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LIFE CYCLE ASSESSMENT FOR BIODIESEL UNDER THE GREEK CLIMATE CONDITIONS

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ABSTRACT: The aim of this paper is the conceptualization and understanding of the biodiesel life cycle produced by various Greek raw materials and under circumstances as already exists in Greece. Furthermore, the paper focuses in assessment and comparison of different biodiesel life cycles with fossil fuels. Three energy crops (rapeseed, sunflower and soy bean), concerning their levels of biodiesel production, have been studied taking into account the existing parameters of Greek climate conditions and production of these plants.

So far in Greece, studies have been conducted concerning the benefits and the environmental impacts by the biodiesel combustion, only at the stage of consumption and emissions, but till today limited number of studies of environmental comparison and assessment of biodiesel production processes exist.

The environmental impact assessment per crop area indicates the biodiesel production under soy bean raw material as the most effective solution among the others and per biodiesel quantity produced, the sunflower one.

This paper concludes that the environmental benefits, in comparison with the fossil fuels, results not only at the emissions stage, but also at the stage of production of biodiesel and that with insignificant modifications it is feasible to decrease environmental impacts at significant degree.

Keywords: biodiesel, life cycle assessment, environmental aspects biomass conversion

1 INTRODUCTON

Nowadays the need for alternative and renewable fuels plays important role both for environmental and economic reasons. Biodiesel, a commercial product, similar and substitute of conventional diesel, which can be used instead of conventional diesel but also mixed with this. Diesel of biological origin is defined as the methylester produced by plant or animal oils, quality of diesel to be used as biofuel.

Most emissions of pollutants are decreased by the use of biodiesel compared to the conventional biodiesel [1-2]. Specifically, CO_2 emissions are decreased at 80% and it is appreciated that even they do not contribute in the greenhouse gas effect, the SO_2 emissions tend in the zero and it contains less aromatic hydrocarbons. Finally, we have increased output of combustion limiting the exhaust of incomplete combustion, decreasing the emissions of the RMX at 48%, CO at 47% and non combustible hydrocarbons at 67%.

Also biodiesel is a non-toxic liquid, it does not cause irritations in the skin, and is safer to use than conventional diesel due to its increased ignition point; it has exceptional lubricant characteristics and it biodegrades 4 times more rapidly and also has increased number of cetanes comparatively from the conventional diesel. Finally, in social level, it can decrease the dependence of country from imported fossil fuels, while it can strengthen the employment withholding of populations in the region with the parallel intensification of domestic agriculture means of energy cultures.

The most important disadvantages of biodiesel are the increased NOx emissions comparatively with the conventional diesel via the use of catalysts, the cost of biodiesel production, the higher point of coagulation and evaporation from the conventional diesel result of which is the requirement of heating of reservoirs of storage. Finally, biodiesel has decreased energy content comparatively with the conventional diesel, [3].

A significant disadvantage of the biofuels is their competition with food, subject not technical but mainly economical and political one. Besides their sustainability depends of their scale of production [4] as well as the energy inputs required for their production [5].

According to the EC Biofuel Directive till 2010 their share in the transport sector should be increased up to 5,75%. For this purpose the intensive cultivation of energy crops is under consideration. The main advantage is that their steady production can ensure a wide range and great scale supply of raw materials, with uniformly quality characteristics in liquid biofuel and energy production units.

In this study, has been studied the life cycle [6-8]of energy crops of rapeseed, sunflower and soy, which are the most popular for biodiesel production in Europe.

2 MATERIALS AND METHODS

2.1 Life cycle definition

The process implemented in this work was the design of biodiesel life cycle based on the international conditions [9-10], data gathering, biodiesel production units and crops under study. Checking these data with Greek information sources [11] and local conditions led to the definition of the parameters used in life cycle assessment. After simulation and comparisons of the results among the different types of biodiesel (according to plant cultivation) and also diesel took place along with different scenarios towards decreasing negative environmental impacts.

For every energy crop has been identified five stages which cover the whole production process from soil preparation till biodiesel production and these are: (i) Soil preparation and cultivation; (ii) Raw material transportation; (iii) Oilseed – Crushing; (iv) Oilseed refinery ; (v) Biodiesel production.

The first stage of life cycle is preparation and cultivation of soil. After the growth and harvest of the plants comes the transportation of first material to the processing unit (second stage), where the two next stages take place. At stage three, the seeds are broken and oilseed is produced and then refined. After oil refining, at last stage the oil is transformed into biodiesel in the biodiesel production unit [12].

2.2 Software description

SimaPro7 software has been chosen as a widely used LCA tool both by professionals and researchers. Its main advantages are the great number of databases and the ability to evaluate results on the environmental load.

SimaPro7 uses many methods for impact assessment, but all of them have the basic structure that follows:

1. Characterization
2. Damage Assessment
3. Normalization
4. Weighting

During characterization, the substances that contribute to a wide category of influences are multiplied by a Characterization Factor, which expresses the grade of contribution of each substance to each effect category. The result is expressed in Impact Category Indicators.

The aim of damage assessment is to combine a number of indicators of wide effect category to a wider Damage Category. To sum up the stress of certain wide effect categories it is easier to evaluate the total stress that is caused by each category of wide effect on damage category.

In normalization we have the ability to compare wide effect category indicators with a given reference point. This comparison is performed by dividing the indicators by the reference point expressing all the indicators to the same measurement unit. This step can be implemented on results from first step and those from second one. The average annual environmental load per country or continent, divided by the population, can be widely used as reference point.

Finally, using weighting, we can multiply by a weighting factor the data we have, either for wide range category indicators or for Damage Category Indicators, adding the new results so as to get a total final result. This step can be implemented in normalized or not data.

The method for comparing and presenting results is Eco – Indicator 99 v 2.1 which includes the capability of analysis through damage valuation step. The categories that have been chosen as the main receivers of environmental loads are the following:

a. Damage to Human Health. The results are expressed as number of years of life lost and number of years of life in disability. Combining these we get the measuring unit Disability Adjusted Life Years (DALY)

b. Damage to Ecosystem Quality. The results are expressed in number of species lost in a certain area during a certain period of time.

Damage to Resources. The results are expressed in energy surpluses required for future fossil fuel extraction.

2.3 Differences between energy crops

Concerning soil preparation processes, all three type of plants need tillage ploughing, hoeing and combine harvesting, while rapeseed also needs tillage harrowing. In Table 1 that follows data concerning irrigation, fertilizer, biocide and pesticide, mass transport, and energy requirements [13] and biomass productivity are shown, according to Simapro.

Table I. Energy -material requirements and factors

Irrigation (m^3)	**Rape seed**	**Sunflower**	**Soy**
Water river	54,00	108,00	216,0
Fertilizer (kg)	**Rape seed**	**Sunflower**	**Soy**
Fertilizer N	23,00	7,00	4,00
Fertilizer K_2O	20,00	-	-
Fertilizer P_2O_5	9,00	-	-
Magnesium Oxide	2,50	-	-
Quantities of weed killers (kg)	**Rape seed**	**Sunflower**	**Soy**
Biocide trifluralin	0,10	0,10	0,10
Pesticide pirimicarb	0,10	-	0,10
Pesticides dicofol	-	-	0,05
Transport of raw material (tkm)	**Rape seed**	**Sunflower**	**Soy**
Truck 16t B250	13,00	10,50	12,00
Energy Demand in the Crushing plant	**Rape seed**	**Sunflower**	**Soy**
Crude oil (kg)	10,03	8,40	7,68
Energy grid (kWh)	18,80	15,75	12,00
Energy requirements in the refinery	**Rape seed**	**Sunflower**	**Soy**
Crude oil (kg)	5,80	5,04	2,60
Energy grid (kWh)	6,50	5,62	2,85
Oil Reactive and Required Energy	**Rape seed**	**Sunflower**	**Soy**
Seed-oil (kg)	98,00	84,00	43,20
MeOH (kg)	21,00	18,17	9,30
NaOH (kg)	0,78	0,67	0,30
Water (kg)	99,00	84,97	43,70
H_3PO_4 (kg)	0,61	0,52	0,26
Energy grid (kWh)	6,37	5,00	3,00
Biodiesel product per cultivation acre	**Rape seed**	**Sunflower**	**Soy**
Produced Quantity (kg)	97,12	83,44	42,91
Production factor	1,00	1,16	2,26

2.3 Alternative scenarios

Then we changed some parameters in order to reduce the environmental stress caused [14]. For every conversion in the current scenario we created a new alternative scenario, in order to distinguish the benefits or stresses arising from the diversification separately. For the differentiation in fertilizing, we tested alternative fertilizers with a specified composition. The composition of four fertilizers was: Ammonium nitrate [NH_4NO_3], Ammonium Sulphate [$(NH_4)_2SO_4$], Calcium nitrate [$Ca(NO_3)_2$], Potassium nitrate [KNO_3]. Then we tested the replacement of industrial fertilizers, non organic origin with organic fertilizers (manure). For differentiations in irrigation we initially decreased irrigation by 20%, while in the second scenario the amount of water required was increased by 20%. Concerning differentiations in fuel oil, we replaced the quantities of petroleum oil, diesel and petrol. The quantities involved have the same energy content with the consumed quantity of fuel oil in the standard scenario, while for the differentiation in energy network we assumed that the use of renewable energy (supply network) has increased by 20%. For every scenario, we assumed that there is hydroelectricity, solar energy or wind energy contribution.

3 RESULTS AND DISCUSSION

3.1 Results per cultivation

The comparison between crops is performed by computing the load for each crop

1. per acre of crop
2. per produced quantity of biodiesel

For the presentation of results per tonnage produced biodiesel the volume of production has been used as a reference point, while per acre crop the reference point used has been feedstock. Per acre crop, the final quantity produced can be shown in Table 1.

Thus, for production of 97.120 kg biodiesel using sunflower as raw material 1,1639 acres are required, while using soy the required acres are 2,2633. The tables and charts of those cases in sunflower and soy will be presented initially for every acre of cultivated and then per 97.120 kg produced biodiesel, whereas in the case of rapeseed tables and charts are presented once as they serve in the two cases.

3.1.1 Rapeseed

The maximum stress is caused by the use of nitrogen synthesis fertilizer at a rate of 32,1% while the overall stress caused by fertilizing the soil exceeds 40% (40,32%). Major environmental loads are added because of the use of methanol, with a contribution rate of 12,9%, while most important factor after fertilizing soils are energy requirements, either in the form of liquid fuel or in the form of energy that comes from the local network, making the particular combination of loads to stand for 21,27% of the total.

The allocation of those costs mainly affects fossil fuels and minerals categories that harm the respiratory system (respiratory inorganic). The effect on the first case is due to the consumption of materials required for the production of energy, whereas in the second case to minerals and particulates emissions.

3.1.2 Sunflower

In the case of cultivation of sunflower it is observed that the biggest part of the environmental load comes from the demands in energy consumed in breaker and oil refinery with a participation rate of 39,3%. Below are the stresses coming from soil fertilizers with a contribution rate of 21,4% and from the use of methanol in the biodiesel production plant at a rate 24,2%. In addition, the main receivers of the stresses per effect category are identical in both cases.

3.1.3 Soy

The stresses rates also in this case come from the energy required with a contribution rate of 41,4%. Following is the environmental load arising from the use of methanol at a rate 17,8%, while fertilizers contribute with 17,5%.

Turning to the soy crop in terms of quantity produced the differences that we have concern only the final result as the structure and limits of life cycle remain unchanged. In this culture, because of the limited potential for biodiesel production per acre crop, we note that by bringing the results in terms of quantity has a strong increase in the output as expected.

3.2 Cultivation comparison

3.2.1 Comparison per cultivation acre

Initially comparing the environmental impacts arising in the production of biodiesel per acre of crop the use of rapeseed as raw material causes the greatest environmental stresses. According to the results, soy seems to be the best raw material.We observe that in all three crops most of the environmental loads come from three factors: a. Fertilizers use (mainly of nitrogen composition), b.Methanol use (during process of oilseed conversion to biodiesel), c.Energy requirements (for oilseed refinery and crushing for the production of the oilseed).

In the cultivation of rapeseed the extensive use of fertilizers and particularly the large quantities of nitrogenous fertilizers, as compared to the other crops, is causing rapid increase in environmental loads and make it more harmful. Among the crops of sunflower and soy major differences result from the smaller requirements of soy crop for all three factors with the biggest environmental load.

The allocation of environmental stresses among three categories (Damage Categories) gives similar results. We observe that stresses in various ecosystems are extremely scarce and follow those on human health. The sector stressed more is the one of sources because both in the manufacturing of fertilizers and methanol important consumption of energy exist.

3.2.2 Comparison per biodiesel produced quantity

Summing the results per quantity generates very different outcomes. According to the possibilities of production per area for every crop, we see that the case of soy is far ahead of the others. Due to the low productivity of soy production for the same quantities of biodiesel, the other two crops require almost twice area. Calculating the stress which arise from quantity produced, the production using rapeseed as raw material remains more harmful for the same reasons as stated in the previous comparison. However in this comparison because of the combination and performance requirements (fertilizing, methanol and energy use), or crop, the cultivation that damages less the environment is that of sunflower.

Similarly to the previous comparison, the distribution of environmental loads of three categories (Damage Categories) has no major differences, and in that comparing the sector that pays more is the field of sources as in the production of fertilizer and methanol we also have consumption of significant energy requirements, as was previously mentioned.

3.2.3 Comparison with compatible biofuel

Then, we compared the stresses arising between equal amounts of biodiesel production from the three different crops that we have studied with the stresses caused by using quantities of conventional diesel. Unfortunately, the energy content of biodiesel is behind the energy content with conventional diesel. The proportion of energy produced from biodiesel conforms with the conventional diesel fuel for equal amounts varies depending on the composition and properties of the fuel. For this study this ratio is considered to be equal to 0,873. According to this ratio we compared the process required for the production of 97.120 kg biodiesel (quantity produced per acre crop rapeseed) from every culture, and 84,78 kg conventional diesel so that the total energy content would be equal at all four cases. The overall result gives us that a part of life cycle till the combustion of fuel, the case of biofuels is by far the most environmentally friendly solution.

Except for biodiesel production when using rapeseed as raw material, the environmental costs resulting from the production quantities of biodiesel with this energy content is less than the corresponding caused by the extraction, transportation and processing of conventional diesel

3.3 Alternative comparison results

The calculations and comparisons of the results were made in accordance with the quantity of biodiesel in each case. However, conversions to baseline scenarios for each case were made and presented, per acre of crop. In comparison stages of the software, each scenario was multiplied with the corresponding coefficient. After multiplying all scenarios, they present the final effect caused by the production of 97.120 kg biodiesel. This amounts to the quantity of biofuel produced per acre of rapeseed cultivation and coefficients as shown in Table 1.

3.3.1 Fertilizer differentiations

3.3.1.1 Rapeseed

In the scenarios that follow, we have chosen to define specific composition of manure on four separate occasions as well as organic fertilizer composition. In any alternative scenario, we get the same amount of nitrogen in order to have the same effects of fertilization. In table 2 that follows, these alternative scenarios are shown, as well as their distinction from the original.

Table II. Life Cycle Analysis fertilizer scenarios for the three different types of energy crops

Fertilizer scenario name	**Rape seed**	**Sunflower**	**Soy**
LCA No1	NH_4NO_3	NH_4NO_3	NH_4NO_3
LCA No2	$(NH_4)_2SO_4$	$(NH_4)_2SO_4$	$(NH_4)_2SO_4$
LCA No3	$Ca(NO_3)_2$	$Ca(NO_3)_2$	$Ca(NO_3)_2$
LCA No4	KNO_3	KNO_3	KNO_3
LCA No5	Organic	Organic	Organic

The quantities of fertilizers in the first four scenarios remain the same as they are calculated according to their overall content of nitrogen. In the case of organic manure, we know that the composition is 4% nitrogen, 6% phosphorus and 4% potassium as nutritious materials (the remaining 86% consists of organic material that helps to further improvement of soil). Thus to cover the needs of nutrients additional 575 kg/ha of cultivated area are required.

We observe that we can reduce the overall environmental impacts using fertilizer, with ammonium sulphate as the main ingredient, scenario LCA rapeseed No2 (reducing output by 11%) or using an organic fertilizing, scenario LCA rapeseed No5 (decrease output by 17,1 %).

3.3.1.2 Sunflower

In the case of cultivation of sunflower, the fertilizer requirements come up to 7 kg of nitrogen. To meet that demand using organic fertilizers the required quantity should be 100 kg. Other elements remain unchanged from the cultivation of rapeseed as shown in Table 2.

In this case as previously alternative scenarios with a more efficient end result are that using fertilizer with main ingredient ammonium sulphate, scenario LCA sunflower No2 (reduction of the output at 6,8%) or using an organic fertilizing, scenario LCA sunflower No5 (reduction of output by 4,8%). We observe that in this case, the rate decrease is equally satisfactory to the case of rapeseed. Also in the case of the sunflower, it is observed that the organic fertilizing is not an optimal solution. In the case of rapeseed, ammonium sulphate can replace nitrogen fertilizer quantities only, while to cover the fertilizing demands phosphoric and potassium fertilizers are used. On the contrary, with the use of organic manure those needs are covered reducing further the environmental load. In the case of sunflower (as in soy), potassium and phosphate synthesis fertilizers are not used, thus reducing the impact from the change of mineral organic fertilizing is limited.

3.3.1.3 Soy

In the case of soy cultivation, the required fertilizers come up to 4 kg of nitrogen. To meet the demand with organic fertilizing the required quantity comes up to 100 kg. Other elements remain unchanged from the cultivation of rapeseed as seen in Table 2.

Reductions in this crop are similar to the case of the sunflower as the basic characteristics remain the same. In this case as in the previous alternative scenarios that have a more efficient end result is that of fertilizer, using as ammonium sulphate the main ingredient, scenario LCA soya (per biodiesel production) No 2 (reduction of the output by 6%) or using an organic fertilizing, scenario LCA soy (per biodiesel production) No 5 (a cut of 4,5%).

3.3.2 Irrigation differentiation

For the control of the importance of irrigation in the environmental impact two alternative scenarios were designed changing water consumption by 20% (increase and decrease respectively). Changes in the end result in all three crops were almost negligible. The assumption is that the environmental load through the consumption of water is several orders lower than that of other parameters.

3.3.3 Fuel type differentiations

3.3.3.1 Rapeseed

In the life cycle of three crops liquid fuel are used in the stages of rupture of grains and oilseed refining. Fuel oil requirements for these stages come up to 10.028 kg, for crushing 250.7 kg raw materials, while 5.866 kg of fuel oil are consumed for refining 97.773 kg of oilseed. The corresponding quantities required in case of gasoline or petroleum diesel use are shown in Table 3 below and the scenarios that were introduced conversions are the scenarios No 9 and No 10 respectively.

Table III. Life Cycle Analysis fuel scenarios for the three different types of energy crops

		Rapeseed	
Fuel scenarios (kg)	**Fuel type**	**Seed-oil industry**	**Refinery**
LCA No 6	Crude oil	10,03	5,86
LCA No 7	Benzene	9,57	5,63
LCA No 8	Diesel oil	9,91	5,83
		Sunflower	
Fuel scenarios (kg)	**Fuel type**	**Seed-oil industry**	**Refinery**
LCA No 6	Crude oil	8,40	5,04
LCA No 7	Benzine	8,06	4,83
LCA No 8	Diesel oil	8,34	5,00
		Soy Bean	
Fuel scenarios (kg)	**Fuel type**	**Seed-oil industry**	**Refinery**
LCA No 7	Benzine	7,37	2,49
LCA No 8	Diesel oil	7,62	2,66

Comparison of the final results does not varies a lot as the source of fuel and its nature remains the same in all three cases.

With very little difference to the final result the first scenario comes as the optimal solution. The difference in the final result with the other scenarios are almost nil, and calculated at 0,01% compared with the scenario No 8 and 0,5% on the scenario No 9.

3.3.3.2 Sunflower

Corresponding transformations have been studied in the other crops too. In the case of the sunflower, fuel oil has been used in fuel oil oilseed and oil refinery. To crush 210 kg of seeds 8,40 kg of fuel oil are needed, while refining 84 kg oilseed requires 5,04 kg of fuel oil. The corresponding quantities and scenarios for these cases are presented in Table 3.

The differences between the final results are relatively small (0.1% on the scenario No 8 and 0.7% on the scenario No 9) and the optimal solution is to use liquid fuel oil. Compared to the cultivation of rapeseed the increase the final result will be slightly larger, and this differentiation is due to the limited use of fertilizers.

3.3.3.3 Soy

In the case of soy requirements of fuel oil for shattering 240 kg of seed is 7,68 kg, while refining of 43,2 kg oilseed requires 2.542 kg of fuel oil. The corresponding quantities and scenarios for these cases are presented in Table 3.

As in previous cases, the differentiations between the final results are relatively small (0.1% on the scenario No 8 and 0,9% on the scenario No 9), and the optimal solution is to use liquid fuel type fuel oil.

3.3.4 Energy grid differentiations

3.3.4.1 Rapeseed

The life stages through which we have energy derived from the network are the stages of breaking seed, of oil refining and the process of converting oil to biodiesel. According to the assumptions, we get the following Table 4.

Table IV. Life Cycle Analysis grid energy scenarios for rapeseed energy crop

		Rapeseed		
Scenario name	**Energy type (kWh)**	**Seed-oil industry**	**Refinery**	**Production unit**
LCA No9	Energy from fossil fuels	18,80	6,55	6,37
LCA No10	Energy from fossil fuels	15,04	5,24	5,10
	Hydroelectric Energy	3,76	1,31	1,27
LCA No11	Energy from fossil fuels	15,04	5,24	5,10
	Solar Energy	3,76	1,31	1,27
LCA No12	Energy from fossil fuels	15,04	5,24	5,10
	Wind Energy	3,76	1,31	1,27

We observe that the increase in the share of renewable energy sources improves the final result in every case. The reduction of stresses in accordance with the final result ranges from 2,2% to 2,8%. The smallest reduce of stresses is caused by the use of photovoltaic systems (2,2%) while the optimal solution presented is that of hydroelectric energy use (2,8%) with a few differences from the case of wind energy(2,75%).

3.3.4.2 Sunflower

Corresponding transformations also studied in the other crops. In the case of the sunflower differentiations in the life cycle data associated with that from the grid power are shown in Table 5. Also in sunflower biodiesel production, the final result is reduced for all three options. The optimum solution seems to be that of increasing the use of hydroelectric energy to the grid (4,5%) showing few differences compared with the increased use of wind power 20% (4,3%). Finally, the case of the exploitation of solar energy is advantageous compared with the original scenario however, the reduction of environmental impacts is the smallest (4,1%).

Table V. Life Cycle Analysis grid energy scenarios for sunflower energy crop

		Soy		
Scenario name	**Energy type (kWh)**	**Seed-oil industry**	**Refinery**	**Production unit**
LCA No9	Energy from fossil fuels	15,75	5,6,	5,47
LCA No10	Energy from fossil fuels	12,6	4,5	4,38
	Hydroelectric Energy	3,15	1,13	1,09
LCA No11	Energy from fossil fuels	12,6	4,5	4,38
	Solar Energy	3,15	1,13	1,09
LCA No12	Energy from fossil fuels	12,6	4,5	4,38
	Wind Energy	3,15	1,13	1,09

3.3.4.3 Soy

In the case of soy beans, conversions and descriptions for the various alternative scenarios are presented in Table 6.

Table VI. Life Cycle Analysis grid energy scenarios for soy energy crop

		Soy		
Scenario name	**Energy type (kWh)**	**Seed-oil industry**	**Refinery**	**Production unit**
LCA No 9	Energy from fossil fuels	12,00	2,85	2,82
LCA No 10	Energy from fossil fuels	9,60	2,28	2,25
	Hydroelectric Energy	2,40	0,57	0,56
LCA No 11	Energy from fossil fuels	9,60	2,28	2,25
	Solar Energy	2,40	0,57	0,56
LCA No 12	Energy from fossil fuels	9,60	2,28	2,25
	Wind Energy	2,40	0,57	0,56

Like the two previous occasions, there are decreasing environmental loads comparing the final results. A greater reduction derives from increased use of hydro-energy (4,5%). Then comes the case of wind power (4,0%), while smaller environmental benefits arise from the increased use of photovoltaic systems (3,8%)

3.4 Comparison to optimum factors

Then, scenarios have been created for every cultivation using the parameters that lead to the greater decrease in environmental impact.

After these changes, final results for all three crops show great decrease while in case of rapeseed for the optimum scenario the final result is less than the equivalent in case of conventional fuels. In case of rapeseed, in new scenario there is a decrease of 19,5% in final result. In case of soy this decrease is 8,2% while in case of sunflower the final result is decreased by 9,1%. As shown in Table 7, the greater the fertilizer demand of cultivation the greater benefit we get by using organic fertilizers.

Table VII: Life Cycle Analysis best scenario results

Scenario name	Final result
LCA rapeseed	18,27
LCA rapeseed final	14,7
LCA soya (per biodiesel production)	13,19
LCA soya (per biodiesel production) final	12,11
LCA sunflower (per biodiesel production)	9,72
LCA sunflower (per biodiesel production) final	8,83
Diesel	15,81

4 CONCLUSION

Comparing the three energy crops, rapeseed turns out to be the more beneficial due to the highest yield of biodiesel production, but it is most problematic cultivation because of the increased amount of fertilizers used for plant growth. Comparing the next two energy crops for their cultivated area the case of soy is the most favorable solution because of the decreased demand in methanol. Comparing the two subsequent crops on the environment effects, in terms of cultivated area, the case of soy is clearly a more favorable solution because of reduced requirements for fertilization in methanol, for the conversion of oil and for consumed energy in other stages of production and refining of oil. But as to the quantity of biodiesel, the results differ because of the most favorable ratio of required fertilizer, use of methanol and consumed energy per volume of produced biodiesel. This is expected because the major environmental stresses are caused by the consumption of fossil materials and the use of fertilizers. By evaluating both comparisons, we conclude that the production of sunflower biodiesel is more favorable and environmentally friendly.

About the results of the stresses first comes the sector of mineral raw materials, for the demands of energy in the whole process and may be regarded as apparent because the result of the process is energy. Moreover, we have substantial expenses also in the emissions of particulates and substances, harmful to human health and particularly to our respiratory system with a larger share of ammonia and sulphur oxides emitted.

In comparison with conventional diesel, without taking in account the negative consequences of burning, we note that the production of biodiesel from rapeseed is the only one that harms the environment to greater extent, and yet, in all three cases high environmental load on the emissions and particulates exists. Generally, the overall picture is positive as the cultivation of soy and especially in sunflower has a lower final result mainly considering the emissions from the burning of fossil fuels.

Comparing alternative scenarios with standards, it seems that if you replace it with an organic fertilizer in the case of rapeseed or fertilizer ammonium sulphate into other crops, such stresses can be significantly reduced while significant reduction can also be achieved with the use of renewable energy.

In conclusion, in any case, the cultivation of sunflower for biodiesel production is the best solution, because it combines the relation between the volume of production and the corresponding implications. The case of soy cultivation follows comparing the positive results with conventional fuels, while rapeseed shows negative results.

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