atmosphere

Article

Environmental Impacts of Biodiesel Production Cycle from Farm to Manufactory: An Application of Sustainable Systems Engineering

Ali Motevali [1,*], Niusha Hooshmandzadeh [1], Ebrahim Fayyazi [2], Mohammad Valipour [3,*] and Jun Yue [4]

1 Department of Biosystem Engineering, Sari Agricultural Sciences and Natural Resources University, Sari 48181-68984, Iran
2 Department of Biosystem Engineering, Tarbiat Modares University (TMU), Tehran 14115-111, Iran
3 Department of Engineering and Engineering Technology, Metropolitan State University of Denver, Denver, CO 80217, USA
4 Department of Chemical Engineering, Engineering and Technology Institute Groningen, University of Groningen, 9747AG Groningen, The Netherlands
* Correspondence: a.motevali@sanru.ac.ir (A.M.); mvalipou@msudenver.edu (M.V.); Tel.: +98-11-336-875-60 (A.M.)

Abstract: One of the key challenges in using fossil fuels is the environmental impacts of these energy sources, and to reduce these destructive effects, the use of renewable energy sources (biofuels) is necessary. One of the important biofuels is biodiesel, which can be produced from cottonseed. To properly manage the chain dealing with biodiesel production from the cottonseed chain (from farm to manufactory), environmental hotspots must be pinpointed. In the present study, it was attempted to examine the environmental impacts of the biodiesel production cycle from cottonseed (agronomic stages, ginning, oiling, and biodiesel production). The data obtained in all three stages were analyzed by the Impact 2002+ method in the SimaPro software. The highest contribution to creating environmental indicators at the agricultural stage was related to the use of nitrogen fertilizers, direct emission from the farm and fossil fuels, the ginning and oiling stage involving the use of diesel fuel and sulfuric acid, and the production of biodiesel in the manufactory involving the use of methanol and electricity. The potential environmental impacts of a functional unit of 1 kg of biodiesel include: human health, 9.05–10^{-6} (DAYLY); ecosystem quality, 1.369 (PDF*m^2*year); climate changes, (kg CO_2 eq.) 17.247; and resources (MJ primary), 89.116. Results showed that agriculture has more significant participation in the environmental impact than other sections (ginning and oiling and biodiesel production), especially due to the application of fertilizers and fuel. Surveying the environmental indicators of the results showed that at the agricultural stage, the human health indicator is 10.43, 1.21, and 5.32 times higher than the ecosystem quality, climate change, and resource indicators, respectively; at the ginning and oiling stages, it is 2.35, 31.68, and 2.09 times higher, respectively; and at the stage of biodiesel production in the manufactory, it is 16.41, 1.96, and 0.99 times higher, respectively, in terms of the destructive effects. The overall results showed that the hotspot points in the present study can be largely modified by reducing the consumption of nitrogen fertilizers, using new equipment and machinery, ginning and oiling, and using fewer methanol ratios than oil.

Keywords: air pollution; biodiesel; cottonseed; ginning and oiling; sustainability; transesterification; life cycle assessment

check for updates

Citation: Motevali, A.; Hooshmandzadeh, N.; Fayyazi, E.; Valipour, M.; Yue, J. Environmental Impacts of Biodiesel Production Cycle from Farm to Manufactory: An Application of Sustainable Systems Engineering. *Atmosphere* **2023**, *14*, 399. https://doi.org/10.3390/atmos14020399

Academic Editor: Armando da Costa Duarte

Received: 28 January 2023
Revised: 10 February 2023
Accepted: 14 February 2023
Published: 18 February 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The study of changes in trends in energy production and consumption across the world has revealed that the level of energy consumption has almost doubled in 10 years. Such a high level of energy consumption results in reduced economic growth and the production of dioxide monoxide and other air-polluting gases, environmental destruction, and increased pollution caused by energy consumption and global warming, which have caused unpredicted issues in human life in recent years. These issues can be categorized as floods, severe storms, the melting of polar ice caps and the rising of seas and oceans, forced migration, and even the aggravation of diseases [1]. The aforementioned problems have caused many countries worldwide to seek solutions to reduce or eliminate these damages, including joining treaties or agreements such as Kyoto, Paris, etc. One of the important clauses of these contracts is the gradual replacement of fossil fuels with renewable fuels, which will help to reduce the greenhouse gas emissions of participating countries [2].

Renewable energies are energy sources with low pollution (due to the closed carbon cycle); therefore, the use of renewable energies in China has reduced SO_2 emissions in China by 17%–35% [3,4]. Among the renewable energies, biodiesel and bioethanol fuels have achieved high development in different generations. Biodiesel is a type of biofuel that has properties similar to diesel fuel, and at the same time, it can be distinguished as having a small number of pollutants and toxic substances such as sulfur, nitrogen, and polycyclic aromatics, as well as having high combustion efficiency, degradability in the environment, improvement of lubrication, and higher safety [5–7]. Studies show that about 60% to 70% of the price of biodiesel production is related to its raw materials, and consequently, the use of waste and residues of agricultural products can be one of the best alternatives for providing raw materials for biodiesel production. This approach can be considered a successful step toward reducing the production cost of this product by reducing the cost of the raw material [8,9].

Moreover, one of the important elements in the production of biodiesel is the use of raw materials with less impact on food production and costs, which does not endanger human food security. Therefore, one of the important products and raw materials for the production of biodiesel is the use of cottonseed, the oil of which needs to be refined and purified for human consumption due to the presence of a toxic substance (gossypol), which causes an increase in the production cost of the edible oil extracted from the cottonseed [10]. With an annual production of 161,163 tons of cotton [11], Iran is considered the twelfth cotton-producing country in the world. Cottonseed oil can be used for biodiesel production because this oil is non-edible oil; therefore, a food versus fuel conflict will not arise if this oil is used for fuel [12].

Cotton is a dual-purpose industrial plant that plays a critical role in the textile and oil extraction industries by producing the highest quality natural fibers and oil. Studies show that the amount of oil extracted from cottonseed is around 20%, so cottonseed is a very strong source of oil and protein, and it is ranked second among the 5 important oilseeds in the world market (i.e., soybean, sunflower, almond, and rapeseed) [13]. Although biodiesel causes less environmental pollution than fossil fuels in the burning phase, it should be noted that there are discrepancies in the benefits of biodiesel fuel. One of the most important cases in the cultivation of raw materials for biodiesel production is the use of different types of fertilizers and chemical pesticides, as well as the use of different types of machines for planting, growing, and harvesting, and water consumption during the growth period of these plants, which can bear negative environmental effects [14]. Therefore, to investigate the benefits and advantages of biofuels, it is necessary to examine the environmental effects of biofuel production using raw materials (cottonseed oil) [15]. Environmental problems are considered to be systemic; therefore, their solution requires a systemic approach. Among the various methods for processes, environment-based studies, and the production of products and services is the life cycle assessment method (LCA), which is based on the international standard 14040 and also comprises a set of systematic methods for collecting and evaluating materials, input, and output energy, and environmental effects accompanied by a product production system throughout its life cycle. Accordingly, the LCA method examines the life cycle of a product from the extraction and supply of raw materials, energy production, and product production [16].

The method of IMPACT 2002+ in the life cycle impact assessment methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results. The IMPACT 2002+ method (developed at the Swiss Federal Institute of Technology) was used to quantitatively analyze the results of the LCIA. This method classifies environmental effects into 15 intermediate categories and 4 final indicators [17]. In the present study, the IMPACT 2002+ method was used to determine the environmental impacts of biodiesel production from cottonseed on climate change, human health, ecosystem quality, and resources.

In a study, the influence of the process and scale parameters on producing biodiesel from rapeseed oil using the life cycle assessment was examined. The results of the study indicated that large-scale and locally concentrated biodiesel production projects have an annual global warming potential (GWP) of 2.63 tCO_2-eq/t and 2.88 tCO_2-eq/t of biodiesel, in which the rapeseed farming stage causes more than 65% carbon emissions. Sensitivity analysis showed high dependence of GWP on canola performance, glycerol reuse strategy, and nitrogen nutrients in fertilizer [18].

The results pertinent to the assessment of the life cycle of biodiesel production using palm kernel oil and a new magnetic catalyst showed that the CML-IA base V3.06 midpoint indicators involved the cumulative abiotic reduction in fossil resources in all processes by 19,037 MJ, the global warming potential as 1114 kg of the carbon dioxide equation, and the human health toxicity for 1000 kg of biodiesel production. The highest damage in all categories was observed during the catalyst preparation and reuse, which was also confirmed in the findings of the endpoint LCA performed using ReCiPe 2016 Endpoint (E) V1.04 [19].

A plethora of studies has been conducted in line with the environmental assessment of the production of biodiesel and bioethanol using different primary sources based on the life cycle assessment method. A study [20] investigated the environmental effects of biodiesel production using the transesterification method from palm kernel oil. This study was carried out using the life cycle assessment method and the results showed that the electrical energy sector had the largest share in the emission of pollutants and adverse environmental effects. Moreover, the authors of [21] investigated the evaluation of the life cycle of cotton production in the Golsat province. The results manifested that land eutrophication and the depletion of fossil resources have the highest indicators of environmental destruction in the production of this product. In another study, the results of the environmental impacts of biodiesel production from tobacco seeds showed that the rate dealing with the destruction of environmental indicators per kilogram of biodiesel production for the indicators of human health, ecosystem quality, and resources is 1.07×10^{-5} (daily), 7.13×10^{-8} (species per year), and IRR 1.42 (MJ primary) [22]. The environmental effects of biodiesel production from soybean, Jatropha, and microalgae in China were investigated and the results showed that the environmental impacts from soy, Jatropha, and micro-algae have 54, 37.2, and 3.67 times less adverse effects than that of diesel, respectively [23]. In another study, the results of oil production from sunflower seeds showed that the environmental impacts of oil production by organic cultivation have more adverse effects than conventional cultivation [24]. The results of the environmental impacts of biodiesel production from sunflower, rapeseed, and soybean seeds showed that the highest environmental impacts in all three products were related to the agricultural stage [25]. In another study [26], the results of environmental impacts of biodiesel production from cottonseed showed that the destruction of living resources is 5.00×0^{-3} kg Sb-eq, acidification potential is 17.5 kg SO_2-eq, global warming is 1475 $kgCO_2$-eq, and eutrophication potential is 10 kg PO4-3 per ton of biodiesel production.

The results of the life cycle assessment for the bioethanol production of the second generation of raw materials (wastes and residues of bananas) showed that the second generation of ethanol derived from banana agricultural waste can reduce greenhouse gas emissions and fossil fuel consumption, and also has a positive energy balance [27]. In another study, the results showed that diesel fuel consumption and nitrogen fertilizer have the highest negative effect on environmental indicators in cotton production [28]. Moreover, researchers [29,30] presented similar results in the field of cotton production. Furthermore, the authors of [31] investigated the cost of production and emission of carbon dioxide gas in the production of biodiesel from rapeseed. The results posited that the total amount of carbon dioxide gas absorbed during the entire biological life cycle of rapeseed biodiesel is much greater than its emission, and biodiesel produced from rapeseed is an environmentally compatible energy source. The results of studies performed by Kumar Agarwal et al. [3] and Tolomelli Luiz et al. [32] showed that the use of diesel fuel and its combustion in the engine create large amounts of $PM_{2.5}$ particles suspended in the air. Examining different studies shows that there is no comprehensive research on the biodiesel production process cycle from different sources (different oils). Previous studies mainly dealt with the process of biodiesel production in the manufactories and its environmental impacts were investigated; however, one of the important steps in the production of biofuels is the investigation of operations and environmental impacts in the stages dealing with the production of the raw material (agriculture stage) of these biofuels.

The results of Jia et al. [33] showed that the use of new methods and technologies in the production of biochar can have a high-performance product that increases the absorption of pollutants and ultimately reduces the environmental effects.

The results of studies performed by Wahyono et al. [34] showed that the total human health and ecosystem quality damage of the life cycle of palm oil biodiesel production was 0.00563 DALY and 2.69×10^{-5} species·yr, respectively. Moreover, the results of Nabi et al. [12] showed that using biodiesel produced from cottonseed reduces emissions to the air from engines more than diesel fuel.

The LCA results of Roque et al. [35] showed that palm oil has an environmental performance superior to soybean oil in biodiesel production. Moreover, palm oil is capable of reducing the global warming potential by up to 75%. Palm oil can reduce environmental impacts in categories such as terrestrial acidification, ozone formation, and consumption of non-renewable resources when compared with diesel.

The results of Hoque et al. [36] showed that using ethanol (E65), electric (EV), and plug-in electric vehicle (PHEV) options can decrease global warming potential (GWP) by 40%, 29%, and 14%, respectively, which is greater than gasoline. According to the literature review, no similar studies on biodiesel production from cottonseed in Iran that employ the LCA method are extant. A few studies were conducted on a life cycle assessment of biodiesel production from cottonseed in Brazil. Therefore, the present research on the LCA of biodiesel production from cottonseed from the agricultural stage to biodiesel production filled the gap. Additionally, previous studies chose the evaluation analysis methods of environmental impacts in such a way that they mostly focused on intermediate environmental indicators. In the present study, Impact 2002+ was chosen, which shows the ultimate damage levels to human health, ecosystem quality, climate changes, carbon traces, and resource reduction for the production of biodiesel functional units. In addition, namely, chemical pesticides, machinery, all required equipment, and all environmental effects dealing with biodiesel production will be considered.

In the current research, by examining the complete cycle of biodiesel production from the cotton production farm to the production manufactory of this product, environmental hotspots caused by the use of various inputs in the agricultural, ginning, oiling, and biodiesel production section were determined.

The novelty of this work is the new analysis (midpoint categories and four damage categories) to estimate the potential environmental impacts of biodiesel production from cottonseed through life cycle assessment from the agricultural phases to biodiesel production (cotton production, ginning, cottonseed oil extraction, and transesterification) in Iran.

2. Materials and methods

2.1. Data Collection

The objective of the current study was to investigate the environmental effects of biodiesel production from cotton planting to fuel production. The present study was organized around three different sections, namely, (a) the cotton production on the farm including the planting, growing, harvesting, and transportation to cotton ginning factories, (b) the cotton-ginning factory including the cleaning, operations of separating the waste from cottonseed, and cottonseed oil extraction, and (c) the biodiesel production process following the production of oil. To investigate the environmental parameters based on several inputs (types of fertilizers and chemical pesticides, fuel, machinery, labor, and water consumption), the required information was collected by having face-to-face interactions with farmers, producers, and the Cotton Research Center of Golestan province. Moreover, in the second stage, factory data related to the separation of cottonseed waste, together with the stages of oil production from cottonseed, were collected from the experts and activists of these factories. Finally, data about the stages of transesterification reactions to produce biodiesel from cottonseed oil (number of catalysts, alcohol, reaction time, amount of electricity consumed, etc.) were obtained from academic experts dealing with the field of biodiesel fuel production.

2.2. The Life Cycle Assessment

To study the environmental effects of producing biodiesel fuel from cottonseed oil based on the standard [16], it is necessary to concentrate on four steps, including the definition of the goal and scope, analysis of the list (determination of inputs and outputs), assessment of life cycle effects, and interpretation of the results.

2.2.1. Definition of Goal and Scope

The goal of this study was to evaluate the life cycle of biodiesel production from cottonseed through the stage of planting on farms to the stage of biodiesel production (Figure 1). The boundaries of this system were considered from the cotton plant to the production of biodiesel in the manufactory, which meant that all the inputs and processes required in the biodiesel production cycle were taken into consideration. The functional unit used in the current research was considered to be 1 kg of biodiesel fuel [22].

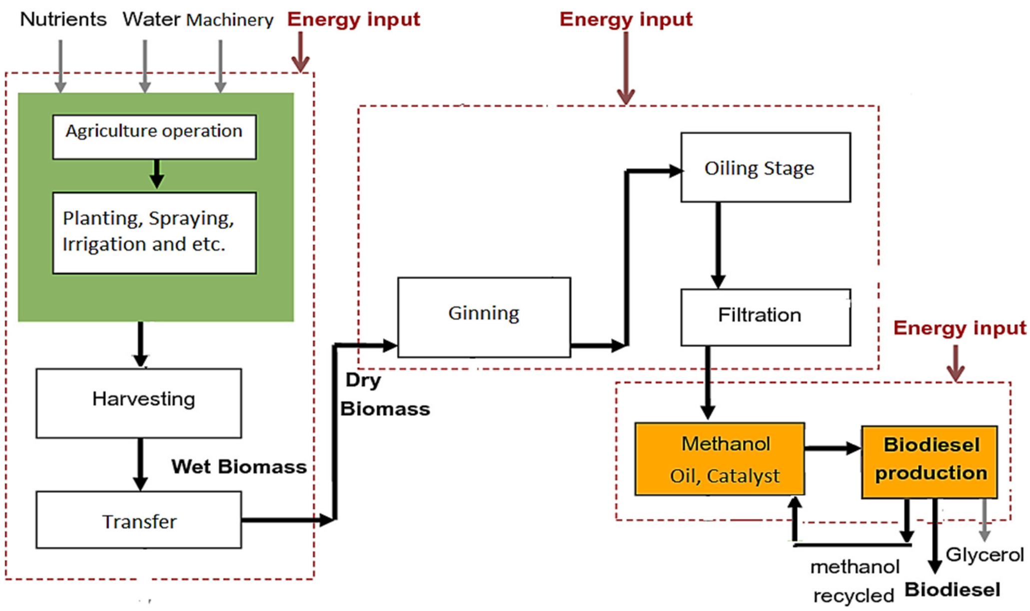

Figure 1. The complete boundary of the cycle of biodiesel production from the farm to the manufactory.

2.2.2. List Cycle Inventory

The stage of listing all required resources (inputs) and environmental emissions (outputs) in the production process and related processes was determined and cataloged.

Inventorying in the Agricultural Stage

In the present study, the data related to agricultural operations and their fuel consumption, types of fertilizers and chemical pesticides, and transportation and irrigation were collected in a face-to-face interviews. The emissions of different pollutants due to the use of different inputs to air, water, and soil were determined using the following methods. To calculate the amount of direct and indirect environmental pollutant emissions from diesel fuel concerning the inputs, electricity, agricultural machinery, and consumption of inputs (related to the production of fertilizers, pesticides, fuel, etc.), the EcoInvent International databases available in SimaPro 8.1 software were used. Moreover, the amount of pollutant emissions due to the consumption of inputs was determined using the methods incorporated in different research works. In this way, the release of phosphorus in the soil was estimated using the method provided by [37]; the release of various toxins (pesticides, fungicides, and herbicides) into the air and soil was estimated using the method provided by (Van den Berg et al.) [38]; the emission of pollutants from chemical fertilizers was estimated using the method provided by [39,40]; and the emission of carbon dioxide from human breathing during work performed in the agricultural, ginning, and oiling stages together with the biodiesel production process were calculated using the method offered by (Nguyen and Hermansen) [41].

Inventorying in the Ginning and Oiling Stage

In the stage dealing with ginning and oiling of cottonseed, after removing the external material and sifting with linters, the gin on the surface of the seed is removed as much as possible using sulfuric acid, the ginned seed is milled and peeled, and then the seed kernel together with a small amount of shell is directed to the press part of the oil extraction machine. At this stage, the kernels of cottonseed are heated up by steam at 80 °C to 100 °C and pressed by a screw press. At this stage, almost 75% of the oil is extracted from the seed and around 25% of the oil is retained in the flour; to extract it, the flour is transferred to the extraction part. At this part, the flour is subjected to the effect of a solvent (petroleum ether C.W60) and after the oil is dissolved through solvent evaporation, the crude oil is obtained. During this process, the amount of electricity, diesel, steel (used equipment), and copper (electric motors) was investigated. The indirect release of environmental pollutants caused by these inputs was estimated using EcoInvent international databases available in SimaPro 8.1 software [32], and the direct release of pollutants from the workforce was calculated using the method developed by (Nguyen and Hermansen [41].

Inventorying in the Biodiesel Production Stage

The transesterification method is commonly used among the three methods of biodiesel production (pyrolysis, microemulsion, and transesterification). Transesterification is a chemical reaction between triglyceride and alcohol in the presence of a proper reagent. This method is also called alcoholysis. Figure 2 shows the transesterification reaction.

Due to its advantages and excellence over the other methods, the transesterification method was used in the current study. Moreover, among the various methods of transesterification, transesterification with an alkaline catalyst was used based on the following advantages: (a) ability to carry out the reaction at low temperature and pressure; (b) production of biodiesel with high conversion efficiency (98%), with minimal side reactions and reaction time; (c) ability to perform direct conversion to biodiesel without the formation of any intermediate compounds; (d) with transesterification of oils, oxygen atoms in biodiesel molecules are preserved and not separated from it; and (e) production with this method requires few facilities and easier conditions. This method is more common and is used in biodiesel production factories across different countries in the world [42].

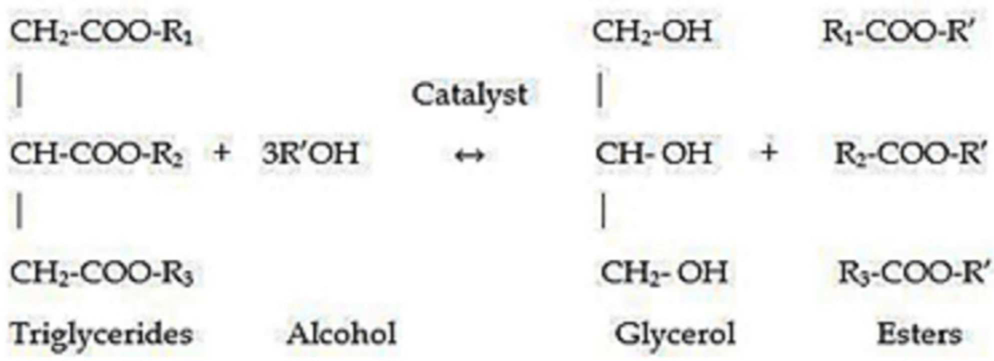

Figure 2. Transesterification reaction.

Cottonseed as the main feedstock were collected from Golestan province. Methanol (CH_3OH) with a purity of 99.9%, potassium hydroxide (KOH) as a homogeneous catalyst with a purity of 99.8%, and n-hexane with a purity of 96% as a solvent were provided by Merck Company, Germany. Moreover, phenolphthalein with a purity of 98% was used as a detector and provided by the Biochem Company of France, which is used in the current experimental work.

Biodiesel was produced using the conventional method in an 80 L stirred tank reactor (STR). Based on the literature in which a similar oil biodiesel production process was investigated, it was found that the methanol to oil molar ratio is 6:1 and the catalyst concentration is 1 (w/w%) [43]. The reaction time set was 60 min and the reaction temperature was kept at 60 °C using the water circulation method [44].

2.3. Assessment of Life Cycle Effects

The third stage in the life cycle evaluation process of biodiesel production is the effect assessment, in which the magnitude and potential environmental consequences of a system or product throughout its life cycle are valued. In the current research, the environmental effect assessment method for the production of 1 kg of biodiesel was carried out based on the Impact 2002 model [17].

2.4. Interpretation of the Results

At this stage, the environmental effects derived from biodiesel production are analyzed and the influencing factors as well as hotspots in the creation of these parameters are determined.

3. Results and Discussion

3.1. Inputs and Outputs in Three Different Biodiesel Production Processes

The number of inputs in different processes of final product production (agricultural, ginning and oiling, and biodiesel production stages) and different outputs, including the pollution and different emissions to air, water, and soil, are given in Table 1 [45–49].

The analysis of the data obtained in Table 1 shows the high transfer of phosphorus to water resources during the process of cotton production in the field, which can be reduced by controlling the use of phosphate fertilizers.

3.2. Comparing the Intermediate Indicators Affecting Human Health in Different Stages of Biodiesel Production

Examining and comparing six intermediate indicators affecting the human health index at three different stages in the biodiesel production cycle (Figure 3) showed that in five indicators, namely, the indicators of carcinogenicity, non-carcinogenicity, ionization, radiation, and the breathing of organic and mineral particles, the agricultural stage has a high contribution to the creation of these indices, and the ginning and oiling sectors had the highest effect in the creation of the ozone layer destruction index. The carcinogenicity index can be due to the inhalation of gases and particles emitted from the use of fertilizers and chemical poisons, especially nitrogen fertilizers, and also due to skin contact with these substances. Moreover, the investigation of the non-carcinogenic index showed that various pollutants in the process of biodiesel production (agricultural, ginning, oiling, and biodiesel production stages) can cause various diseases in humans by transferring pollution to water, air, and soil sources. The results of various studies showed that exposure to particles with a diameter of PM2.5 is associated with various health side effects and reduced life expectancy, including chronic and acute respiratory and cardiovascular diseases, lung cancer, diabetes, and adverse birth outcomes. According to the results obtained in Table 1, it is clear that the production of particles with a diameter of PM2.5 in the agricultural stage is much higher than the other two stages, i.e., the ginning and oiling as well as the biodiesel production sector, due to the high consumption of fossil fuel.

Table 1. The different inputs and outputs in the process of 1 kg biodiesel production.

	Input	Consumption Level		Input	Consumption Level		Input	Consumption Level
Agricultural Operations	Diesel fuel (L)	0.247	**Ginning Operation**	Diesel fuel (L)	0.456	**Biodiesel Production**	Methanol (kg)	0.250
	Nitrogen (kg)	0.259		Electricity (kWh)	0.257		Potassium hydroxide (kg)	0.011
	Phosphorus (kg)	0.142		Labor force (h)	0.090		Electricity (kWh)	0.28
	Potassium (kg)	0.183		Electro motor (kg)	0.001		Steel (kg)	0.001
	Herbicides (kg)	0.004		Steel (kg)	0.004		Electro motor (kg)	0.0001
	Fungicides (kg)	0.008		Sulfuric acid (kg)	0.320		Labor Force (h)	0.065
	Pesticides (kg)	0.003						
	Electricity (kWh)	0.299						
	Labor force (h)	0.615						
	Agricultural machinery (kg)	0.00365						
Agricultural Pollutants	**Emission to Air (kg)**							
	CO_2	2.873	**Ginning and Oiling Pollutants**	CO_2	1.386	**Biodiesel Production Pollutants**	CO_2	0.023
	N_2O	0.008		N_2O	8.82×10^{-2}		N_2O	1.31×10^{-5}
	CH_4	0.011		CH_4	7.72×10^{-3}		CH_4	8.35×10^{-3}
	PM_{10}	1.50×10^{-2}		PM_{10}	2.75×10^{-3}		PM_{10}	6.79×10^{-7}
	NOx	0.005		NOx	2.66×10^{-3}		NOx	91.0×10^{-5}
	SO_2	0.019		SO_2	0.011		SO_2	1.00×10^{-3}
	CO	2.12×10^{-2}		CO	3.86×10^{-3}		CO	2.75×10^{-6}
	NH_3	0.053		NH_3	0		NH_3	0
	Herbicides	0.51×10^{-2}						
	Fungicides	1.80×10^{-2}						
	Pesticides	0.50×10^{-2}						
	Emission toWater (kg)							
	NO^{3-}	0.158		-				-
	Phosphate	0.175		-				-
	Emission toSoil (kg)							
	Herbicides	1.97×10^{-2}		-				-
	Fungicides	4.20×10^{-2}		-				-
	Pesticides	1.16×10^{-2}		-				-

Moreover, examination of the respiration indices of organic and mineral particles shows the dispersion of primary and secondary particulates, where the primary particulates are directly emitted particles and secondary particulates are mineral particles that are formed through the reaction of chemical gases such as nitrogen oxides (NOx), sulfur oxides (SOx), ammonia (NH_3), and semi-volatile and volatile organic compounds (VOC) [50]. Organic dust is a complex mixture that is often contaminated with endotoxins, and exposure to this dust affects the development of respiratory diseases such as asthma, sensitive pneumonitis, byssinosis, chronic bronchitis, and emphysema. One of the sources of primary particle production of respirable inorganic substances is the use of fossil fuels in addition to cultivation and work at the farm level directly [51]. In addition, the application of nitrogen fertilizers has a large part to play in the production of secondary particles in this sector. Furthermore, organic dust in agricultural operations (in terms of kilograms of C_2H_4) is created due to the use of fossil fuels such as diesel, emissions of direct pollutants from the farm surface, and urea fertilizer. The obtained results also confirm the effect of these factors and the high share of the agricultural sector compared with the other two sectors in creating these indicators in the biodiesel production process.

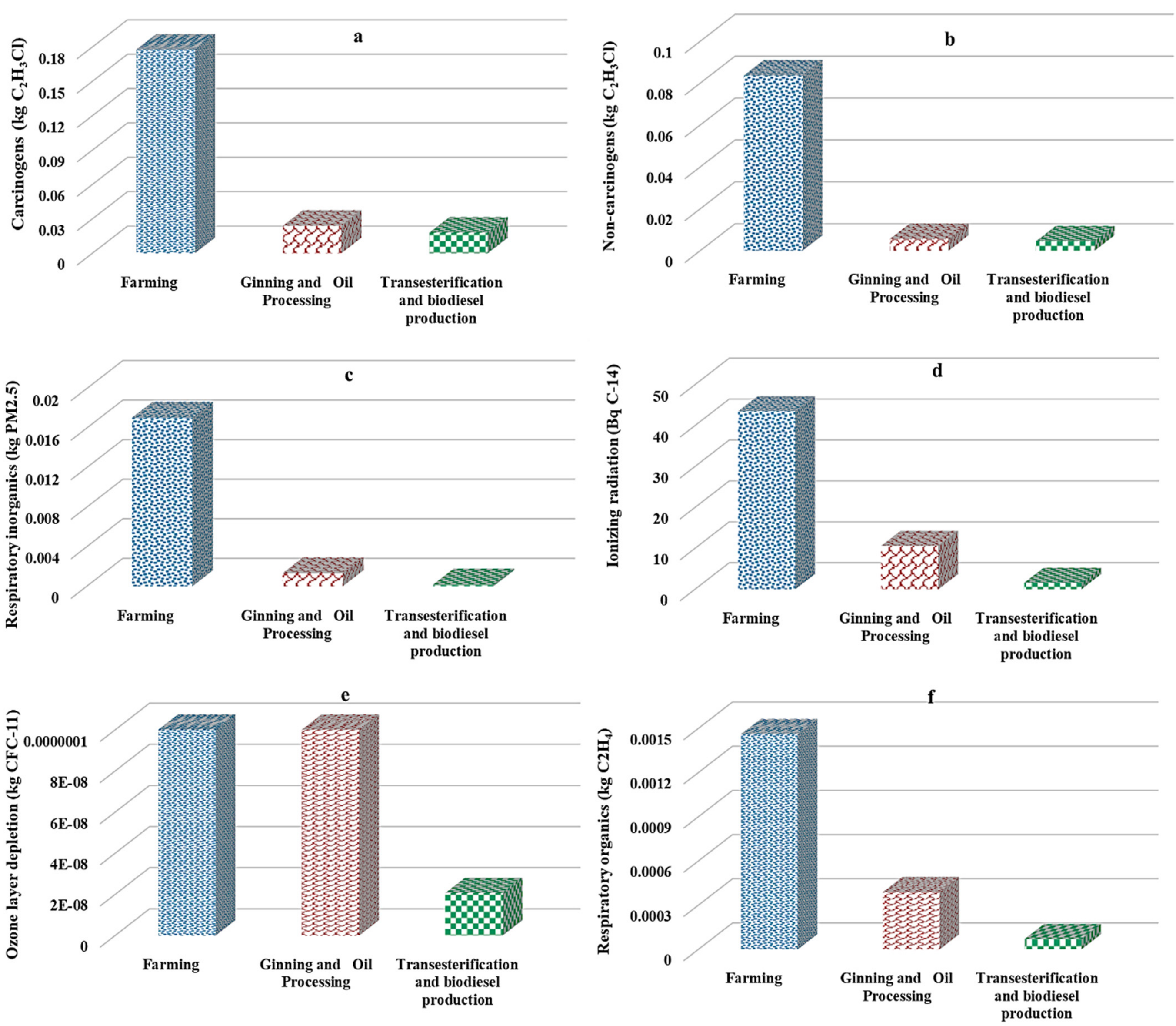

Figure 3. The effectiveness of various intermediate environmental indicators in creating the human health indicator for the production of 1 kg of biodiesel fuel. (**a**; carcinogenic), (**b**; non-carcinogenic), (**c**; respiratory inorganics), (**d**; ionizing radiation), (**e**; ozone layer depletion), (**f**; photochemical oxidation).

The destruction of the ozone layer is the result of the emission of N_2O, methane, halocarbons, methyl bromide, and methyl chloride. N_2O gas, which has a synergistic effect on the destruction of this layer, is produced by microorganisms as a result of nitrification and denitrification along with the application of nitrogen fertilizer in the soil entering the atmosphere [49]. The use of chemical fertilizers such as urea and diesel fossil fuel in the production of agricultural products also causes the production of NOx, methane, and CFC11 gases and results in their release into the atmosphere. In addition to the mentioned cases, the use of herbicides is also one of the important sources of ozone layer destruction. The analysis of the obtained results shows the high share of diesel fuel in the ginning and oiling sector of cottonseed, followed by the production of NOx, CH4, and CFC11 gases compared with the other two sectors, i.e., the agriculture sector and biodiesel production.

Finally, the index of the destruction of the ozone layer increases in the ginning and oiling sectors. In the ginning and oiling process, diesel fuel has negative adverse effects due to its high consumption in the production of hot steam and the establishment of some parts of the ginning and oiling devices. One of the important reasons for the high consumption of fuel in these processes is that ginning and oiling equipment is old and worn out. The trend of cotton planting has been declining for the past 20 years according to the statistics of Jihad Keshavarzi, and this has caused demotivation on the part of the factory owners to renew and update the relevant equipment. Moreover, the incorporation of depreciated agricultural machines, which use diesel fuel in agriculture and cotton production, can be a source of aggravation of such an effect.

By passing through the environment, ionizing rays produce negatively and positively charged particles and can reach the Earth's surface at a high level due to the destruction of the ozone layer. As the results of the previous sector show, the agricultural sector has a high level of destruction concerning the ozone layer in the biodiesel production process. Therefore, it is expected that higher levels of ionizing radiation will reach the Earth's surface. The physical effects of ionizing radiation range from partial and temporary disorders in some physiological actions to serious risks such as reduced life expectancy, reduced resistance to diseases, reduced reproductive power, cataracts, leukemia or other types of cancer, and damage to the developing fetus, which threaten human health. The present study showed that in the agriculture sector, the use of diesel and nitrogen fertilizer; in the ginning and oiling sector, the use of diesel; and in the biodiesel production sector, the use of electricity in the manufactory have the highest contributions to the generation of ionizing radiation. This can be attributed to the fact that the use of diesel, nitrogen, and electricity can cause the production of harmful gases in the ozone layer, and due to the increase in the destructive potential of this vital layer for the Earth, more ionizing lights such as the x reach the Earth from solar radiation. Since in the present study, the process of producing biodiesel from oil is performed by the transesterification method and the ratio of oil to alcohol is 5:1 [52], the consumption of methanol (volume ratio of 1:4 with oil) is high compared with other inputs in converting oil to biodiesel, and has high environmental effects compared with other inputs on environmental indicators. Moreover, since the process of converting oil to biodiesel requires a reaction temperature of about 58 °C and this temperature is provided by the elements of the system (device) using electricity, as well as the fact that the circulation of water in the system is carried out using an electric pump to maintain the reaction temperature, and on the other hand, during the reaction process, together with the fact that the mechanical stirring must also be done continuously, it is safe to conclude that electricity is another influencing factor on environmental indicators. Examining the results [22] in the production of biodiesel from tobacco seeds in the stage of biodiesel production in the manufactory showed that the use of electricity has the highest adverse environmental effects.

3.3. Comparing the Intermediate Indicators Affecting Ecosystem Quality in Different Stages of Biodiesel Production

Investigation of the toxicity indicators of water and soil environments showed that the agriculture sector has a higher share than the other two sectors, i.e., the ginning and oiling sector as well as the biodiesel production sector (Figure 4). The analysis of the results showed that in the agricultural sector, the use of nitrogen fuel, agricultural pesticides, and diesel fuel; in the ginning and oiling sector, the use of electricity and diesel fuel; and also in the biodiesel production sector, the use of methanol and electricity have high contributions to creating two indicators of water and soil toxicity environments. The examination of the number of inputs in Table 1 showed that for the production of 1 kg of biodiesel, significant amounts of nitrogen, phosphorus, and potassium fertilizers are consumed. The use of these fertilizers transfers significant amounts of heavy metals (Pb, Cd, As, Zn, and Ni) to the soil [53]. Moreover, the excessive use of pesticides in the cotton plant pollutes the soil with a heavy accumulation of metals, stable organic compounds, etc. Groundwater is also polluted due to the use of chemical fertilizers (nitrogen, phosphorus, and potash) and the transfer and migration of heavy metals through the soil to the surface and underground water.

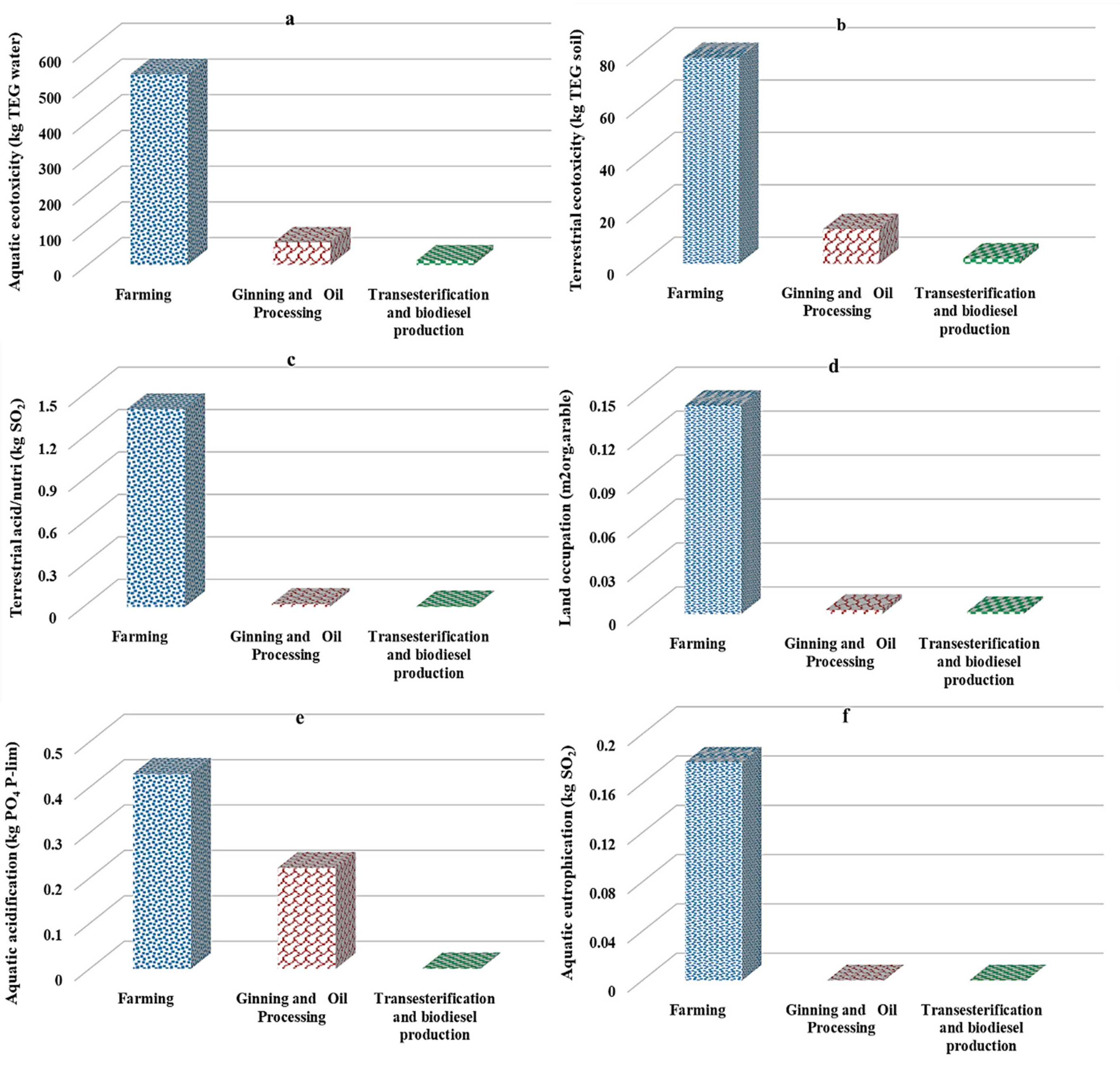

Figure 4. The effect of different parameters on creating the ecosystem quality in the process of producing oil from cottonseed per kilogram of biodiesel fuel. (**a**; aquatic ecotoxicity), (**b**; terrestrial ecotoxicity), (**c**; terrestrial acidification/nutrification), (**d**; land occupation), (**e**; aquatic acidification), (**f**; aquatic eutrophication).

The analysis of the obtained results showed that in the agricultural stage, it is the direct pollutants from the farm level; in the ginning and oiling stage, it is the production pollutants from the manufactory level; and in the biodiesel production stage, it is the electricity consumption to convert oil into biodiesel that have the highest shares in creating an indicator of acidification of water and soil environments. Acidification is the result of the production of NH_3, SO_2, NO_X, and NO gases, and in the agricultural sector, due to the consumption of nitrogen fertilizers and fossil fuels (diesel), these polluting gases are released into the air [54]. These emissions are acidified by a complex set of atmospheric and chemical transfer processes, and this in turn creates harmful effects on ecosystems, and plant and animal populations [55]. Although ammonia is alkaline, it is oxidized to nitric acid in the atmosphere and along with other gases reaches the Earth's surface as acid rain after reacting with air molecules [56]. Moreover, sedimentation of these pollutants in the soil causes soil acidification after exceeding the natural neutralization capacity of the soil, which can reduce soil fertility [57]. Additionally, in the ginning and oiling sector, existing methods in ginning such as the mechanical method (brushed ginning machine) and thermal method (use of flame) do not outperform the chemical method (use of sulfuric acid) in cleaning the cottonseed, and the use of acid causes the production of clean seeds suitable for oiling or seed preparation. At the same time, an examination of the environmental indicators posited that the use of sulfuric acid for ginning operations has a high contribution to creating the ecosystem quality indicator. Analysis of the results [20] in the production of biodiesel from tobacco seeds in the breaking and oiling stage illustrated that the use of electricity and LPG gas will have the highest adverse environmental effects. Moreover, exploring the results of the study [58] concerning the process of ginning cottonseed showed that electricity has the highest share of the energy consumed in this process.

An examination of the water enrichment indicator in the biodiesel production cycle shows that in the agricultural sector, it is the direct pollutants from the farm surface; in the ginning and the oiling sector it is the diesel fuel consumption; and in the biodiesel production sector, it is the consumption of electricity and methanol that have high percentages in creating such an indicator. The main source of eutrophication is phosphorus, which is caused by the production of pollutants due to the high consumption of phosphorus chemical poisons that are created for excluding insects and fungi at the farm level. Eutrophication refers to the enrichment of the water body by incoming organic matter or surface runoff containing nitrates and phosphates, which directly controls the growth of algae and other aquatic plants. This process happens naturally but slowly and with a period of more than a hundred years, however, human activities accelerate this process [58]. Furthermore, one of the important factors causing nitrates to enter the water is the use of nitrogenous fertilizers, which are used for the fertility of agricultural farms and increasing production efficiency. Research has shown that 30% to 40% of the nitrogen used in the farm is released into the environment in the form of NH3, nitrogen oxides (NO, N_2O, and NO_2), and molecular and leaching nitrogen in the form of nitrate and ammonium [59]. Nitrification and denitrification are the two important stages of converting nitrogen into these forms in farms. Phosphorus is considered another factor of eutrophication. Such an element in water originates from an external source and is absorbed by algae in mineral form (PO_4^{3-}) and enters the structure of organic compounds. The use of phosphate fertilizers and their leaching from agricultural farms is one of the main sources of phosphate entering water sources.

Moreover, exploring the land use change indicator in the biodiesel production cycle showed that in the agricultural sector it is the use of nitrogen; in the ginning and oiling sector it is the use of diesel fuel and electricity; and in the biodiesel production sector it is the use of electricity that have the highest contributions to creating this indicator.

3.4. Comparing the Intermediate Indicators Affecting Climate Change in Different Stages of Biodiesel Production

Studying the global warming indicator in the biodiesel cycle production process (Figure 5) showed that it is the direct emissions from the farm in the farming, ginning, and oiling stage, and the use of electricity in the biodiesel production stage, that are counted as the inputs affecting this indicator. Nitrous oxide (N_2O), a gas affecting global warming, has a 6% greenhouse effect (radiative forcing) and can absorb infrared rays 298 times more than carbon dioxide [60]. This gas enters the atmosphere mainly during the process of nitrification in the nitrogen cycle. Moreover, the combustion of fossil fuels and the use of nitrogenous chemical fertilizers in the process of cotton cultivation is among the most important sources. Nitrous oxide gradually enters the stratosphere after deionization from the biosphere and lasts for about 150 years in the atmosphere [60]. Furthermore, the production of CH_4 gas in the agriculture, ginning, and oiling sectors is the result of the high consumption of diesel fuel and its combustion, which is because agricultural equipment and machines are worn out in the farm sector, as well as the fact that cotton machines are worn out due to lack of updating of this equipment in the ginning sector. The consumption of this fuel has caused the creation of pollutants at the farm and manufactory level, which can increase the contribution of direct emissions from the farm level to the global warming indicator.

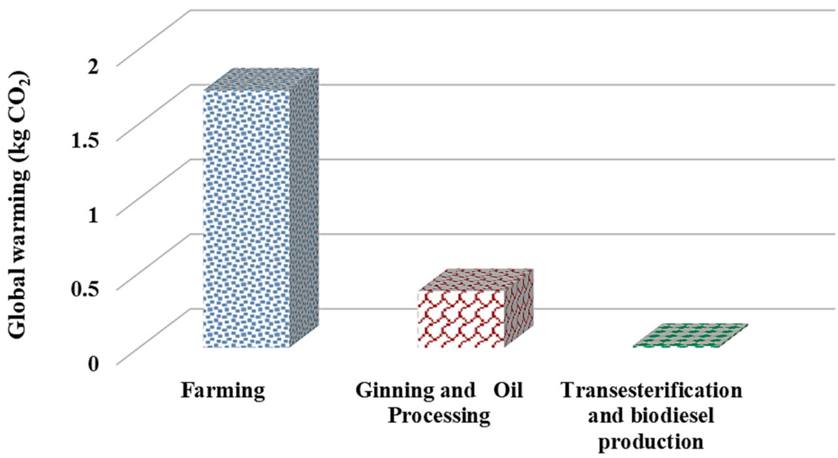

Figure 5. The effect of different parameters entering the manufactory on creating climate change in the process of converting oil to biodiesel for the production of 1 kg of biodiesel fuel.

3.5. Comparing the Intermediate Indicators Affecting Depletion of Resources in Different Stages of Biodiesel Production

An investigation of the non-renewable energy indicator postulated that it is the use of diesel fuel in the stages of agriculture, ginning, and oiling, and it is the use of methanol in the biodiesel production stage that have the highest contributions to the creation of this indicator. Moreover, the results of the investigation concerning the mineral extraction indicator showed that it is the use of nitrogen fertilizer in the agricultural stage, the use of sulfuric acid to separate gins from cottonseed, and the use of methanol in the biodiesel production sector in the manufactory that have the highest contributions to creating this indicator (Figure 6). As it is known, diesel fuel is one of the important non-renewable sources and is used in agricultural equipment and machines, and at the same time, it is also widely used in cotton-picking machines. One of the ways to reduce these indicators, in addition to using new equipment in the farming process, is to offer driving training to tractor drivers in the process of tilling, planting, and growing, and to consider suitable patterns for such an operation to reduce the amount of traffic at the farm level.

The study and comparison of environmental indicators [26] in the cycle of biodiesel production from cottonseed in Brazil in three stages (agriculture, ginning, and oiling as well as biodiesel production or transesterification) showed that the agricultural sector and the production of cotton or cottonseed on farms have the highest contributions to the destruction of living (biological) resources, global warming, acidification, and land enrichment, followed by the production of biodiesel or transesterification, ginning, and oiling. This is in line with the results obtained in the current study. Furthermore, the findings of the present study conform to the ones reported by [23] in producing biodiesel from soy, Jatropha, and microalgae.

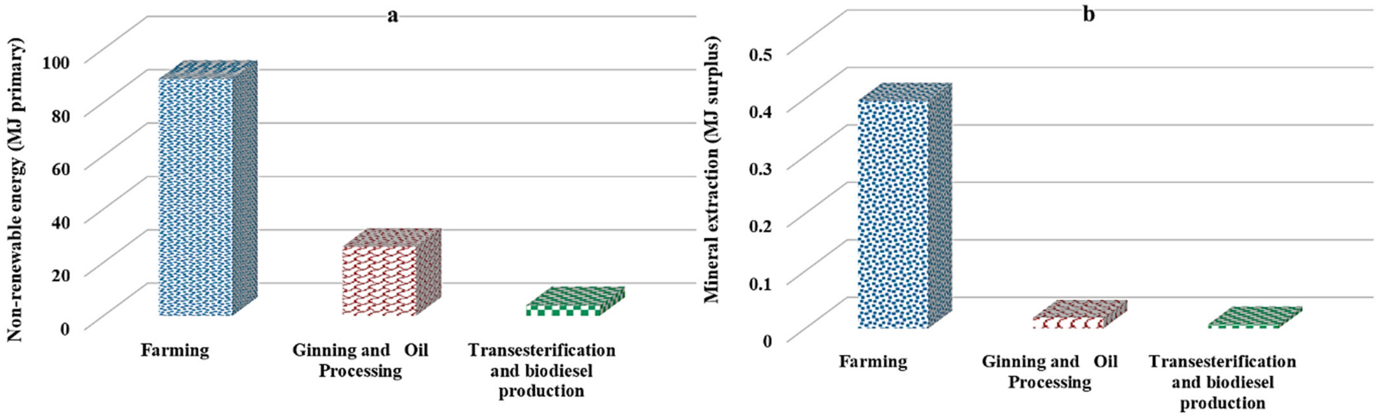

Figure 6. The effect of all input parameters from the farm to the manufactory on creating the depletion of resources for the production of 1 kg of biodiesel fuel. (**a**; non-renewable energy consumption), (**b**; mineral extraction).

3.5.1. Evaluation of Damage Category

Examining the damage category or the long-term effects of the biodiesel production cycle from the farm to the manufacturer showed that direct pollution has the highest contribution to the destruction of categories such as human health, ecosystem quality, and climate change, while the highest share in the destruction of resources is related to diesel fuel. A more detailed examination of the results shows (Table 2) that diesel fuel, nitrogen fertilizer, and electricity have the highest share of inputs in the destruction of damage category, and following the consumption of these inputs, the amount of direct pollutants increases in different agriculture stages. One of the environmental hot spots is the consumption of diesel fuel, which is the main reason for the wear of agricultural equipment and machines, as well as ginning and oiling equipment. Moreover, the use of nitrogen fertilizers has highly destructive effects, which should be replaced with animal manure or other organic fertilizers to reduce their harmful effects.

Table 2. The effect of different inputs on the biodiesel production process from field to manufactory on final environmental indices.

Damage Category	Human Health	Ecosystem Quality	Climate Changes	Resources
Unit	Daily	PDF*m^2*year	kg CO_2 eq	MJ Primary
Total	1.27×10^{-5}	2.257	17.247	89.116
Direct emission	9.05×10^{-6}	1.369	13.302	0
Diesel	4.27×10^{-7}	0.175	0.393	40.550
Nitrogen fertilizer	1.54×10^{-6}	0.422	2.170	19.521
Phosphate fertilizer	5.26×10^{-7}	0.097	0.281	5.159
Potassium fertilizer	8.76×10^{-8}	0.026	0.095	1.674
Pesticides	3.78×10^{-8}	0.005	0.026	0.501
Herbicides	3.10×10^{-10}	0.005	0.035	0.675
Fungicides	1.48×10^{-7}	0.045	0.047	0.993
Steel	1.56×10^{-8}	0.004	0.009	0.103
Copper	1.58×10^{-8}	0.012	0.002	0.054
Methanol	2.47×10^{-7}	0.019	0.104	6.788
Potassium hydroxide	2.01×10^{-8}	0.003	0.021	0.327
Sulfuric acid	1.77×10^{-7}	0.036	0.048	2.278
Electricity	5.27×10^{-7}	0.072	0.758	12.768

3.5.2. Human Health

An investigation of the impact of different inputs on the human health category shows that the consumption of different inputs causes direct emissions (pollution and various gases due to fuel combustion in the tractor engine on the farm and the machine engine in the ginning process, and heavy metal pollution due to the use of various fertilizers and chemical pesticides, etc.) and indirect emissions (pollutions related to electricity in power plants and the production of agricultural machines in factories, etc.).

3.5.3. Ecosystem Quality

The investigation of the ecosystem quality category showed that the use of nitrogen and phosphate fertilizers, diesel fuel, and electricity produces pollution that will reduce plant growth and plant diversity (the number of species that grow in a certain period in a certain area is reduced or lost) and the plant ecosystem suffers from disruption in growth and development. Thus, the quality of the ecosystem decreases with the increase in the number of pollutants. Moreover, the direct or indirect use of fossil fuels in the production process of biodiesel fuel, as well as the production of gases such as N_2O due to the use of nitrogen fertilizers, have high impacts on the creation of this category. It should be noted that the excessive use of agricultural inputs causes pollution such as carbon dioxide, methane, nitrous oxide, ammonia, etc., released into the air, and pollution such as heavy metals, nitrates, phosphates, etc., released into to the water and soil. The spread of emissions from the farm level causes direct emissions and after that, it can have many negative effects on the environmental indicators.

3.5.4. Resources

Examining the resources category showed that the highest contribution to the creation of the category was related to diesel fuel. Moreover, this input provides the highest amount of energy required to create new resources (the energy required for extracting fossil fuels and mining in the future).

3.5.5. Climate Change

The results in the ginning and oiling process show that the climate change category has the highest adverse environmental effects compared with the other three indices (human health, ecosystem quality, and resources). Therefore, the category of climate change has more destructive effects than the indicators of human health, ecosystem quality, and resources, respectively, 2.35, 31.68, and 2.09 times. Among the reasons for these results, we can point out the use of diesel fuel and the subsequent production of many polluting gases such as carbon dioxide, methane, and nitrous oxide (Table 1), and these gases have a high potential to cause global warming and then climate change. In order to reduce the amount of destruction, electric systems can be used instead of diesel engines to start the equipment, and this factor can reduce the amount of pollutants and reduce the amount of destruction.

3.6. Evaluation of Damage Category

A comprehensive examination of the final and weighted environmental effects on the production process of the biodiesel cycle from the farm to the manufactory in Figure 7 shows that the highest and lowest levels of destruction are related to the human health indicator and ecosystem quality, respectively. Moreover, the results depicted that the human health indicator has more destructive effects when compared with indicators of ecosystem quality, climate change, and resources, respectively, shown as 10.84, 1.03, and 3.05 times. Factors affecting the human health indicator include the carcinogenic and non-carcinogenic categorized groups, inhalation of mineral and organic substances, ionizing radiation, and destruction of the ozone layer. Moreover, the group affecting the climate change indicator includes the global warming category.

One of the reasons for the high rate of destruction of human health indicators and climate change is direct pollutants from the farm level due to the consumption of diesel fuel, fertilizers, and chemical pesticides. These pollutants include various gases such as carbon dioxide, nitrous oxide, methane, suspended particles in the air, heavy metals in water and soil, etc., which can increase the destroying level of human health indicators and climate change. Moreover, factors affecting the ecosystem quality indicator include land use change, soil and water environment toxicity, water enrichment, and soil acidification/nitrification. In addition, factors such as nitrates, phosphates, sulfur dioxide gases, etc., intensify the destruction of this indicator. Furthermore, the influencing factors on the resources indicator include the groups of non-renewable energies and the extraction of mineral materials, where a high consumption of diesel fuel and electricity, as well as the consumption of fertilizers and chemical pesticides, can give rise to the destruction rate of this indicator. Studies show that due to the use of a high ratio of methanol to oil, one can expect higher environmental effects. Since this ratio (oil to alcohol 5:1) was obtained from the research conducted by [52], it should be noted that to reduce the consumed methanol, experiments with other levels of oil to alcohol ratio should be used to obtain the best conversion coefficient of biodiesel and to reduce the environmental effects concerning the production of this product. Another solution is to use more modern methods with lower energy consumption and less need for additional alcohol compared with the stoichiometry of the reaction, in which the ratio of alcohol to oil is 3:1 [44].

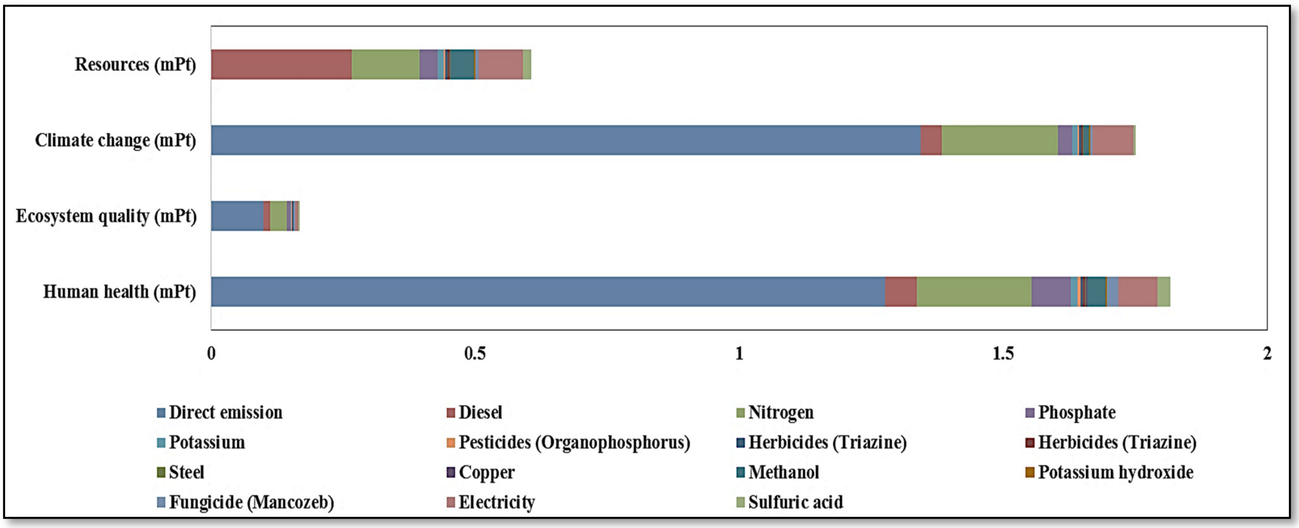

Figure 7. The contribution of different inputs in the complete cycle of fuel production concerning the damage category in the production of 1 kg of biodiesel.

Furthermore, an examination of Figure 7 shows that the agricultural sector has the highest share of destruction in environmental indicators compared with the other two sectors (ginning, oiling, and biodiesel production in the manufactory). The results of the research performed by [25] showed that the highest factor in creating the indicator of ecosystem quality destruction lies in the production of biodiesel from sunflower seeds, soy, and rapeseed, respectively, at the rates of 48.6%, 35.6%, and 12.5%, dealing with the agricultural process and seed production at the farm level. In addition, the results reported by [24] concerning the production of biodiesel from sunflower seeds showed that the highest share of the destruction of environmental indicators was respectively the quality of the ecosystem, resources, and human health, which was one of the most important reasons for the results obtained concerning the consumption of fertilizers, chemical pesticides, and the consumption of diesel fuel in the biodiesel production process.

3.7. Comparison of the Results of the Present Study with Other Studies

The results of Carvalho et al. [22] showed that the rate dealing with the destruction of environmental indicators per kilogram of biodiesel production for the indicators of human health, ecosystem quality, and resources is 1.07×10^{-5} (daily), 7.13×10^{-8} (species per year), and IRR 1.42 (MJ primary). The results of the environmental impacts of biodiesel production from sunflower, rapeseed, and soybean seeds [25] showed that the highest values were related to the agricultural stage. Furthermore, the results of the evaluation concerning the environmental effects of biodiesel production from the cottonseed in Brazil showed that the agricultural stage has the highest environmental adverse effects share compared with other stages such as the ginning, oiling, and performing the biodiesel production reactions [26]. Outcomes of the present study indicated that in the process of biodiesel production from the cottonseed, the agricultural sector has the highest share of pollutants and environmental effects. The results of the study conducted by [24] illustrated that in the process of biodiesel production from sunflowers, the agricultural stage has the highest share in creating intermediate environmental indicators. Moreover, an examination of the damage levels posited that the resource damage level creates the highest share. Findings of the study performed by [18] concerning the biodiesel production from rapeseed oil on small and large scales showed that the energy required in the process of biodiesel production in the manufacturing and the agricultural sector has the highest share in the biodiesel production cycle. Meanwhile, the greenhouse pollutant gases in the agricultural stage created 81% and 69% of the total produced greenhouse gases on small and large scales, respectively. Findings of the study undertaken by [34] concerning biodiesel production from palm demonstrated that the highest share of environmental effects pertains to the palm production stage in the agricultural sector, and other stages such as the oiling, ginning, and biodiesel production have lower environmental effects. In addition, examining the ultimate damage levels in three levels, namely, human health, ecosystem quality, and resources showed that the agricultural sector causes the highest damage. The results of this research are important to meet the sustainable development goals in the era of global warming and climate change [61–64].

4. Conclusions

The present study was conducted to investigate the environmental impacts of the biodiesel production cycle from cottonseed (agronomic stages, ginning and oiling, and production of biodiesel), and the results were compared with each other in the form of four final environmental indicators (human health, ecosystem quality, climate change, and resources).

The examination of the greenhouse pollutant gases in each of the three levels dealing with biodiesel production indicated that CO_2 and N_2O have the highest effects in creating adverse environmental indicators, respectively. Moreover, a comparison of the intermediate indicators in every three levels of biodiesel production showed that the agricultural sector (cottonseed production stage) has the highest share of adverse environmental effects compared with other levels. The investigation of the ultimate levels of damage showed that human health and climate changes experience the highest levels of destruction in biodiesel production.

Wahyono et al. [34] showed that the total human health and ecosystem quality damage of the life cycle of palm oil biodiesel production was 0.00563 DALY and 2.69×10^{-0} species·yr, respectively. Moreover, the results of Lima et al. [26] showed 5.0×10^{-3} kg Sb-eq. for the abiotic depletion potential; 1475 kg CO_2-eq. for global warming potential; 17.5 kg SO_2-eq. for acidification potential; and 10 kg PO_4^{3-}-eq. for eutrophication potential. The above data are lower than the environmental impact of biodiesel production from cottonseed in Iran. The reason for these results in Iran was the indiscriminate use of chemical fertilizers, as well as the use of worn-out agricultural machines and oil extraction equipment.

For more adaptation of the biodiesel production process to the environment, one can lower the use of fertilizers such as urea and apply manures instead. Furthermore, one can use power sourced from renewable resources such as the use of photovoltaic systems instead of power sourced from non-renewable resources. Finally, yet importantly, one can use different processes and technologies in biodiesel production intensification, such as cavitation, ultrasonic, microwave, etc., phenomena instead of the conventional process of biodiesel production to reduce both the energy consumption and environmental impacts.

Author Contributions: A.M., conceptualization, supervision, validation, review and editing, writing—original draft. N.H., conceptualization, methodology, software, investigation, formal analysis, validation, visualization. E.F., conceptualization, supervision, validation, review and editing. M.V., validation, review and editing. J.Y., methodology, review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: The authors would like to thank the Sari Agricultural Sciences and Natural Resources University (SANRU) for financial support of this research under contract number 02-1401-06.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data can be provided upon request.

Acknowledgments: We gratefully acknowledge the support provided by the Sari Agricultural Sciences and Natural Resources University.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. IEA. *Energy and Air Pollution, World Energy Outlook Special Report*; International Energy Agency 9 rue de la Federation 75739: Paris, France, 2016.
2. Kazemi, A.; Mehregan, M.R.; Shakouri, H.G. An Energy Supply Model of Iran Aiming to Reduce Greenhouse Gases. *J. Indust. Engin.* **2012**, *46*, 63–75. (In Persian)
3. Agarwal, A.K.; Das, L.M. Biodiesel development and characterization for use as a fuel in compression ignition engine. *J. Eng. Gas Turbines Power.* **2001**, *123*, 440–447. [CrossRef]
4. Haghighi, A.; Babapoor, A. Using of renewables energies such as effective way to reduce environmental pollution. *Renew. Energy Quart.* **2018**, *5*, 40–50. (In Persian)
5. Rajaeeifar, M.A.; Akram, A.; Ghobadian, B.; Rafiee, S.; Abdi, R. Energy and economic assessment of biodiesel production from olive pomace oil: A lifecycle approach. *Biosys. Eng.* **2015**, *46*, 209–218. (In Persian) [CrossRef]
6. Makareviciene, V.; Skorupskaite, V.; Levisauskas, D.; Andruleviciute, V.; Kazancev, K. The optimization of biodiesel fuel production from microalgae oil using response surface methodology. *Int. J. Green Energy* **2014**, *11*, 527–541. [CrossRef]
7. Shahid, E.M.; Jamal, Y. Production of biodiesel: A technical review. *Renew. Sust. Energy Rev.* **2011**, *15*, 4732–4745. [CrossRef]
8. Zahedi, A.; Mirabdoli, M.; Shayan Nezhad, A. Commercial optimization of biodiesel production from rapeseed oil as a clean fuel for thermal power plants. *Modares Mech. Eng.* **2016**, *16*, 135–142. (In Persian)
9. Enweremadu, C.C.; Mbarawa, M.M. Technical aspects of production and analysis of biodiesel from used cooking oil-A review. *Renew. Sust. Energy Rev.* **2009**, *13*, 2205–2224. [CrossRef]
10. Najafi, M.A.; Haddad Khodaparast, M.H. Production of edible Cottonseed protein concentrates by Mixed Solvent (Water: Acetone: Hexane). *Agriculture* **2005**, *7*, 45–51. (In Persian)
11. Ministry of Agriculture Jihad. *Statistics of Agricultural Products*; Ministry of Agriculture Jihad: Tehran, Iran, 2015. (In Persian)
12. Nabi, N.; Rahman, M.; Akhter, S. Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions. *Appl. Therm. Eng.* **2009**, *29*, 2265–2270. [CrossRef]
13. Ahmadi, M.; Agha Alikhani, M. Energy use analysis of cotton production in Golestan Province and a few strategies for increasing resources productivity. *Agroecology* **2012**, *4*, 151–158. (In Persian)
14. Crutzen, P.J.; Mosier, A.R.; Smith, K.A.; Winiwarter, W. N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmos. Chem. Phys.* **2008**, *8*, 389–395. [CrossRef]
15. Thorn, M.J.; Kraus, J.L.; Parker, D.R. Life-Cycle Assessment as a Sustainability, Management Tool: Strengths, Weaknesses, and Other Considerations. *Environ. Quality Manag.* **2010**, *20*, 20285. [CrossRef]
16. *ISO 14040*; International Standard, Environmental Management- Life Cycle Assessment- Principles and Framework. International Organization for Standardization: Geneva, Switzerland, 2006.
17. Jolliet, O.; Margni, M.; Charles, R.; Humbert, S.; Payet, J.; Rebitzer, G.; Rosenbaum, R. Impact 2002: A new life cycle impact assessment methodology. *Int. J. Life Cycle Assess.* **2003**, *8*, 324. [CrossRef]
18. Gupta, R.; McRoberts, R.; Yu, Z.; Smith, C.; Sloan, W.; You, S. Life cycle assessment of biodiesel production from rapeseed oil: Influence of process parameters and scale. *Biores. Technol.* **2022**, *360*, 127532. [CrossRef]
19. Al-Mawali, K.; Osman, A.; Al-Muhtaseb, A.; Mehta, N.; Jamila, F.; Mjallia, F.; Vakili-Nezhaad, R.; Rooney, D. Life cycle assessment of biodiesel production utilising waste date seed oil and a novel magnetic catalyst: A circular bioeconomy approach. *Renew. Energy* **2021**, *170*, 832–846. [CrossRef]
20. Zolghadr, M.; Hassan-beigi, S.R.; Kianmehr, M.H. Life Cycle Assessment (LCA) of Biodiesel Production from Date Pit Oil. In Proceedings of the 10th International Conference on Internal Combustion Engines, Tehran, Iranian Society of Engines Sciences, Tehran, Iran, 13–15 February 2017. (In Persian)
21. Khojastehpour, M.; Taheri-Rad, A.; Nikkhah, A. Life cycle assessment of cotton production in Golestan province based on the production of biomass, energy and net income. *Biosys. Eng.* **2015**, *46*, 95–104. (In Persian) [CrossRef]
22. Carvalho, F.S.; Fornasier, F.; Leitao, J.O.M.; Moraes, J.A.R.; Schneider, R.C.S. Life cycle assessment of biodiesel production from solaris seed tobacco. *J. Cleaner Prod.* **2019**, *230*, 1085–1095. [CrossRef]

23. Hou, J.; Zhang, P.; Yuan, X.; Zheng, Y. Life cycle assessment of biodiesel from soybean, jatropha and microalgae in China conditions. *Renew Sust. Energy Rev.* **2011**, *15*, 5081–5091. [CrossRef]
24. Spinelli, D.; Jez, S.; Basosi, R. Integrated Environmental Assessment of sunflower oil production. *Process. Biochem.* **2011**, *47*, 1595–1602. [CrossRef]
25. Sanz Requena, J.F.; Guimaraes, A.C.; Quirós Alpera, S.; Relea Gangas, E.; Hernandez-Navarro, S.; Navas Gracia, L.M.; Martin-Gil, J.; Fresneda Cuesta, H. Life Cycle Assessment (LCA) of the biofuel production process from sunflower oil, rapeseed oil and soybean oil. *Fuel Process. Technol.* **2011**, *92*, 190–199. [CrossRef]
26. Lima, A.M.F.; Torres, E.A.; Kiperstok, A.; De Freitas Moreira Santos, G. Environmental impacts of the biodiesel production chain of cotton seed in Bahia, Brazil. *Clean Technol. Environ. Policy* **2017**, *19*, 15–23. [CrossRef]
27. Guerrero, A.B.; Muñoz, E. Life cycle assessment of second generation ethanol derived from banana agricultural waste: Environmental impacts and energy balance. *J. Cleaner Prod.* **2018**, *174*, 710–717. [CrossRef]
28. Bevilacqua, M.; Emanuele Ciarapica, F.; Mazzuto, G.; Paciarotti, C. Environmental analysis of a cotton yarn supply chain. *J. Cleaner Prod.* **2014**, *82*, 154–165. [CrossRef]
29. Matlock, M.; Nalley, L.; Clayton-Niederman, Z. *Carbon Life Cycle Assessment of United States Cotton: A View of Cotton Production Practices and Their Associated Carbon Emissions for Counties in 16 Cotton Producing States*; Cotton Incorporated, Center for Agricultural and Rural Sustainability University of Arkansas Division of Agriculture: Arkansas, AR, USA, 2009.
30. Ismail, S.; Chen, G.; Baillie, C.; Symes, T. Energy uses for cotton ginning in Australia. *Biosys. Eng.* **2011**, *109*, 140–147. [CrossRef]
31. Li, N.; Guo, Y. Life Cycle Assessment of Rapeseed Biodiesel. *World Elec. Vehicle J.* **2010**, *4*, 804–808. [CrossRef]
32. Tolomelli Luiz, G.; Barreta Pedro, T.; Lacava Dermeval Carinhana, J. Study of the Influence of Biodiesel in Soot Emissions of Diesel Laminar Diffusion Flames. *J. Brazilian Chem. Soci.* **2017**, *28*, 1384–1388. [CrossRef]
33. Jia, L.; Cheng, P.; Yu, Y.; Chen, S.H.; Wang, C.X.; He, L.; Nie, H.T.; Wang, J.C.; Zhang, J.C.; Fan, B.G.; et al. Regeneration mechanism of a novel high-performance biochar mercury adsorbent directionally modified by multimetal multilayer loading. *J. Environ. Manag.* **2023**, *15*, 326–116790. [CrossRef]
34. Wahyono, Y.; Hadiyanto, H.; Budihardjo, M.A.; Adiansyah, J.S. Assessing the Environmental Performance of Palm Oil Biodiesel Production in Indonesia: A Life Cycle Assessment Approach. *Energies* **2020**, *13*, 3248. [CrossRef]
35. Roque, L.F.A.; da Costa, R.B.R.; de Souza, T.A.Z.; Coronado, C.J.R.; Pinto, G.M.; Cintra, A.J.A.; Raats, O.O.; Oliveira, B.M.; Frez, G.V.; Alves, L.F.R. Experimental analysis and life cycle assessment of green diesel (HVO) in dual-fuel operation with bioethanol. *J. Cleaner Prod.* **2023**, *389*, 135989. [CrossRef]
36. Hoque, N.; Biswas, W.; Mazhar, I.; Howard, I. Environmental Life Cycle Assessment of Alternative Fuels for Western Australia's Transport Sector. *Atmosphere* **2019**, *10*, 398. [CrossRef]
37. Nemecek, T.; Kagi, T. Life cycle inventories of agricultural production system. *Final. Rep. Ecoinvent* **2007**, *15*, 1–360.
38. Van den Berg, F.; Kubiak, B.W.G.; Majewski, M.S.; Yates, S.R.; Reeves, G.L.; Van der Linden, A.M.A. Emission of pesticides into the air. *Water Air Soil Poll.* **1999**, *115*, 195–218. [CrossRef]
39. Buendia, H.S.; Miwa, K.; Ngara, T.; Tanabe, K. (Eds.) IPCC, Guidelines for national greenhouse gas inventories. In *Eggleston, Prepared by the National Greenhouse Gas Inventories Programme*; IGES: Kanagawa, Japan, 2006.
40. Mousavi-Avval, S.H.; Rafiee, S.; Sharifi, M.; Hosseinpour, S.; Shah, A. Combined application of Life Cycle Assessment and Adaptive Neuro-Fuzzy Inference System for modeling energy and environmental emissions of oilseed production. *Renew. Sust. Energy Rev.* **2017**, *78*, 807–820. [CrossRef]
41. Nguyen, T.L.T.; Hermansen, J.E. System expansion for handling co-products in LCA of sugar cane bio-energy systems: GHG consequences of using molasses for ethanol production. *Appl. Energy* **2012**, *89*, 254–261. [CrossRef]
42. Fayyazi, E.; Ghobadian, B.; Mousavi, S.M.; Najafi, G. Intensification of continues biodiesel production process using a simultaneous mixer-separator reactor. *Energy Sources Part A: Rec. Util. Environ. Eff.* **2018**, *40*, 1125–1136. [CrossRef]
43. Farvardin, M.; Hosseinzadeh Samani, B.; Rostami, S.; Abbaszadeh-Mayvan, A.; Najafi, G.; Fayyazi, E. Enhancement of biodiesel production from waste cooking oil: Ultrasonic-hydrodynamic combined cavitation system. *Energy Sources Part A: Rec. Utilize. Environ. Eff.* **2022**, *44*, 5065–5079. [CrossRef]
44. Fayyazi, E.; Ghobadian, B.; Najafi, G.; Hosseinzadeh, B. Genetic algorithm approach to optimize biodiesel production by ultrasonic system. *Chem. Prod. Process Model.* **2014**, *9*, 59–70. [CrossRef]
45. Darzi-Naftchali, A.; Motevali, A.; Keikha, M. The life cycle assessment of subsurface drainage performance under rice-canola cropping system. *Agric. Water Manag.* **2022**, *266*, 107579. [CrossRef]
46. Saber, Z.; Esmaeili, M.; Pirdashti, H.; Motevali, A.; Nabavi-Pelesaraei, A. Exergoenvironmental-Life cycle cost analysis for conventional, low external input and organic systems of rice paddy production. *J. Cleaner Prod.* **2020**, *263*, 121529. [CrossRef]
47. Hosseini-Fashami, F.; Motevali, A.; Nabavi-Pelesaraei, A.; Hashemi, S.J.; Chau, K.-W. Energy-Life cycle assessment on applying solar technologies for greenhouse strawberry production. *Renew. Sust. Energy Rev.* **2019**, *116*, 109411. [CrossRef]
48. Alishah, A.; Motevali, A.; Tabatabaeekoloor, R.; Hashemi, S.J. Multiyear life energy and life cycle assessment of orange production in Iran. *Environ. Sci. Poll. Res.* **2019**, *26*, 32432–32445. [CrossRef]
49. Motevali, A.; Hashemi, S.J.; Tabatabaeekoloor, R. Environmental footprint study of white rice production chain-case study: Northern of Iran. *J. Environ. Manag.* **2019**, *241*, 305–318. [CrossRef]

50. Hänninen, O.; Knol, A.B.; Jantunen, M.; Lim, T.-A.; Conrad, A.; Rappolder, M.; Carrer, P.; Fanetti, A.-C.; Kim, R.; Buekers, J.; et al. Environmental burden of disease in Europe: Estimates for nine stressors in six countries. *Environ. Health Perspec.* **2014**, *122*, 439–446. [CrossRef]
51. Heath, G.A.; Granvold, P.W.; Hoats, A.S.; Nazaroff, W.; Nazaroff, W.W. Intake fraction assessment of the air pollutant exposure implications of a shift toward distributed electricity generation. *Atm. Environ.* **2006**, *40*, 7164–7177. [CrossRef]
52. Nurun, N.; Mustafizur, R.; Shamim, A. Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions. *Appl. Therm. Eng.* **2009**, *29*, 2265–2270. [CrossRef]
53. McCauley, A.; Jones, C.; Jacobsen, J. Commercial fertilizers and soil amendments. *Nutr. Manag. Module* **2009**, *10*, 4410–4449.
54. Permadi, D.A.; Sofyan, A.; Kim Oanh, N.T. Assessment of emissions of greenhouse gases and air pollutants in Indonesia and impacts of national policy for elimination of erosene use in cooking. *Atm. Environ.* **2017**, *154*, 82–94. [CrossRef]
55. Bare, J. TRACI 2.0: The tool for the reduction and assessment of chemical and other environmental impacts 2.0. *Clean Technol. Environ. Policy* **2011**, *13*, 687–696. [CrossRef]
56. Mogensen, L.; Hermansen, J.E.; Halberg, N.; Dalgaard, R.; Vis, J.; Smith, B.G. Life cycle assessment across the food supply chain. *Sust. Food Ind.* **2009**, *Chapter 5*, 115–144. [CrossRef]
57. Schumann, B. The Causes of Soil Acidity. New South Wales Acid Soil Action Program. New South Wales Department of Agriculture: Orange, NSW, Australia, 1999.
58. Brentrup, F.; Küsters, J.; Kuhlmann, H.; Lammel, J. Environmental impact assessment of agricultural production systems using the life cycle assessment methodology: I. Theoretical concept of a LCA method tailored to crop production. *Eur. J. Agron.* **2004**, *20*, 247–264. [CrossRef]
59. Brentrup, F.; Palliere, C. *GHG Emissions and Energy Efficiency in European Nitrogen Fertilizer Production and Use*; International Fertilizer Society: York, UK, 2008.
60. World Meteorological Organization (WMO) Greenhouse Gas Bulletin (GHG Bulletin)—No. 3: The State of Greenhouse Gases in the Atmosphere Using Global Observations through 2006. National Oceanic and Atmospheric Administration, Annual greenhouse gas index (AGGI). Available online: https://library.wmo.int/index.php?lvl=notice_display&id=3030#.Y1JBvkxBzIU (accessed on 31 December 2022).
61. Keikha, M.; Darzi- Naftchali, A.; Motevali, A.; Valipour, M. Effect of nitrogen management on the environmental and economic sustainability of wheat production in different climates. *Agric. Water Manag.* **2023**, *276*, 108060. [CrossRef]
62. Mazlan, N.A.; Zaki, N.A.M.; Narashid, R.H.; Talib, N.; Manokaran, J.; Arshad, F.C.; Fauzi, S.S.M.; Dom, N.C.; Valipour, M.; Dambul, R.; et al. COVID-19 Restriction Movement Control Order (MCO) Impacted Emissions of Peninsular Malaysia Using Sentinel-2a and Sentinel-5p Satellite. *Earth Syst. Environ.* **2023**, *7*, 347–358. [CrossRef] [PubMed]
63. Khan, A.R.; Mustafa, A.; Hyder, S.; Valipour, M.; Rizvi, Z.F.; Gondal, A.S.; Yousuf, Z.; Iqbal, R.; Daraz, U. Bacillus spp. as Bioagents: Uses and Application for Sustainable Agriculture. *Biology* **2022**, *11*, 1763. [CrossRef] [PubMed]
64. Dean, S.; Akhtar, M.S.; Ditta, A.; Valipour, M.; Aslam, S. Microcosm Study on the Potential of Aquatic Macrophytes for Phytoremediation of Phosphorus-Induced Eutrophication. *Sustainability* **2022**, *14*, 16415. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.