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Comparative Life Cycle Assessment of Rapeseed Oil and Biodiesel from Winter Rape Produced in Romania

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***Abstract*—**The environmental performance of rapeseed oil (RO) and rapeseed methyl ester (RME) from winter rape as fuels produced in Romanian agroclimate is analyzed in this paper. The proposed methodology is life cycle assessment (LCA) and takes into consideration the influence of grain production and agroclimatic conditions. This study shows favorable results first for RO and then for RME. When compared to diesel fuel, both studied biofuels show better results in the following impact categories: Abiotic depletion potential (ADP), Ozone layer depletion (ODP) and Photochemical ozone creation potential (POCP).Furthermore, the environmental performance of the two biofuels studied can be improved by changing the type of fertilizer used and also by using biofuels instead of diesel in the field works.

***Keywords*—**Biodiesel, life cycle assessment, rapeseed oil.

I. Introduction

IN2009 the European Commission presented the Directive 2009/28/EC on the promotion of the use of energy from renewable sources [1]. According to this directive, the share of biofuel in the fuel used in transportation sector rises to a minimum 10% in every Member State in 2020. The directive wants to ensure that, as we expand the use of biofuels in the EU, we use only sustainable biofuels which generate a clear and net GHG saving and have no negative impact on biodiversity and land use [1], [2].In this context it is necessary to assess the environmental performance of the biofuels produced in Romania.

Brassica napus – also known as Canola – belongs to the *Brassicacea* family and is an ideal raw material (oil) with regard to combustion characteristics, oxidative stability and cold temperature behavior in producing biodiesel [3]. It is also a popular crop in Romania with an annual production rather constant.

This study focuses on environmentally assessing rapeseed oil and rapeseed methyl ester production as a potential energy source.

With this purpose we compiled agricultural production data for winter rape cultivated on 150ha from eastern Romania (the region of Moldavia).

The agricultural harvesting work does not include the collection of the entire plant, but only the seeds, the solid biomass (straws, leaves, capsules) remaining on the land.

Finally, the study compares the environmental performance of RO and RME produced from winter rape and an equivalent quantity of fossil diesel in order to demonstrate the viability of this energy source along with the fossil fuel.

II. Methodology

A. Agronomic Aspects

The plot selected for this study is 1ha of the total of 150ha cultivated with winter rape in the eastern Romania. In Table I are considered the main variables such as mean annual temperature, annual rainfall and average number of frost days.

B. Environmental Assessment

Guided by other studies published in the area of bioenergy production and environmental assessment [4]–[7], the methodology used to analyze the environmental performance of *B. napus* cropping system was Life Cycle Assessment (LCA).This environmental tool is used to assess all environmental impacts associated with a product, process or activity by accounting for and evaluating resource consumption and emission [8], [9]. LCA is a methodology that follows the ISO 14040 guidelines [8], [9] and is divided into four steps: 1. Definition of goal and scope, 2. Inventory analysis, 3. Impact assessment, 4. Interpretation.

The environmental analysis was conducted using the software program SimaPro 7.3 by Pré Consultants.

III. LCA of RO and RME Production by Means of B. Napus Cropping System

A. Goal Definition

The aim of the study was to evaluate the environmental performance of winter rapeseed cropping system in order to determine if this energy crop is suitable for biofuels production. A specific goal of the present study is to evaluate the environmental impacts of RO, RME and then compare the results with conventional diesel. The second specific goal is to determine the activities with the biggest impact in RO and RME production and suggest measures to improve the

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environmental results.

TABLE I
AGROCLIMATIC CONDITIONS OF THE STUDIED AREA

Geo-coordinates	Mean annual temperature(°C)	Annual rainfall(mm)	Frost days(days*year^{-1})
45.53N, 28.08 E	10,7	420 – 430	92

B. Functional Unit

In this study, the selected functional unit is the production of 1kg of RO and 1kg of RME by means of transesterification of RO produced in Romania. To compare the biofuels with fossil diesel on the basis of LHV, the equivalent quantity of fossil diesel of 870g is considered [3].

C. Systems Description

1. Rapeseed Oil System

The energy crop system studied includes agricultural production, transport of inputs/outputs and oil extraction. The main stages analyzed in the life cycle of rapeseed oil are represented in Fig. 1 along with the life cycle of biodiesel and conventional diesel. The system includes all agricultural inputs and outputs, and their corresponding emissions, during the agricultural stage. Inputs are: all agricultural machinery, seeds, fertilizers with their corresponding emissions, insecticides, herbicides. Transportation of agricultural machinery and other inputs from the farm to the land and back is also considered an input. Transportation of seeds and bales is also included as an input. Farmer transport stage includes a total number of 10 round trips [4].

Outputs are seeds and biomass bales. To obtain the final product, we have to consider the extraction of the vegetable oil phase and its refining.

The oil extraction yield is considered 97% taking into account the seed's oil content of 41% [10]–[12]. The extraction takes place in two steps: pressing and hexane extraction. The outputs of these processes are meal and rapeseed oil (1.48kg kg^{-1}) [13]. The refinement of the vegetable oil is also taken into account. In this study meal is considered a co-product of rapeseed oil and its impact is subtracted from the systems total impact according to the allocation procedure selected.

2. Biodiesel System

The biodiesel system consists of the rapeseed oil system along with the transesterification stage. Additional inputs are water, methanol and energy and the outputs of this system are biodiesel and glycerin. The avoided impact of glycerin has been considered in an expanded system allocation procedure. The transport subsystem does not include the manufacturing of vehicles, the impact of this being considered negligible, representing up to 10% [16] of the total impact generated during their life cycle.

3. Diesel System

The reference system used to compare all fuels consists of production and transportation of diesel to a refinery. Crude oil extraction and transportation from the petrol field to refinery are the main stages of the system.

4. Allocation Procedure

To compare the three production systems is necessary to focus on the main function which is fuel for diesel engines production. Therefore the environmental impact of the co-products is subtracted from rapeseed oil system and biodiesel system. Thereby, from the rapeseed oil system it has been subtracted the impact of soymeal production [12] and from the biodiesel system it has been subtracted the impact of glycerin produced from propane gas [12], [14].

5. Quality of Data

The rapeseed production system uses field data collected from a survey carried out during 2012 agricultural year, such as fertilizers, insecticides, herbicides, seed application dose, type of machinery used, and operating rate, diesel fuel consumption. The data for generalized and standardized production processes for agrochemicals, tractors and implements along with data related to the life cycle of the fuel (production, distribution and consumption) were taken from the Ecoinvent database [15]. In Table II are presented the information used for the compilation of the agricultural inventory. The data related to oil extraction factor of 41% has been taken from bibliography [12], as well as oil conversion factor to biodiesel of 0.97.

TABLE II
FIELD OPERATION EXPERIMENTAL DATA USED IN THE ASSESSMENT

Operation	Tractor	Implement				Inputs
	Weight[kg.]		Weight[kg.]	Operating rate[h·ha^{-1}]	Fuel[l·ha^{-1}·y^{-1}]	
Soil tilling	9.000	plow	800	2	20	
Soil milling	9.000	mill	1.500	1	10.50	
Chisel pass	9.000	disc harrow	3.000	0.50	6	
Fertilizer application	4.000	spreader	1.200	0.50	2	500 kg·ha^{-1}·y^{-1} NPK 15-15-15
Sowing	9.000	seeder	800	0.75	7.50	3.500 kg·ha^{-1}·y^{-1}rape seeds
Herbicide application	4.000	Boom sprayer	3.000	0.25	2	1 kg·ha^{-1}·y^{-1}Fusilade Forte
Insecticide application	4.000	Boom sprayer	3.000	0.25	2	0.15 kg·ha^{-1}·y^{-1}Karate-Zeon
Harvesting	10.000			1	10	

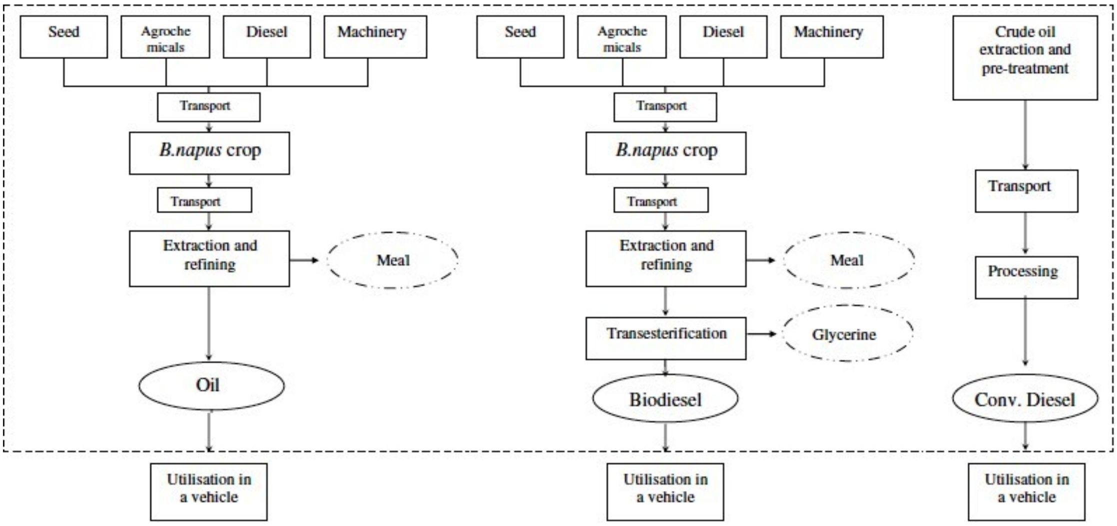

Fig. 1 Boundaries of the rapeseed oil production system, biodiesel production system and conventional diesel

D.Life Cycle Inventory Methodology

The methods used in the life cycle inventory phase were mainly based on the Life Cycle Inventories of Agricultural Production Systems methodology [15] and on the EU Concerted Action AIR-CT94-2028 "Harmonization of Environmental Life Cycle Assessment for Agriculture" [5].

1. Tractor and Agricultural Implement Production

The energy and material needed to produce the proportional fraction of tractors and agricultural implements used in the agricultural stage were estimated and taken into account in the life cycle inventory.

The proportional fraction of tractor and implements was estimated according to (1).

$$AMF=W \cdot OT/LT \tag{1}$$

where
AMF=the fraction of amount of tractor and implement used in the field work ($kg \cdot FU^{-1}$), FU is the functional unit in this study;
W=the weight of tractor and implements (kg);
OT=operating time for each field work ($h \cdot FU^{-1}$);
LT=life time of the tractors or implements (h) (12.000 h. for tractors and 800 – 3.000 h. for implements) [17], [18].

The material used in tractors and implements maintenance and repair during their lifetime was calculated using specific parameters from specialized bibliography [19], [20] and is defined as the repair cost during life time divided by the price of new machinery. In this study it has been assumed to be 20% for tractors and 54% for agricultural utensils [20].

2. Fuel Consumption and Emissions Associated to the Use of Agricultural Machinery and Transportation of the Two Biofuels

Fuel consumption for each field operation was well documented from the accounting records of the total parcel of 150 ha. and the emissions associated to fuel combustion were estimated using (2) and the emission factors proposed by the Swiss Agency for the Environment, Forests and Landscapes and other authors of Ecoinvent database [21], [22].

$$WG=FC \cdot EF \tag{2}$$

where:
WG=waste gases emitted ($g \cdot FU^{-1}$);
FC=fuel consumption ($kg\ fuel \cdot FU^{-1}$);
EF=emission factor for each gas (g waste gas·kg fuel).

3. Production of Fertilizers

Data related to the energy use and the emissions associated to the production process of the intermediates such as ammonium nitrate, ammonium nitrate phosphate and potassium nitrate and the final product, multinutrient fertilizer, were taken from the Ecoinvent database [23].

4. Production of Herbicides

Data related to the energy use and the emissions associated to pesticides production were taken from Ecoinvent database [24].

5. Production of Sowing Seeds

The production of the sowing seeds ($3.500 kg \cdot ha^{-1}$) was considered in the same way as the production of the studied crop. Thereby the land required for sowing seeds production of $50m^2$ is added to the total area of the studied parcel. The electrical energy used to for the processing of the seeds was included and is of $0.058\ kWh \cdot kg^{-1}$ of seeds [25].

6. Diffuse Emissions of the Application of Herbicides and Insecticides

The data related to the emissions of the application of pesticides were estimated according to the method proposed by Hauschild [26].

7. Diffuse Emissions of the Application of Fertilizers

Previous LCA studies have shown the importance of air emissions, such as NH_3, NO_x and N_2O produced by the application of synthetic fertilizers on the cultivated field [6], [27]–[31].

TABLE III
ENVIRONMENTAL IMPACT OF ONE KG OF RAPESEED OIL

Impact category	Unit	Agricultural stage			Transport stage	Conversion stage	Total
		Field works	Fertilizers production and use	Pesticides production and use	All transports	Oil extraction and refining	
ADP	g Sbeq	1,603	0,939	0,030	0,045	5,806	8,426
AP	g SO_2eq	0,986	1,452	0,033	0,024	2,595	5,091
EP	g PO_4--- eq	0,428	0,392	0,009	0,006	2,929	3,767
GWP100	kg CO_2eq	0,192	0,214	0,004	0,006	0,621	1,038
ODP	mg CFC-11 eq	0,018	0,013	0,002	0,001	0,061	0,096
HTP	kg 1,4-DB eq	0,232	0,115	0,004	0,001	0,480	0,834
FWAEP	kg 1,4-DB eq	0,080	0,040	0,000	0,000	0,494	0,616
MAEP	kg 1,4-DB eq	161,036	92,182	1,485	1,201	1082,322	1338,227
TEP	g 1,4-DB eq	4,469	0,930	0,010	0,013	10,760	16,182
POCP	g C_2H_4 eq	0,050	0,041	0,001	0,000	0,119	0,212

ADP: Abiotic Depletion Potential, AP: Acidification Potential, EP: Eutrophication Potential, GWP: Global Warming Potential, ODP: Ozone Layer Depletion Potential, HTTP: Human Toxicity Potential, FWAEP: Fresh Water Aquatic Ecotoxicity Potential, MAEP: Marine Aquatic Ecotoxicity Potential, TE: Terrestrial Ecotoxicity Potential; POCP: Photochemical Oxidation Potential.

IV. RESULTS

In the classification stage, each burden is linked to one or more impact categories, while in the characterization stage the contribution of each burden to each impact category is calculated by multiplying the burdens by a characterization factor [32]. The classification and characterization method used was CML 2 baseline 2000 [33].

4.000kg of rapeseeds is the average production of the studied parcel. This corresponds to approximately 1.591kg oil or 1.326kg of biodiesel. These results have been used to analyze the environmental performance of the biofuels.

In this paper we calculated the relative magnitude of different contributors to all impact categories to compare the three fuels.

The environmental impact of rapeseed oil production system is shown in Table III and biodiesel production system using *B. napus* oil is shown in Table IV. Both results are to be compared with diesel production systems environmental impact which is presented in Table V.

1. Contribution of the Life Cycle Stages to the Total Environmental Impact for RO and RME

In the case of rapeseed oil the results show that the extraction and refining of the oil is the activity with the biggest impact in all impact categories, with a contribution between 50.97% and 80.87%. Field works contribute to the total impact as the second most impacting activity.

In the case of biodiesel, the extraction and refining of the vegetable oil remains the activity with the greatest environmental impact. Still, the transesterification reaction has an important contribution to the following impact categories: 21.05% on Ozone Layer Depletion Potential, 18.57% on Abiotic Depletion Potential and 9.72% on Photochemical oxidation Potential.

2. Comparison of the Total Environmental Impact between Rapeseed Oil, Biodiesel and Diesel

When compared with diesel fuel, rapeseed oil shows better results in three impact categories: Ozone Layer Depletion Potential is reduced by 76%, Abiotic Depletion Potential by 57.87% and Photochemical Oxidation Potential is reduced with 29.33%.

When compared biodiesel with diesel fuel, similar results are obtained. Ozone Layer Depletion Potentialis reduced by 66.75%, Abiotic Depletion Potential by 43.94% and Photochemical Oxidation Potential is reduced with 14.33%.

In the Global Warming Potential both biofuels seem to be worse than diesel fuel as the combustion process is not considered. To demonstrate the benefits of the studied biofuelsin this category, the quantity the CO_2emitted from the equivalent quantity of diesel (0.870kg) used in a car is subtracted from the rapeseed oil GWP category, respectively from the biodiesels GWP category as CO_2 eq. of 2.7kg per kg of rapeseed oil, respectively kg of biodiesel.

The contribution of the rapeseed oil system is, in this case, of -1,662kg CO_2 eq. and for biodiesel is of -1,478kgCO_2 eq.

In all categories of toxicity, rapeseed oil and biodiesel present a poorer environmental performance.

For Acidification Potential rapeseed oil and biodiesel have more impact than diesel, of 1.82% respectively 17.22%.

For Eutrophication Potential the increase of rapeseed oil and biodiesel results is bigger, between 650.40% and 753.80%.

TABLE IV
ENVIRONMENTAL IMPACT OF 0.870 KG OF DIESEL

Impact category	Unit	Total
ADP	g Sbeq	20
AP	g SO_2eq	5
EP	g PO_4--- eq	0,5
GWP100	kg CO_2eq	0,41
ODP	mg CFC-11 eq	0,40
HTP	kg 1,4-DB eq	0,40
FWAEP	kg 1,4-DB eq	0,03
MAEP	kg 1,4-DB eq	270,51
TEP	g 1,4-DB eq	1,70
POCP	g C_2H_4eq	0,30

TABLE V
ENVIRONMENTAL IMPACT OF ONE KG OF RAPESEED METHYL ESTER

Impact category	Unit	Oil production	Transesterification	Total
ADP	g Sbeq	10,111	2,082	11,212
AP	g SO_2eq	6,110	0,263	5,861
EP	g PO_4--- eq	4,520	0,122	4,269
GWP100	kg CO_2eq	1,245	0,083	1,222
ODP	mg CFC-11 eq	0,115	0,028	0,133
HTP	kg 1,4-DB eq	1,000	0,032	0,949
FWAEP	kg 1,4-DB eq	0,740	0,020	0,699
MAEP	kg 1,4-DB eq	1605,872	47,537	1520,311
TEP	g 1,4-DB eq	19,419	0,400	18,224
POCP	g C_2H_4eq	0,255	0,025	0,257

V. CONCLUSIONS

In terms of environmental performance both biofuel systems present smaller AD, ODP and POCP resource impact. When the usage phase is included in the assessment, a lower contribution to GWP is distinguished. Contrariwise there are two categories in which biofuels obtained particularly worse results when compared to diesel. According to our calculations, Acidification Potential is greater by 1.82% and Eutrophication Potential by 653.40% in case of rapeseed oil. For biodiesel, Acidification Potential is greater by 17.22% and Eutrophication Potential by 753.80%. These impacts are mainly associated with the agricultural stage, necessary to rapeseed production, where in order to assure minimum production intensive agricultural techniques such as mineral fertilizers are applied in the field and to oil extraction and refining.

This study helps us draw another conclusion that of the use of co-products from biofuels processes (rape flour, glycerin and rape meal) help improve their environmental performance. It appears to be necessary that these co-products have an established capable market to absorb their production and that in this way allowing them to reduce the impact of the whole system.

Furthermore and based on the results obtained, the environmental performance of the systems could be improved by changing the fertilizers used to alternative ones from agriculture, agribusiness, livestock waste, etc. [4] and by reducing the energy-insensitive demand of the industrial process to obtain biofuels.

The methodology described in this study allows us to determine that Romanian agroclimate is suitable from an environmental point of view to be designated as agricultural areas to produce *B. napus* oil and biodiesel.

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