ENVIRONMENTAL IMPACT ASSESSMENT OF BIODIESEL PRODUCTION FROM SOYBEAN

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Abstract

In this study the environmental impacts of biodiesel production from soybean were determined by using life cycle assessment (LCA) methodology. In order to achieve this objective all four LCA stages (goal setting, life cycle inventory, impact assessment and interpretation) were followed. The system boundaries included: cultivation, transport, crushing and extraction, soy oil refining and biodiesel production. The functional unit considered in this study is 1000 kg of biodiesel. All the inputs and outputs for each process included in the biodiesel production system were collected, calculated and estimated in the inventory phase. Environmental impact assessment step was performed considering LCA methods such as: CML 2001, CML 96, EDIP 2003 and ReCiPe. The impact categories selected for this evaluation were: *global warming potential* (GWP), *acidification potential* (AP), *eutrophication potential* (EP), *human toxicity potential* (HTP), *photochemical ozone creation potential* (POCP), *agricultural land occupation* (ALO); *climate change ecosystems* (CCE); *climate change human health* (CCHh); *fossil depletion* (FD); *particulate matter formation* (PMF) etc. Results showed that negative values were obtained for GWP, EP, CCE, CCHh indicators which means positive impacts of biodiesel production on the environment while the others impact categories have positive low levels respectively negative environmental impacts. Overall the greenhouse gases (GHG) are emitted from combustion of fuel used; the diesel used for soybean transportation also contributes to GHG emissions; the transesterification process significantly contributes to the emissions of these gases.

Key words: biodiesel, climate change, LCA, soybean

The European Union (EU) proposed in 2009 a target for 10% renewable transport fuels and a 6% reduction of greenhouse gas emissions (GHG) for all transport fuels by 2020 (EC, 2018). The biofuels contribution in achieving these objectives is significant. Biodiesel, the most common renewable fuel in Europe is obtained from rapeseed, soybeans, palm oil, used cooking oil and others. Rapeseed oil is the dominant biodiesel feedstock in the EU, while significant amounts of soybeans are imported from Brazil, Argentina, and Canada etc. In the EU approximately 850 million liters of soybean oil were used for biodiesel production in 2014 and 700 million liters in 2017 (USDA, 2018). It is considered that from 3.5-5 t/ha of soybeans can be extracted one tonne of soybean oil. Production of biodiesel and renewable diesel has increased in the last years in the EU (*figure 1*) and the dominant biodiesel feedstock in EU is rapeseed oil with 45% of total production (*figure 2*), followed by used cooking oil (21%) and palm oil (18%), while soybean oil (5%) is limited by standard DIN EN 14214.

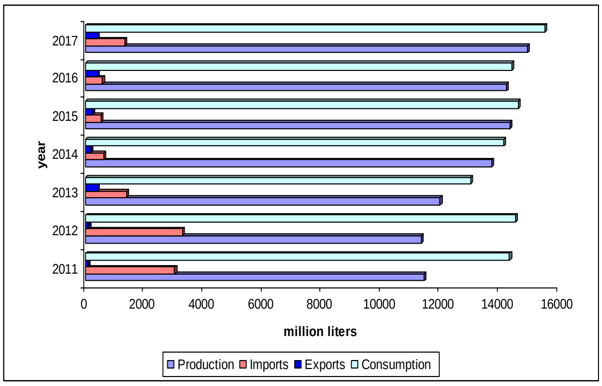

Figure 1 **EU production, consumption, import and export of biodiesel and renewable diesel (according to USDA, 2018)**

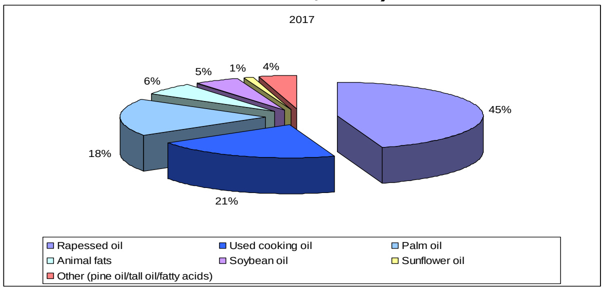

Figure 2 **Feedstock use in biodiesel production in the EU (according to USDA, 2018)**

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The largest amount of soybean oil is used in Spain and smaller quantities are used in countries like: Germany, Italy, Portugal, Romania, Bulgaria and Greece (USDA, 2018).

In 2017, in Romania soybean was cultivated on 165143 ha and the total production was 365 thousand tons according to INS (2018). Biofuels are obtained in Romania from rape, corn, sunflower and soybean (Colesca S.E., Ciocoiu C.N., 2013; Scridon S. *et al*, 2011). During 2006-2010, the biodiesel production in Romania was estimated approximately at 278000 thousand liters and the contribution of soybean oil to this amount was about 2.97% according to Popescu A. (2012).

The environmental impacts of biodiesel production were investigated in various studies:

- Castanheira E.G. *et al* (2015) compared the environmental impacts of biodiesel production from soybean in Brazil and exported to Portugal to biodiesel produced in Portugal from soybean and soybean oil imported from Brazil. Their results showed that biodiesel used and produced in Portugal with raw materials imported from Brazil has low environmental impacts comparative with utilization of biodiesel produced directly in Brazil.

- quantification and comparison of environmental impacts derived from soybean oil, jatrophal oil, and microalgal oil were performed by Hou J. *et al.* (2011). They demonstrate that utilization of biodiesel as replacement of fossil fuel contributes significantly to the reduction of global warming potential and abiotic depletion potential.

- Fernández-Tirado F. *et al* (2016) showed that a suitable raw material for biodiesel production is soybean originating from Argentina which is more environmental sustainable even than rapeseed which is the dominant feedstock in the EU.

- according to Hu Z. *et al* (2008) soybean biodiesel is considered to be much more renewable than conventional fuels; combustion of conventional fuels is responsible with pollutant emission especially CO_2, while soybean biodiesel combustion is for CO and NO_X emissions. The main stages responsible for particulate emission are soybean cultivation, biodiesel conversion and combustion. SO_x and CO_2 are emitted in soybean cultivation and biodiesel conversion steps.

Results reported in the literature differs due to different data, functional unit, scenarios and modeling procedures so that Castanheira É.G., Freire F. (2013) reported 0.1 – 17.8 kg CO_2eq kg^{-1} soybean, while Kim S., Dale B.E. (2009) about 0.4 – 2.5 kg CO_2eq kg^{-1} soybean oil. It was also estimated that the use of 1 kg of biodiesel may lead to a reduction of 3 kg CO_2 (EBB, 2018).

The main aim of this study is to establish the environmental impacts of biodiesel production from soybean culture through LCA according to the ISO standards (ISO 2006a, b).

MATERIAL AND METHOD

Goal, scope and functional unit. The goal of this study was to determine the environmental impacts resulted from biodiesel production. In order to achieve this goal life cycle assessment (LCA) methodology was applied and one tool which includes different LCA methods was used. The system boundaries established for this evaluation are illustrated in *figure 3*. Functional unit considered for this study is 1000 kg of biodiesel produced.

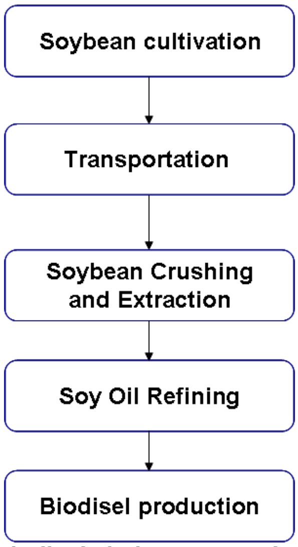

Figure 3 **Biodisel chain – system boundaries**

Inventory analysis. For all phases included in the biodiesel production were established inputs and outputs data. These data were collected from a biodiesel production plant, databases, literature and also were calculated and estimated.

In order to obtain 1000 kg of soybean according to USB (2010) the inputs are: diesel (14.3 L), electricity (25 MJ), LPG (32 MJ), natural gas (48 L), while outputs are represented by agrochemicals (0.52 kg), nitrogen fertilizer (1.6 kg), phosphorus fertilizer (5 kg), potash fertilizer (9.3 kg). CO_2, CO, NO_x, N_2O, PM10, CH_4, SO_2 and hydrocarbons represents the pollutants which are emitted in air during soybean transport. The amounts of these emitted pollutants were calculated considering the emissions resulted from burning 1 kg of diesel (Ghinea C., Leahu A., 2018).

Soybean processing data for 1000 kg of oil are (USB, 2010):

- material inputs: soybeans (5891 kg), hexane (11.9 kg), water (19.4 kg);
- products: soy meal produced (4478 kg), soybean oil produced (1000 kg);
- air emission: hexane (10.15 kg);

- water effluents: water (453 kg), fats, oils, and grease (5 kg);
- solid waste (46 kg).

Pre-refining operations of raw materials - crude oils, are the first step in the biodiesel manufacturing process. This stage comprises two processes: acid degumming and separation of fatty acids. Biodiesel Production includes the following steps in processing of refined vegetable oils: oil drying; transesterification; separation of methyl esters and glycerol; purification and concentration of glycerol; purification of glycerine - separation of soaps; purification of glycerol - separation of methyl alcohol and purification of methyl alcohol.

The raw materials and auxiliary materials related to finished products: 1000 kg biodiesel and 116 kg glycerin secondary product are presented in *table 1*. *Table 2* includes the specific data for utilities consumption per 1000 kg of obtained biodiesel, while in *table 3* are presented the potential sources of pollutant emissions in air and water.

Table 1
Raw materials and auxiliary materials

Raw materials and auxiliaries	Measure unit	Refined oil	Crude oil
Oil	kg	993	1021
Methanol (CH_3-OH)	kg	97.5	97.2
Sodium methylate (CH_3-ONa)	kg	18.33	18.33
Hydrochloric acid 36% (HCl)	kg	8	8
Sodium hydroxide 50%	kg	2	4.5

Table 2
Specific consumption of utilities/1000 kg of biodiesel

Utilities	Measure unit	Refined oil processing	Crude oil processing
Electric energy	kWh	21	30
Steam	kg	300	430
Recirculated water 4 ^oc	m^3	30	38
Methane gas	kg	-	3.3
Air	Nm^3/h	50	50

Table 3
Potential sources of pollutants emission in air and water from the biofuel production plant

Process	Inputs	Outputs
Biodiesel production	-oil -methanol -process water -other chemical substances	- ammonia (NH_3) - carbon dioxide (CO_2) - used catalysts - nitrogen oxides (NO_x) -wastewater
Central heating	-methane gas - diesel	- steam - flue gas
Wastewater treatment plant	- process wastewater and sewage	- treated wastewater - mud

The emission limit value for volatile organic compounds (VOC) in the process plant is 20 mg/Nm^3, while fugitive emission will not exceed the values established by the MAPM Order 592/2002. The quality indicators of the wastewater shall be complied in compliance with NTPA 002/2005.

Waste resulted for biodiesel production plant are: mud from wastewater treatment plant, paper and cardboard, plastics, absorbent materials, solvents, oil from engine, transmission and lubrication, acidic gums, household waste.

RESULTS AND DISCUSSION

The data obtained in the inventory step were introduced in the GaBi software and modelled in order to obtain the environmental impacts of biodiesel production chain. Different LCA methods were chosen for the evaluation CML 2001, CML96, EDIP 2003 and ReCiPe. These methods include different impact categories such as: *global warming potential* (GWP), *acidification potential* (AP), *eutrophication potential* (EP), *human toxicity potential* (HTP), *photochemical ozone creation potential* (POCP), *agricultural land occupation* (ALO); *climate change ecosystems* (CCE); *climate change human health* (CCHh); *fossil depletion* (FD); *particulate matter formation* (PMF) etc.

In *figure 4* are illustrated the environmental impacts of biodiesel production obtained by applying CML 2001 method, while *figure 5* presents the environmental impacts obtained with ReCiPe method. The results were normalised and expressed in PE = person equivalents. It can be observed that negative values were obtained for EP (*figure 4*), CCE, CCHh indicators (*figure 5*) which means positive impacts on the environment.

Overall the greenhouse gases (GHG) are emitted from combustion of fuel used; the diesel used for soybean transportation also contributes to GHG emissions; the transesterification process significantly contributes to the emissions of these gases. The contribution of biodiesel production to GWP is presented in *figure 6*.

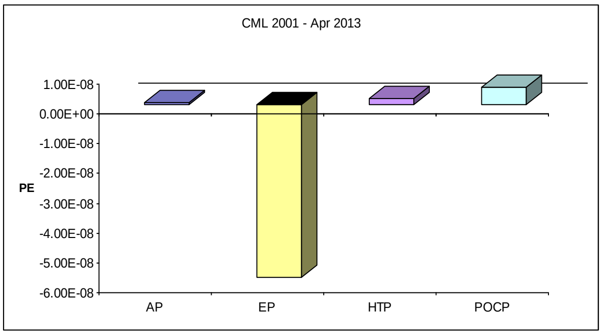

Figure 4 **Environmental impacts of biodiesel production – CML 2001 method**

According to the values obtained (*figure 6*), it can be said that the whole biodiesel production chain has a positive impact and lead to a reduction of CO_2 emission.

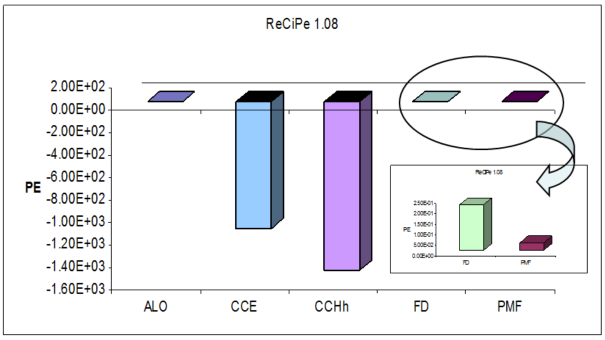

Figure 5 **Environmental impacts of biodiesel production – ReCiPe method**

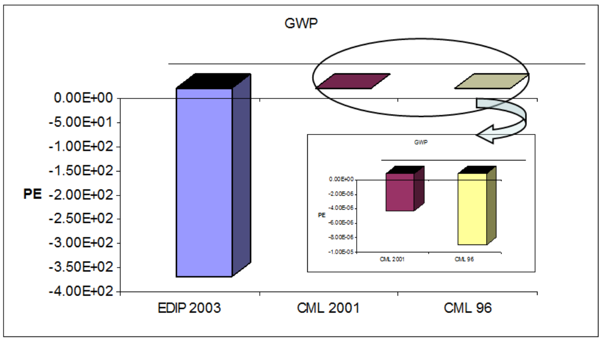

Figure 6 **Contribution of biodiesel production to GWP – EDIP 2003, CML 2001 and CML 96 methods**

CONCLUSIONS

In this paper the environmental impacts of soybean biodiesel production were investigated. These impacts were determined by applying LCA methodology. Results showed that this process affects the environment and has an impact on it mainly due to the consumption of raw materials, energy and burning of diesel during transport. CO_2 NH_3 and NO_x are the main pollutants emitted during the biodiesel production step, while hexane is emitted in air during soybean processing phase.

ACKNOWLEGMENTS

This paper was performed with the support of GaBi Life Cycle Assessment Software.

REFERENCES

Castanheira É.G., Freire F., 2013 - *Greenhouse gas assessment of soybean: implications of land use change and different cultivation systems*. Journal of Cleaner Production, 54:49-60.

Castanheira E.G., Grisoli R., Coelho S., da Silva G.A., Freire F., 2015 - *Life-cycle assessment of soybean-based biodiesel in Europe: comparing grain, oil and biodiesel import from Brazil*. Journal of Cleaner Production, 102: 188-201.

Colesca S.E., Ciocoiu C.N., 2013 - *An overview of the Romanian renewable energy sector*. Renewable and Sustainable Energy Reviews, 24:149-158.

EBB, 2018 – *Biodiesel*. European Biodiesel Board, available on-line at: http://www.ebb-eu.org/biodiesel.php.

EC, 2018 – *Biofuels*. European Commission, available on-line at: https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels.

Fernández-Tirado F. Parra-López C., Romero-Gámez M., 2016 - *Life cycle assessment of biodiesel in Spain: Comparing the environmental sustainability of Spanish production versus Argentinean imports*. Energy for Sustainable Development, 33: 36-52.

Ghinea C., Leahu A., 2018 - *Environmental evaluation of pork meat chain: a Romanian case study*. Food and Environment Safety, XVIII: 205 – 212.

Hu Z., Tan P., Yan X., Lou D., 2008 - *Life cycle energy, environment and economic assessment of soybean-based biodiesel as an alternative automotive fuel in China*. Energy, 33: 1654-1658.

Hou J., Zhang P., Yuana X., Zheng Y., 2011 - *Life cycle assessment of biodiesel from soybean, jatropha and microalgae in China conditions*. Renewable and Sustainable Energy Reviews, 15:5081-5091.

INS, 2018 - *Agricultural crop production increased in 2017 compared to year 2016, to all crops*. National Institute of Statistics, available on-line at: http://www.insse.ro/cms/sites/default/files/com_pr esa/com_pdf/prod_veg_r17_1.pdf.

ISO, 2006a - ISO 14040:2006. Environmental management. Life cycle assessment. Principles and framework.

ISO, 2006b - ISO 14044:2006. Environmental management. Life cycle assessment. Requirements and guidelines.

Kim S., Dale B.E., 2009 - *Regional variations in greenhouse gas emissions of biobased products in the United States-corn-based ethanol and soybean oil*. Int.ernational Journal of Life Cycle Assessment, 14:540-546.

Popescu A., 2012 - *Research on Romania's oil seeds biodiesel production potential*. Annals of the Academy of Romanian Scientists, Series on Agriculture, Silviculture and Veterinary Medicine Sciences, 1:70-81.

Scridon S., Socaciu C., Sână S., 2011 - *Biofuels Aspects in Romania*. Bulletin UASVM Agriculture, 68:330-332.

USB, 2010 - *Life Cycle Impact of Soybean Production and Soy Industrial Products*. The United Soybean Board.

USDA, 2018 - *EU Biofuels Annual 2018*. GAIN Report Number: NL8027, available on-line at: https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_The%20Hague_EU-28_7-3-2018.pdf.