of these indicators, the possible reason for high energy consumption in a specific sector or system is discovered easily and the researcher could solve the problems and help to consume energy appropriately. This important issue in addition to the energy indicators is to assess environmental indicators for agricultural production. The demand to achieve a healthy environment has led the researchers to perform detailed procedures related to the environmental impacts of consumption and production of crops. SimaPro Software version 1.8 is used to perform LCA study along with the related database. In this study, to classify and quantify environmental impacts of rapeseed production the model CML-IA baseline V3.01/EU25 is selected that is usually used in LCA studies of agricultural products. The software eventually presents the environmental indicators (acidification potential, global warming potential, Eutrophication, toxicity, etc.) individually [9]. The modes of emission of these gases in sub sections associated with agricultural activities include the effects of chemical fertilizers, applied pesticides and diesel fuel on the agricultural lands and diesel fuel is considered as the only fuel consumed in tillage, planting, and harvesting of rapeseeds. Also in this study the crop production method is considered. System boundaries are considered as the farm's gates and the functional unit is determined as a ton of rapeseed; i.e. the environmental impact is calculated per one ton of product weight. Functional unit is the quantitative description of the product system to be used as the reference in an LCA study [16].

Farm operation and the system boundary are presented in Figs. 2 and 3.

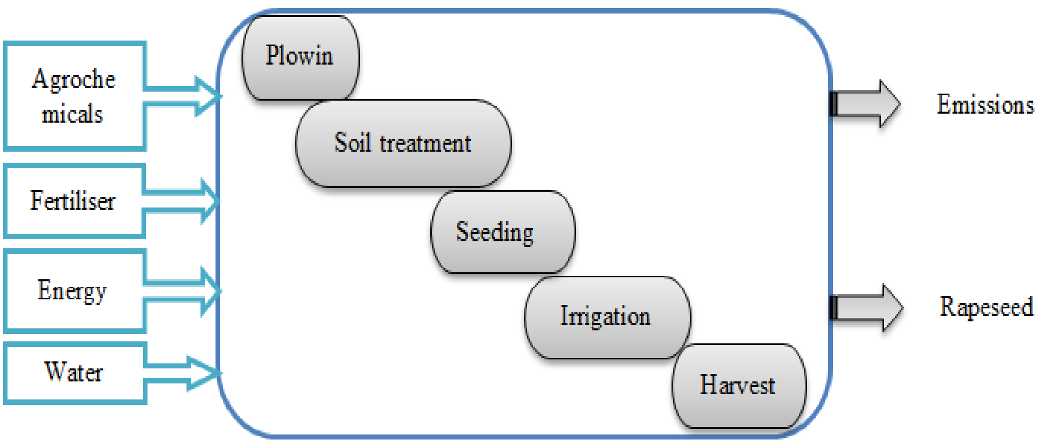


**Figure 2.** Outline of the canola crop cultivation farm in operation

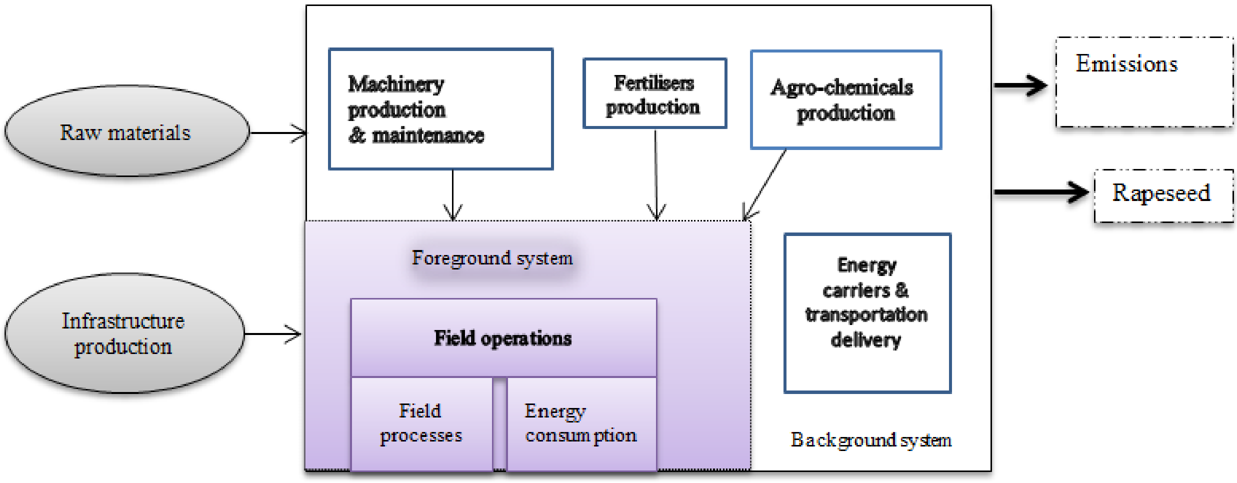


**Figure 3.** The system boundary in LCA of rapeseed production

At this stage all required resources (inputs) and environmental emissions (outputs) in the production process and related processes should be determined and listed.
The data required for LCI in the present study such as planting, harvesting, farm operations and their associated fuel consumption, fertilizer, pesticides, farm and road transportation, soil and groundwater and surface water specifications is obtained and then processed and classified. The input data to the system is presented in Table 1 to produce rapeseed.

**TABLE 1.** Energy consumption and output for rapeseed production (MJ ha-1).

| Item | Energy intensity | Average energy consumption (MJ ha-1) | Average consumption (Unit ha-1) | Source |
|---|---|---|---|---|
| Inputs | | | | |
| Labor Human | 1.96 | 17.66 | 9.01 | [17] |
| Fertilizing | | | | |
| Nitrogen | 78.1 | 6480.73 | 82.98 | [18] |
| Potassium (K2O) | 13.7 | 652.12 | 47.60 | [18] |
| Phosphorus | 17.5 | 1282.4 | 73.28 | |
| Di Ammonium | 11.93 | 791.43 | 66.34 | [19] |
| Chemical | 288 | 1909.44 | 6.63 | [20] |
| Seed | 25 | 253 | 10.12 | [21] |
| Diesel | 47.8 | 2294.87 | 48.01 | [22] |
| Transport | 6.3 | 12.41 | 1.97 | [23] |
| Machinery | 62.7 | 511.78 | 511.78 | |
| Tractor | 93.6 | 25.74 | 4.62 | [23] |
| Combines and equipment | 87.63 | 486.04 | 392.25 | [23] |
| Total energyinput | | 14205.86 | | |
| Output | | | | |
| Yield (kg) | 25 | 22192.75 | 887.71 | [14] |

There is a wide range of information on energy in SimaPro Software. System inputs are considered based on the system boundary in the form of chemical fertilizers, pesticides and diesel fuel. The environmental impacts are based on the use of chemical fertilizers due to the emission of dinitrogen oxide, ammonia and nitrogen oxides (NOx) that are calculated based on the proposed equations by Nemecek et al [2]. Research results on the emission of chemical fertilizers in IPCC showed that for 100kg nitrogen, 1.25kg nitrogen oxide is emitted [4]. It is also shown in a study that 35-50% of the total pesticide consumption is emitted [24].

In this study, the consumption of diesel fuel as the only fuel for tillage, planting, and harvesting of rapeseed was considered. Diesel fuel emission factors were expressed by Sahle and Potting (2013) that included $CO_2$, NMVOCs and NOx, $N_2O$, $CH_4$, $SO_2$, and CO [13].

Since SimaPro Software works under certain conditions, prior to entering the data to the application, field conditions including farm slope, soil physical and chemical properties, mode of irrigation and plant characteristics will be studied. The emissions related to any of the inputs are calculated with the formula and finally entered into the software. Greenhouse gas emission is calculated as follows:

### 2.1. Nitrate leaching to the groundwater ratio

Although nitrate is absorbable by plant, heavy rains cause nitrate leaching and its entrance to the groundwater. Eq. 1 calculates nitrate leaching by the model SQCB-$NO_3$[25].

$$NO3\text{-}N=21.37+(P/(C\times L))[0.0037\times S+0.0000601\times N_{org}-0.00362\times U] \quad (1)$$

Formula components are presented in the following order:

P: precipitation (mm per year), C: clay percentage, L: root depth (m), S the value of nitrogen supplied through fertilizer (kg N/ ha), nitrogen uptake (kg N/ ha) and $N_{org}$ is the amount of nitrogen in organic matter (kg N/ ha) U: the amount of nitrogen uptake by the crop in terms of kg N / ha.

### 2.2. A-Phosphorous to water diffusion

Phosphorus is one of the important plant nutrients that should be supplied to the plant sufficiently. Drainage and soil erosion causes a part of the phosphorus to be leached. To calculate the amount of greenhouse gas emitted by the phosphor in Ecoinvent (Processes producing the consumed materials) factors such as land use, the amount of phosphorus in fertilizer and the type and duration of coverage are considered to measure the level of soil erosion. Diffusion of phosphorus to the water is in three forms. (A) - phosphate leaching to groundwater that is calculated by formula (2)[2]:

$$P_{gw}= P_{gwl}* F_{gw} \quad (2)$$

Where: $P_{gw}$ is leached phosphorus for a specific group of the intended field in [kg/(ha*a)] and $F_{gw}$ is the correction factor for the fertilizer. ”*a*” is the accumulation factor which is equal to 1.86.

### 2.2. B- Phosphate runoff to surface waters

Phosphate runoff to surface in a similar manner is calculated by formula (3)[4]:

$$P_{ro}=p_{rol}*F_{ro}=0.175*0.6412 \quad (3)$$

In this formula, $P_{ro}$ is the amount of phosphorus entrance to the river by runoff in [kg / (ha * a)]. $P_{rol}$ is the average amount of phosphorus lost by runoff for a series of farms. $F_{ro}$ is the correction factor for fertilizer.

Phosphorus emissions to surface water through water erosion [2]:

$$Per= Ser* Pcs* Fr* Ferw \quad (4)$$

$S_{er}$ is the amount if eroded soil in (kg/ha*a). Pcs is the phosphorus at the higher level of the soil in kg (kg of phosphorus per kg soil). Fr is the Phosphorus enrichment factor. $F_{erw}$ is a fraction of eroded soil entering the river.

### 2.3. Production of greenhouse gases from N2O into the air

$N_2O$ is one of important greenhouse gases that cause 5% of the total greenhouse effects. Soil as one of the most important sources of $N_2O$ emission includes 65% of the total global $N_2O$ emissions.

Increasing the $N_2O$ amount reduces ozone stratosphere and increases ultraviolet radiation received by the Earth. Apart from the effects on the atmosphere, $N_2O$ emission from the soil reduces the available nitrogen to the plants. Nitrogen oxide ($N_2O$) as an intermediate product in the denitrification process is generated by soil microorganisms. $N_2O$ is a greenhouse gas with high impact. $N_2O$ emission calculations are based on IPCC[2] methods. Formula (5) presents $N_2O$ greenhouse gas emissions [2]:

$$N_2O=44/28*(0.01(N_{tot}+N_{CR})+0.01*14/17*NH_3+0.0075*14/62*NO_3^-) \quad (5)$$

where, $N_{tot}$ is the total nitrogen in organic and chemical fertilizer (kg/ ha), $NH_3$ is the amount of lost nitrogen in the form of Ammonium (kg $NO_2^-$ / ha), Ncr is the remaining Nitrogen content in the product (Kg/ ha) and $N_2O$ in (kg $N_2O$/ ha) is 0.922.

### 2.4. Greenhouse gas emissions from NOx into the air

During denitrification processes in the soil, nitrogen oxide ($NO_x$) might be produced as well. This pollutant from $N_2O$ emissions is calculated by formula (6):

[1]Inter-governmental Panel On Climate Change

$NO_x=0.21*N_2O=0.193$ (6)

### 2.5. Carbon dioxide emissions with the use of urea

For each kg of urea 1570 grams of carbon dioxide is emitted which is recorded in eco invent database [2].

## 3. RESULTS AND DISCUSSION

Various indicators are considered for an appropriate analysis of the production system with an energy viewpoint. Indicators such as energy rate (ER), energy productivity (EP), net energy gain (NEG) and specific energy (SE) are considered by which it is possible to compare the energy consumption in different areas and it is also possible to compare several production systems and additionally the possibility to compare several production systems with each other is provided. With the help of these indicators, the possible reason for high energy consumption in a specific sector or system is discovered easily and the researcher could solve the problems and help to consume energy appropriately. Table (2) presents energy indicators in the production of rapeseed crops. Based on the obtained results the energy ratio is 1.56 and this index indicates that the energy derived from farm is 1.5 times greater than the input energy. Energy index indicates that to produce one kilogram of product,16 MJ/ kg energy is consumed. The small value of this index indicates the high performance of the production system.

**TABLE 2.** Energy indices at agricultural production stage.

| Index | Consumption | Unit |
|---|---|---|
| Energy use efficiency | 1.56 | - |
| Specific energy | 16.002 | MJ kg-1 |
| Net energy | 7986.89 | MJ ha-1 |
| Energy productivity | 0.06 | Kg MJ-1 |

Greenhouse gas emissions obtained by fuel consumption at different stages of farm operations and theble use of nitrogen, phosphate, potassium, ammonium fertilizers and herbicide in rapeseed farms are calculated and reported in Table 3.

**TABLE 3.** Effective environmental factors of rapeseed (ton/ha).

| Environmental indicators | Unit | Total |
|---|---|---|
| Abiotic depletion | kg Sb eq | 0.0243 |
| Abiotic depletion (fossil fuels) | MJ | 14424.98 |
| Global warming potential | kg $CO_2$ eq | 412.73 |
| Ozone layer depletion | kg CFC-11 eq | 0.000189 |
| Human toxicity | kg 1,4-DB eq | 501.49 |
| Marine aquatic toxicity | kg 1,4-DB eq | 284.016 |
| Water toxicity | kg 1,4-DB eq | 1535653.60 |
| Ecotoxicity potential | kg 1,4-DB eq | 11.187 |
| Photochemical oxidation | kg $C_2H_4$ eq | 0.357 |
| Acidification | kg $SO_2$ eq | 8.523 |
| Eutrophication | kg $PO_4$ eq | 46.416 |

According to Table 3, the amount of non-renewable energy (depletion of fossil resources) in the production of one ton of rapeseed is reported as 14424.89 MJ. In this area in order to produce one ton of product, 1112.73 kg of $CO_2$eq Greenhouse gases are emitted to the atmosphere. Previously, Mousavi Avval et al. in their study achieved a value lower than the index for rapeseed in Mazandaran [26].

In this regard Tzilivakis et al. (2005) estimated the total GWP per unit area of potato, wheat, rapeseed, barley and peas products as 7, 2.1, 7.1, 3, and 7 $CO_2$ ton/ha, respectively [27].

The effect of applying nitrogen and emissions in the farm has a great impact on this indicator. Agriculture stage is considered as the largest producer of ammonia in Switzerland for the same reasons as the use of nitrogen fertilizers and manure [2]. The total amount of GHG emissions from consumption of inputs is calculated and presented in Table 3. The amount of each indicator for the performance of rapeseed in the area was obtained, and then the amount was allocated per person based on the region's population. Table 4 presents the emissions index per person. As the results show for each person in the area, 450 g/year carbon dioxide enters into the air.

As the effect of inputs on the global warming potential is presented in Fig. 4. In Fig. 5, the importance or magnitude of calculated indexes are calculated according to reference information. To this end, the normalization coefficients were used and the indexes of normalized become Without units.

**TABLE 4.** Emissions of environmental pollutants per person in the region.

| Environmental indicators | (unit/ kg) | Emissions per person |
|---|---|---|
| Abiotic depletion | 0.663 | 0.000026 |
| Abiotic depletion | 394156.37 | 15.76 |
| Global warming potential | 11277.66 | 0.451 |
| Ozone layer depletion | 0.0051 | 0.0000002 |
| Human toxicity | 13702.99 | 0.548 |
| Marine aquatic toxicity | 7760.61 | 0.310 |
| Water toxicity | 41961074.29 | 1678.44 |
| Ecotoxicity potential | 305.67 | 0.0122 |
| Photochemical oxidation | 9.75 | 0.00039 |
| Acidification | 232.88 | 0.0093 |
| Eutrophication | 1268.29 | 0.0507 |

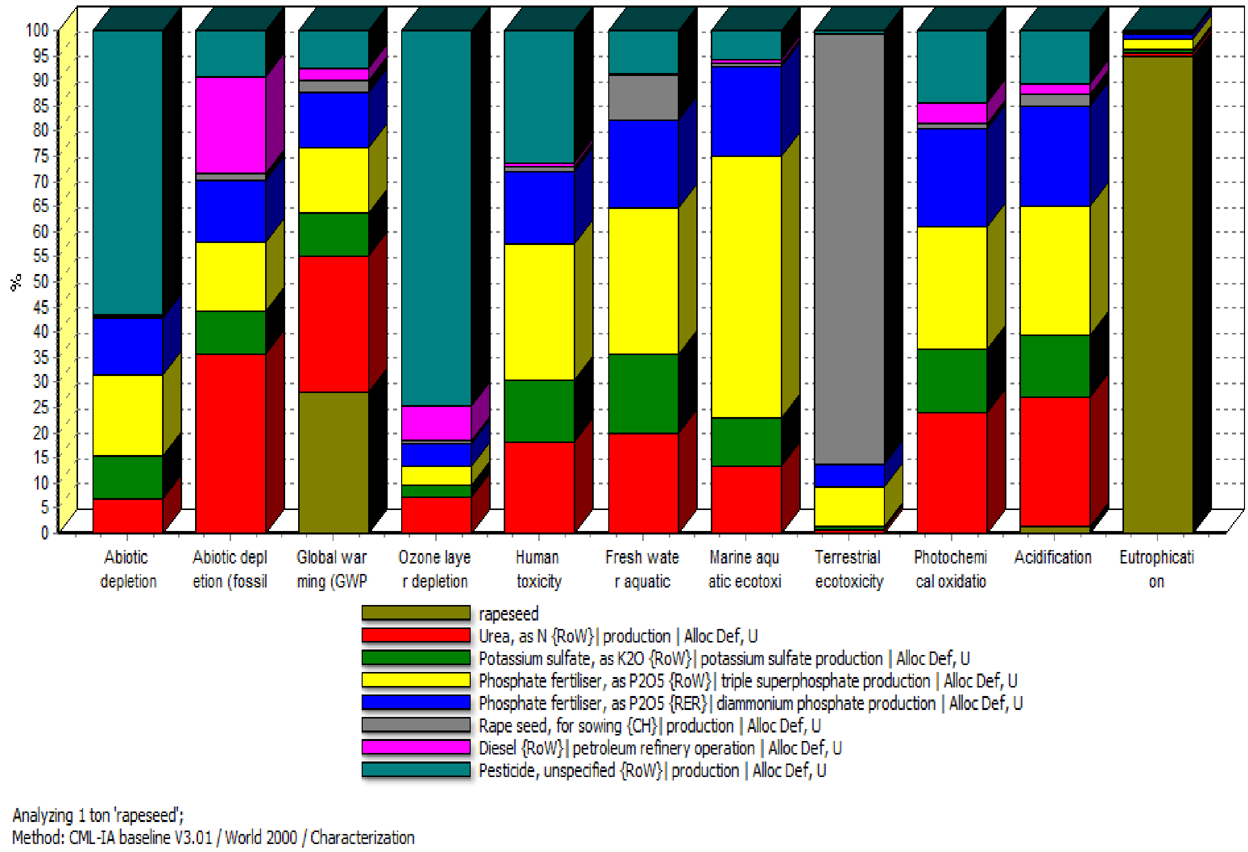


**Figure 4.** The role of inputs on the environmental indicators of rapeseed cultivation

The most effective factor in global warming is the use of chemical fertilizers, especially nitrates fertilizer. In a study conducted by Nemecek et al. (2007) it was shown that di-nitrogen oxide and carbon dioxide emitted by fertilizers and diesel fuels have the greatest impact on global warming potential [2].

According to Fig. 4 the insecticide input with 82% level has the greatest impact on the ozone layer depletion in the stratosphere. Different types of pesticides, insecticides including toxic organic substances are being widely used. In this material, breaking of carbon bonds into chlorine is hard and the presence of chlorine reduces the reactivity of other bonds in the organic molecules. This property means that by entrance of chlorinated organic compounds to the environments, their degradation is slowed and they would be more inclined to snuggle and that is why they have become a big environmental problem. Toxicity potential for humans for one ton of rapeseed is about 50.49 kg eq 1.4-DB (Paradichlorobenzene). The highest share of environment pollution indicator is allocated to insecticides and phosphate fertilizers. Generally, 68% of the share of this indicator was caused by applying chemical fertilizers in the field.

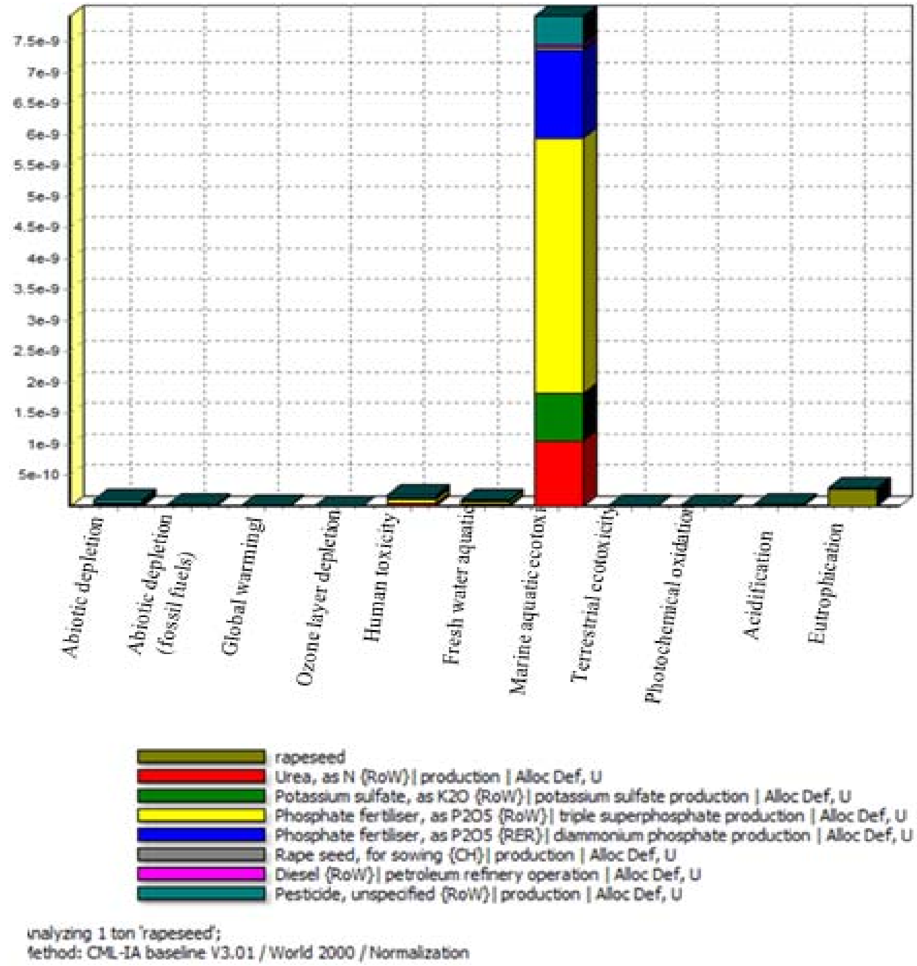


**Figure 5.** The production level of environmental indicators of rapeseed with normalized input.

Sahle and Potting (2013) in their study titled "LCA of the environment in rose cultivation in Ethiopia" reported the effect of chemical fertilizer on human toxicity index as 75.5% [13]. This emission with the release of toxins in the air causes skin, liver and nervous system diseases in humans. Where the photochemical oxidation potential increases, it forms the ozone layer in lower layers of the atmosphere and can have adverse effects on human health and ecosystems. Photochemical oxidation potential indicator for the production of a ton of rapeseed in the area enters 0.357kg $C_2H_4$ to the environment that the use of phosphate fertilizers by 28 per cent has the highest share in this regard. Fossil fuels' combustion causes emission in the air and in general $SO_2$, $NO_2$ and $NH_3$ cause acidification effects in the air. By producing 1 ton of rapeseed, 8.523 kg $SO_2$ enters the environment (Table 3).

One of the main and effective reasons contributing to the acidification of air is the excessive use of phosphate fertilizers. In this study, the use of phosphate fertilizer form 30% of the whole share of air acidification. In the production of 1 ton of rapeseed, 46.416 kg $PO_4$- was released to the environment that had eutrophication effects. Eutrophication in surface waters can cause algae growth leading to the loss of life in ponds and lakes [28]. Most potassium fertilizer due to the optimal consumption on farms has the least impact on Eutrophication index and other indexes.

According Fig. 3 triple super phosphate and nitrogen fertilizers have the greatest impact on air pollution in the cultivation of oilseed in the region.

In the research performed by Rajaiifar et al. (2014), the releases of ammonia from agricultural activities as well as the emissions from urea and potassium sulfate fertilizers for olive production had the highest share of 70.36%, 18.42%, and 5.63% [29]. In fact, the use of nitrogen and manure are the main reasons for the high ammonia emissions. The use of nitrogen fertilizers leads to NO3 emission to the soil, and $N_2O$, $NH_3$, and NOX into the atmosphere. Various influencing factors in the level of emission are fertilizer, fertilization method, fertilization time, the amount of fertilizer soil, and weather conditions [30].

## 4. CONCLUSIONS

According to the above mentioned factors, chemical fertilizers have the greatest impact on the environmental pollutant emissions. According to the results, generally the phosphate and nitrogen fertilizers and chemical pesticides are the most effective indicators of global warming, lake strangulation, human toxicity, acidification potential, ozone layer depletion, reduced organic sources, photochemical oxidation, soil poisoning, and surface poisoning of the seas. The amount of greenhouse emission for rapeseed was equal to 112.73 kg of carbon dioxide equivalent. It was also revealed that chemical fertilizer has the highest share among the evaluated inputs within the life cycle. In the production of 1 ton of rapeseed, 46.416 kg $PO_4$- was released to the environment that had eutrophication effects. Failure to properly manage the distribution and application of agricultural inputs has caused the surface waters to be more toxic and be subjected to higher risk compared with other indicators.

## 5. ACKMOWLEDGMENT

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