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Assessment of Environmental Impacts and Energy of Biodiesel Production from Chicken Fat by Life Cycle Assessment Method

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To preserve fossil fuel sources and reduce environmental pollution, it is necessary to use higher quality and more efficient fuels that cause lower pollution and are recovered more easily. Therefore, this study will investigate the cycle of biodiesel production from chicken fat by life-cycle assessment (LCA). To achieve this purpose, information on the amount of inputs consumed and produced by some broiler-farming units was collected using questionnaire. The value of net energy in this cycle was assessed to be a large negative number, and the energy ratio lower than one indicates high energy consumption of the production of this fuel. The net yield of biodiesel production was 0.574 liter-biodiesel per kg of waste fat. In the cycle, the greatest impact of pollutants was exerted on the Marine aquatic ecotoxicity intoxication and the least effect on ozone depletion. According to the global warming index, production of 1 liter of biodiesel yielded 1.90 kg CO_2, and the depletion rate of fossil fuel sources for the production of 1 liter of biodiesel was obtained 21.35 MJ. The production of biodiesel from chicken slaughterhouse waste fat is considered a kind of energy recycling and is an effort to reduce environmental pollution.

1. INTRODUCTION

The industrialization of developing countries, the increasing population of the world, and increased quality of life have led to an increase in fossil fuel consumption. About 80 % of the world's energy is supplied by fossil energy sources [1].

The increasing use of fossil fuels, i.e., one of the main sources of environmental pollution, and increased greenhouse gas emissions in the current century have reduced the amount of fossil fuel sources and, also, have polluted the environment and endangered human health [2, 3]. The cumulative exploitation of fossil fuels, energy security concerns, environmental pollution, and sustainable development have led to a tendency toward replacing energy sources with renewable, efficient, affordable, and environmentally-friendly ones [4, 5]. Researchers have recently been seeking to replace fossil fuels with renewable, sustainable and environmentally friendly energy sources [6]. Renewable energy sources are environmentally friendly and cause less contamination in both stages of production and consumption.

Another feature of this kind of energy is the distribution of production sources and the possibility of their production by means of various levels of technology around the world [7]. In recent decades, biodiesel has been introduced as a type of renewable and biological fuel to replace diesel to facilitate engine function, reduce combustion emissions, and improve fuel combustion.

Biodiesel can be used alone or in combination with diesel at different ratios in internal combustion engines [8]. Scientific research across the world has mainly focused on resolving the problems related to adapting renewable energy sources to available energy consumption systems. In addition to recoverability and bio-degradation, biodiesel has a significant impact on the quality of the pollutants emitted from the combustion of the engine, such as CO, suspended solids, and unburnt hydrocarbons.

It is also noteworthy that the organic carbon in the structure of this kind of fuels has a photosynthetic origin, thus preventing any increase in the greenhouse effect due to increased CO_2 [9].

The production of biofuels depends on two factors: the production of fuel and the fuel production process [10]. The biofuels are produced by processing biomasses (plant material, animal, algae, and wastes) and used in internal combustion engines and boilers [11].

Because raw materials are the most important cost factor for biodiesel production (accounting for roughly 70 % of total production costs of vegetable oils) [12, 13] and lack of food products and their sources is likely, it is essential to use non-edible sources and wastes to produce this kind of fuel. Discovering sustainable sources that can serve as raw materials for biodiesel production in the commercialization of clean fuel production is the most important challenge that faces this industry [7, 14, 15].

The poultry industry, the most important constituent of which is chicken farming, is currently one of the most widespread industries in Iran. Chicken slaughterhouses, which produce large quantities of waste each day, are working in most parts of Iran. One of these wastes is the chicken skin and the fats inside the chicken abdominal cavity where large amounts of fat accumulate due to the particular diet and inactivity of the chickens throughout the growth period, such that it has been reported that 2-12 % oil can be obtained by processing this fat [16].

Chicken waste fat can be used as a biodiesel source to help protect the environment and increase the efficiency of the energy consumed for chicken farming. It has been reported

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that chicken fat can be converted to biodiesel. Promising results regarding the chemical properties of this fuel have been reported [17].

There is no report on the energy cycle and environmental impacts of fuel production from chicken waste in Iran. The purpose of energy analysis is to study the possibility of reducing energy inputs, replacing non-renewable energy sources with renewable ones, reducing the cost of production as much as possible, and using environmentally friendly production methods to achieve an optimal management system [18]. Therefore, in this research, the life cycle of biodiesel production using chicken slaughterhouse waste fat was investigated by the transesterification method.

2. MATERIALS AND METHODS

Life-cycle assessment (LCA) is a technique used to assess the environmental impact of a product, process or activity over its lifetime. This method consists of four steps, goal and scope definition, inventory analysis, impact assessment, and interpretation of results [19]. The purpose of this study is to assess the energy indicators and environmental effects of biodiesel production from chicken slaughterhouse waste fat. The system boundaries that determine the scope of the study start with the poultry farming and end with biodiesel production (Figure 1). All production inputs to the system except for the building and machinery, with little impact on the cycle due to long-term use, as well as all outputs and emissions within the system's boundaries were taken into account. The transportation of living chickens to the slaughterhouse was carried out with special trucks and, as a result, the inputs of the transportation stage included the driver and diesel, which were calculated based on the distance traveled. The results in this stage were included in the analysis. The functional unit is a quantitative description of the function of the production system that is used as a reference in the LCA [20]. The functional unit in this study was considered to be 1 liter of biodiesel. In the LCA, the amounts of energy of inputs and outputs, obtained by means of questionnaire, interview, laboratory equipment, and databases were calculated by using the corresponding energy equations for each substance.

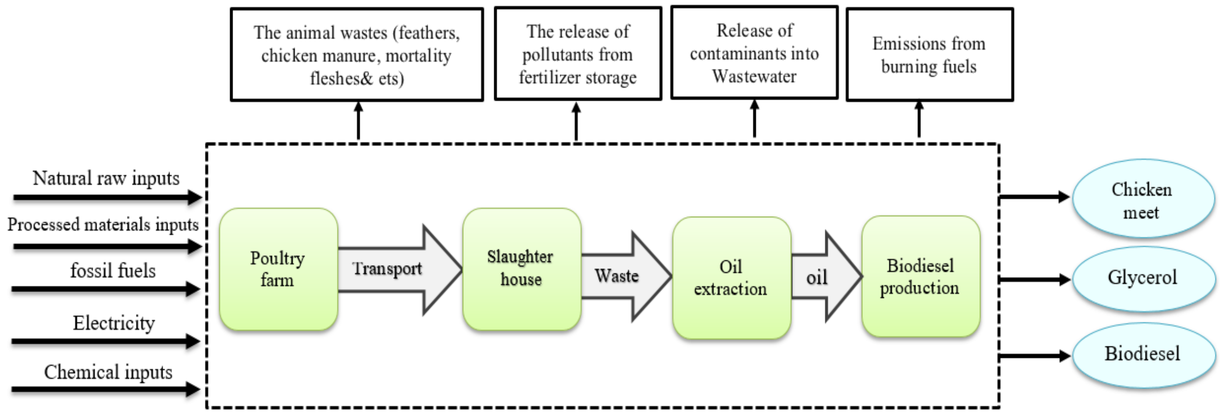

Figure 1. The boundaries of the life-cycle assessment of biodiesel production from chicken slaughterhouse wastes fat.

2.1. Sampling

The life cycle of the biodiesel produced from the fat of the chicken slaughterhouse wastes by the transesterification method began with the introduction of broiler chickens into the chicken farm and ended with the production of biodiesel.

This included four stages: chicken farming, slaughter, oil extraction, and biodiesel production. During the four stages, two products (chicken meat and biodiesel) and three by-products (poultry litter, oil extraction rubbish, and glycerin) were obtained. The sampling time was the spring of 2017. Sampling was conducted in an area of 105,937 km^2 in Isfahan Province, central Iran (30 degrees and 43 minutes to 34 degrees and 27 minutes north, 49 degrees and 36 minutes to 55 degrees 31 minutes east).

2.2. Aviculture

Data on the amounts of inputs and outputs of the broiler breeding stage, beginning from disinfection before incubation to chickens slaughter, were collected from a number of chicken farms in Isfahan province by means of questionnaire and interview. Sample size was determined by using Cochran's formula and samples were selected by random, convenience sampling [21]. The data collected in this study included dietary ingredients, the materials used to disinfect the building, medicines and vaccines, fuel, electricity, machinery, chickens, bedding materials, workforce, and breeder chickens and poultry litter.

2.3. Slaughterhouse

Mature chickens were transported to the slaughterhouse. Information on the amount of inputs used in the slaughterhouse including machinery, fuel, electricity, disinfectants, packaging materials, and workforce and the amounts of produced meat and wastes as outputs per one month was collected from a number of Isfahan province slaughterhouses by means of questionnaire. The slaughterhouses' wastewaters were also sampled to conduct biochemical oxygen demand (BOD) and chemical oxygen demand (COD) testing.

2.4. Oil extraction

To obtain oil-containing lower amounts of fatty acids, the oil should be extracted by using indirect heat. The inputs and outputs of oil extraction stage were obtained through interviews and observation of traditional workshops and oil extraction in the laboratory. The properties of chicken fat oil are listed in Table 1.

Table 1. Fatty acid profile and properties of used chicken fat oil.

Properties	Unit	Amount
Density	gcm^{-3}	0.902
Kinematic viscosity	mm^2/s	47.1
Acid value	mg KOH/g oil	0.84
Iodine value	g I^2/ 100 g oil	61.6
Water content	mg g^{-1}	0.21
Myristic (C14:0)	wt. %	1.4
Palmitic (C16:0)	wt. %	26.5
Palmitoleic (C16:1)	wt. %	3.9
Stearic (C18:0)	wt. %	12.1
Oleic (C18:1)*	wt. %	43.6
Linoleic (C18:2)*	wt. %	10.3
Linolenic (C18:3)*	wt. %	1.6
Other fatty acids	wt. %	0.6
* Carbon atoms number: double bond number.		

2.5. Biodiesel production

Due to the lack of biodiesel production centers, this step was carried out in laboratory and biodiesel was produced by the transesterification method [17]. The amounts of consumed and produced materials and energy needed for the production of 1 liter of biodiesel were also calculated [21].

2.6. Calculation of emissions

The emissions of this cycle include gases produced from gas and gasoline combustion and emissions from poultry litter and pollutants that enter slaughterhouse wastewater. To calculate the emissions from diesel combustion, the emission coefficients for diesel fuel (Ecoinven database [23]) were used. In addition, the amounts of pollutants produced from natural gas combustion were obtained by using emission coefficients [24] after unit conversion. Another emission due to chicken meat production is methane, which is produced from the fermentation of poultry bowl. The amount of methane is calculated through Equation 1 [25].

For the emission of methane from the accumulation and decomposition of poultry litter, the IPCC instruction (Equation 2) was used [26]. Another pollutant in this cycle is the slaughterhouse wastewater whose amount was determined by measuring the amounts of the COD and BOD in the laboratory.

Equation 1:

$$E = 26.49DMI + 1.46 \quad (1)$$

where E: Methane emitted from bowl fermentation (kg) and DMI: Consumed food weight (kg).

Equation 2:

$$\text{CH4manure} = VS * BO * MCF * 0.67 \quad (2)$$

where 'CH4manure' is the weight (g) of methane produced per each chicken, 'VS' is the volatile solids excreted (kg dry matter/broiler/day), 'Bo' is the methane-producing potential from manure (m^3CH_4/kg VS), 'MCF' is the methane conversion factor that varies with the climate (% of Bo), and '0.67' is the conversion factor of m^3CH_4 to kg CH_4.

2.7. Energy calculation

The energy balance between the production process and the biodiesel produced from a certain source is the most important factor in evaluating biodiesel production from that source [27]. Improving the efficiency of energy cycle in industries is one of the main measures to improve energy consumption and save costs, preserve natural sources, and reduce environmental pollution [28]. To study the energy flow of biodiesel production cycle, the standard energy indicators for production of 1 liter of biodiesel were calculated (Equations 3-6). In addition, the amounts of direct and indirect energy consumed in the cycle and the amounts of renewable and non-renewable energy sources were compared.

$$\text{Energy use efficiency} = \frac{\text{Energy output}(\text{MJ}(1\text{ L biodiesel})^{-1})}{\text{Energy input}(\text{MJ}(1\text{ L biodiesel})^{-1})} \quad (3)$$

$$\text{Specific Energy} = \frac{\text{Energy input}(\text{MJ}(1\text{ L biodiesel})^{-1})}{\text{yield}(\text{kg}(1\text{ L biodiesel})^{-1})} \quad (4)$$

$$\text{Energy use efficiency} = \frac{\text{Yield}(\text{kg}(1\text{ L biodiesel})^{-1})}{\text{Energy input}(\text{MJ}(1\text{ L biodiesel})^{-1})} \quad (5)$$

$$\text{Net Energy} = \text{Energy output}(\text{MJ}(1\text{ L biodiesel})^{-1}) - \text{Energy input}(\text{MJ}(1\text{ L biodiesel})^{-1}) \quad (6)$$

2.8. Environmental assessment

To investigate the environmental impacts of the biodiesel production cycle from chicken slaughterhouse wastes fat, CIMAPRO software was used. Since 1990, the software has been widely used by researchers, institutes, and universities to study the LCA. Comprehensive database including Agrifoot print and Ecoinvent is one of the features of this software. It also enables producers to investigate and decide on the production of a sustainable product or a change in the life cycle of a product to make ecosystems more sustainable and to protect the environment. In this study, all data were incorporated into the CIMAPRO software version 8.2.3.

The production process of the product of interest was thoroughly evaluated by the CML-IA baseline V3.01/EU25 method, and 10 environmental indicators including the depletion of fossil fuel sources, global warming index, ozone depletion, human toxicity, free water intoxication, soil contamination, photochemical oxidation, acidification potential, and eutrophication were investigated by the selected model.

3. RESULTS AND DISCUSSION

3.1. Energy

The main purpose of energy consumption in the studied cycle is the production of chicken meat rather than the production of wastes; however, the production of fuel from wastes produced alongside chicken meat is a type of energy recycling. As illustrated in Figure 2, the highest consumption of inputs and energy is related to the chicken farming; however, it should be noted that the energy in this stage was used to produce chicken meat, and the fat, used to produce biodiesel, was obtained from chicken wastes. Lopez et al. (2010) also pointed out that the modification of animal production and community consumption patterns was the best method to reduce energy of inputs in the production of biodiesel from animal fat [29].

In our study, the energy ratio was drawn lower than 1 and the net energy lower than zero. Our data showed that, during a complete cycle of biodiesel production from chicken waste fat, the total energies of inputs and outputs were 70137.48 and 34951.78 MJ, respectively. The large negative value of the net energy indicated that the consumed energy in the production cycle was greater than the generated energy. The research conducted in the USA on the life cycle of biodiesel obtained from animal fat has also reported an energy ratio of less than one [29]. However, in studies concerning the energy indicators for producing biodiesel from oily grains, the energy ratio was reported to be greater than one and net energy values to be positive [30-32].

However, it should be noted that despite the higher energy productivity in producing biodiesel from plants, the supply of food sources for the community may be influenced because of the edibility of the primary source in most cases and the use of sources for cultivating the product that will be solely used to produce fuel.

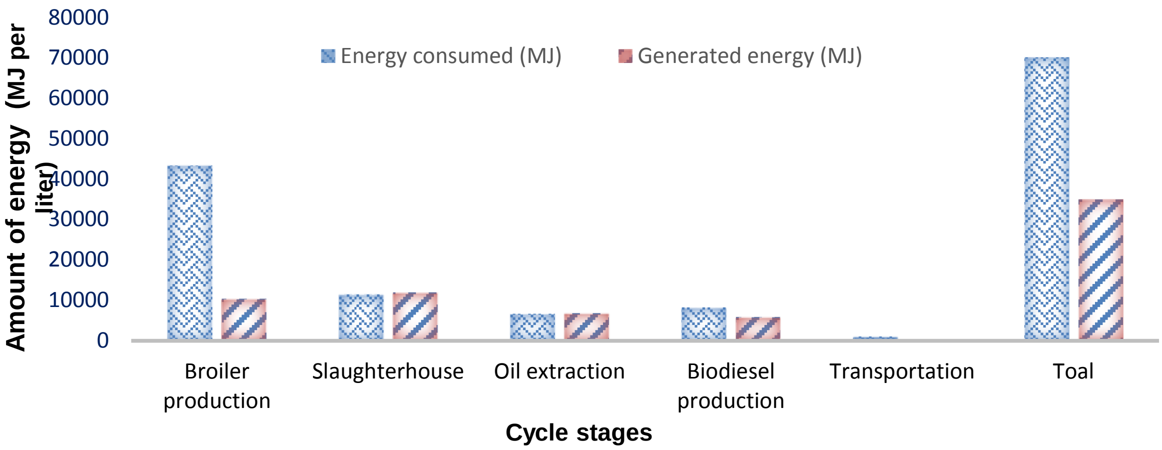

Figure 2. Comparison of energy consumption in the biodiesel production cycle.

The ratio of fossil energy in the studied cycle was 0.37, indicating that the amount of the consumed fossil energy was higher than that of the generated biofuel (Table 2).

In addition, data analysis showed that, during this cycle, the amount of direct energy was higher than that of indirect energy, and the amounts of the consumed renewable energy sources were less than those of the non-renewable ones. This is due to the closed environment of chicken farming and slaughterhouses, making them dependent on cooling and heating devices and use minimal amounts of natural energy sources.

3.2. The environment

A summary of the results regarding ten environmental indicators of the biodiesel production cycle from chicken slaughterhouse wastes fat is presented in Table 3 and Figure 3.

The results showed that the production cycle had the most negative impact on the aquatic toxicity index. Detergents and disinfectants are the main causes of free water intoxication. The rate of this pollution can be reduced by using biological detergents and disinfectants and treating chicken farming and slaughterhouse wastes. The Ozone Depleting Gas Index represents the potential of certain pollutants, such as chlorofluorocarbons, to deplete the ozone layer. Ozone depletion causes excess sunlight ultraviolet radiation on the earth that leads to human diseases, reduction in plant and animal populations, and damage to plants and animals [33]. The studied cycle had the lowest impact on the Ozone Depleting Gas Index. In our study, electricity had the greatest impact on the ozone depletion and, interestingly, fossil fuels did not affect this index.

Table 2. Indicators of energy for the production of 1 liter of biodiesel.

Indicator	Average per 1 L biodiesel	Unit
Energy use efficiency	0.498	-
Energy productivity	0.002	$kg.MJ^{-1}$
Specific Energy	463.07	$MJ. kg^{-1}$
Net energy	-35185.7	$MJ.L^{-1}$
Fossil energy ratio	0.376	-

Table 3. Environmental indicators in production of 1 liter of biodiesel.

Impact category	Unit	Total
Abiotic depletion (fossil fuels)	MJ	21.35046
Abiotic depletion	kg Sb eq	3.05E-07
Global warming (GWP100a)	kg CO_2 eq	1.902108
Ozone layer depletion (ODP)	kg CFC-11 eq	9.79E-08
Human toxicity	kg 1.4-DB eq	0.534225
Freshwater aquatic ecotox	kg 1.4-DB eq	0.381114
Marine aquatic ecotoxicity	kg 1.4-DB eq	692.8326
Terrestrial ecotoxicity	kg 1.4-DB eq	0.113285
Photochemical oxidation	kg C_2H_4 eq	0.000485
Acidification	kg SO_2 eq	0.015002
Eutrophication	kg PO_4 eq	0.008436

According to Table 3, the production of 1 liter of biodiesel from chicken slaughterhouse wastes fat reduced energy sources by 21.35 MJ. In our study, gasoline had the greatest impact on the changes in this index. In the studied area, gasoline is the main fuel in most chicken farms. This index can be reduced by using renewable fuels. The global warming index represents the amount of greenhouse gas particles that affect global warming. Global warming potential is used to determine the contribution of released gases from agroecosystems that cause climate change [34]. The global warming index in our study was obtained 1.90 kg CO_2. This index was reported to be 17.81 in a study of biodiesel production from sheep fat [35]. The wood used for laying has a 5 % positive impact on the global warming index, which can be attributed to the photosynthesis of trees. Soybean meal (34.4 %), followed by corn meal (25.5 %), has the greatest impact on the global warming index. The use of chemical fertilizers and pesticides and gasoline-fueled agricultural machinery throughout the cultivation of soybean and corn increases the global warming index. In addition, in the study of Nemecek et al., NO_2 and CO_2 emissions from chemical fertilizers and diesel had the greatest impact on the global warming index [36]. Electricity (22.5 %) is the second leading factor for an increase in global warming. Electricity consumed in the studied area is generated from thermal power plants by using fossil fuels. The increase in this indicator can be partly prevented by decreasing power consumption. In addition, changing the uses of lands, forests, and natural sources into agricultural uses will have an impact on biodiversity and, therefore, a significant amount of carbon enters the atmosphere each year. Soy cultivation has the greatest impact on land change. Eutrophication refers to the potential influences of the increase and accumulation of natural or synthetic nutrients such as nitrogen and phosphorus and the resulting ecosystem's response. These responses can lead to the growth of algae in surface waters and the death of aquatic creatures and plants [37].

Eutrophication for the production of 1 l of biodiesel was estimated at 0.0084 kg phosphate. Pollutants released from the chicken farm hall such as ammonia, transportation, and food production, especially soybean cultivation, have led to an increase in this index due to the use of phosphorus fertilizers such as di-ammonium phosphate.

This index has been reported as 0.11 kg phosphate for the production of biodiesel from sheep fat [35], which is higher than the value obtained in the present study. The value of eutrophication was lower than those for all biodiesel samples examined by Sendzikiene et al. (2018) [38].

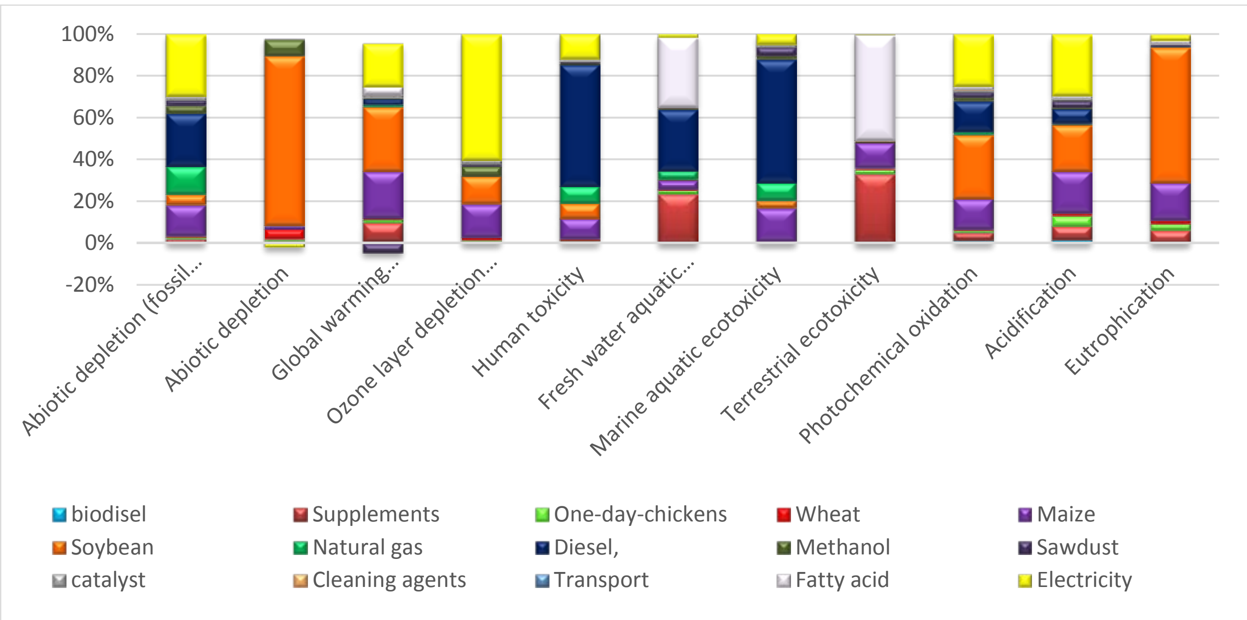

Figure 3. The effects of inputs on environmental indicators.

Acidification potential indicates the effects of released acidic substances on ecosystems. The acidification index indicates the increase in pH in the environment that depends on the release of acidic substances, including NH_3 from manure and SO_2 from fossil fuel combustion [39-42].

The ammonia released from chicken manure in the hall is one of the main factors for the acidification of this cycle. In addition, the SO_2 produced from the combustion of gasoline and gas, as the fuel of the power plant, has been found to be effective. It should be noted that 90 % of the diet of broiler chicken is composed of soy and corn meal. Figure 3 illustrates the effect of these two meals on the acidification index. Soybean cultivation leads to land change and entails the use of phosphorus and nitrogen.

An increase in acidification index is influenced by an increase in ammonia, NO_2, and SO_2 in the air. The acidification index has adverse effects on the environment, plants, and animals, as well as the whole ecosystem and structures [43].

The production of 1 liter of biodiesel using chicken slaughterhouse waste fat resulted in the emission of 0.015 % of SO_2 into the environment that is less than the value of acidification index obtained in the study of biodiesel production from sheep fat [35]. Chemical reactions between nitrogen oxides and volatile organic compounds including non-methane volatile organic compounds emitted from cars, power plants, refineries, chemical plants, and other sources in the presence of sunlight resulted in photochemical oxidation, leading to the formation of ozone near the surface of the earth. The photochemical oxidation potential index showed that 0.00084 kg C_2H_4 entered the environment due to production of 1 l of biodiesel in the studied cycle. Over 30 % of this pollutant is related to soybean meal, for cultivation of which large amounts of phosphorus are used. Figures 3 and 4 illustrate the significant effect of nutrition and fossil fuels on all environmental pollution indicators. Among the biodiesel production inputs, slaughterhouse wastes constitute an integral part of chicken farming and have the same effects as those of chicken. Alcohol and catalysts also had minor effects and were ineffective in certain indicators.

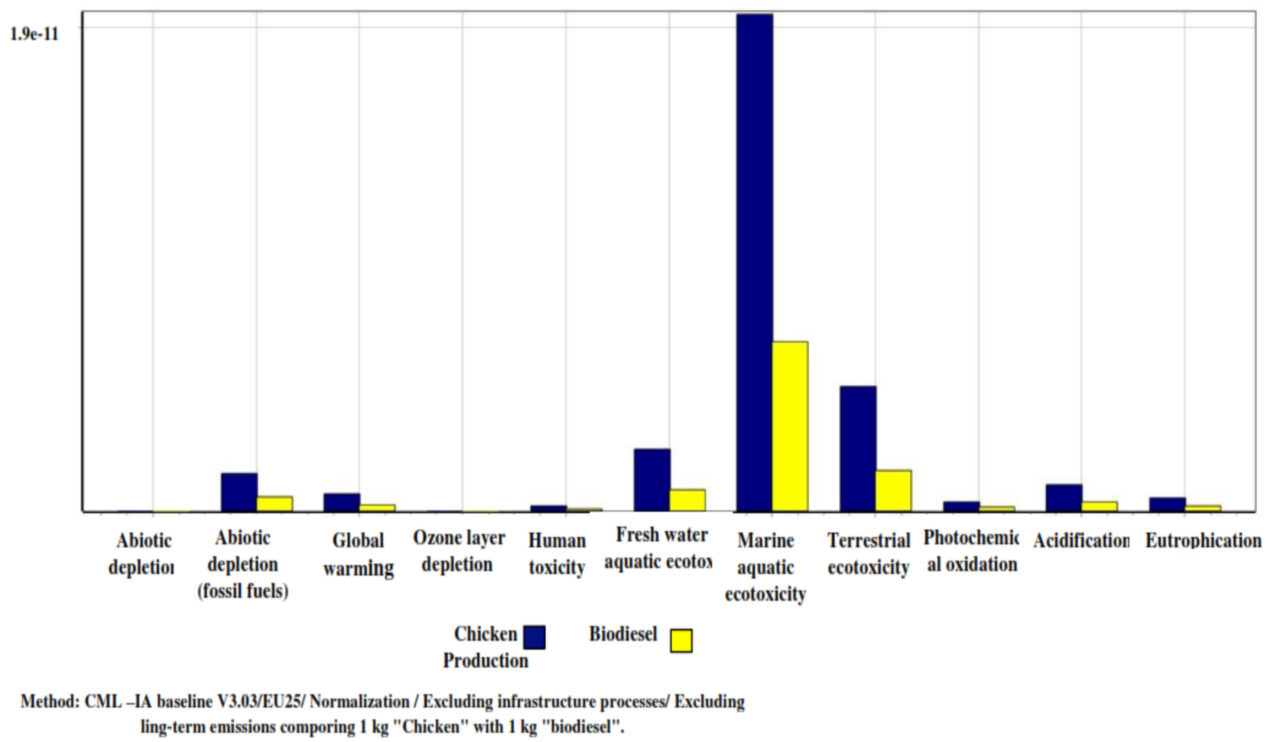

Figure 4. Comparison of biodiesel production from chicken fat in different stages.

4. CONCLUSIONS

The assessment of the biodiesel production cycle from chicken slaughterhouse wastes fat showed that most of the consumed energy and pollutants in the cycle were related to the chicken farming stage. It is, therefore, essential to make certain corrections in the stages of chicken farming and slaughter to reduce energy consumption and pollutant emissions. In addition to using up-to-date equipment with high energy efficiency, we can also use solar energy, thanks to the sunny climate of the area in most of the days of the year to produce electricity so that lower amounts of fossil fuels will be consumed. In addition, if natural fuels and even chicken farming wastes are used instead of diesel in the heating system, the environmental pollution indicators will be enhanced greatly. Another constituent of the pollutants is the diet. If diets with better conversion coefficients are used, the amount of consumption and even the type of nutrition can be modified so as to reduce pollution. In addition, if natural detergents are used, the slaughterhouse wastewater can be transferred to agricultural farms, thus needing less amounts of fertilizers and causing comparatively less pollutants to enter into the treatment system.

5. ACKNOWLEDGEMENT

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