International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:7, No:9, 2013

A Carbon Footprint Analysis of Rapeseed Oil and Rapeseed Methyl Ester Produced in Romania as Fuels for Diesel Engines

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***Abstract*—**Considering the increasing need of biofuels in Europe and the legislative requirements of the European Union it is needed to quantify the greenhouse gas emissions of biofuels life cycle. In this article a carbon footprint analysis to quantify these gases emitted during production and use of Romanian rapeseed oil (RO) and biodiesel from rapeseed oil (RME) was conducted. The functional unit was considered the LHV of diesel oil of 42.8 $MJ{\cdot}kg^{-1}$ corresponding to 1.15kg. of RO and 1.10 kg. of RME. When the 3 fuels were compared, the results show important benefits when using rapeseed oil or biodiesel instead of diesel. The most impacting stage in terms of GHG emissions is the use of the fuels. In this stage, rapeseed oil registers a total quantity of 3,229 kg $CO_2eq.{\cdot}FU^{-1}$ and biodiesel register a total quantity of 3,088 kg $CO_2eq.{\cdot}FU^{-1}$ while mineral diesel registers a total quantity of 3,156 kg $CO_2eq.{\cdot}FU^{-1}$ emitted in the air. Taking into account that rape plant absorbed during growth stage the same quantity of CO_2 as emitted into atmosphere during usage stage of the fuel, when compared the three fuels, rapeseed oil and biodiesel obtain obvious benefits against fossil diesel. Results show that by substituting diesel with RO a total quantity of 5,663 kg. $CO_2eq.{\cdot}FU^{-1}$ would be saved while using biodiesel a total quantity of 5,570 kg. $CO_2eq.{\cdot}FU^{-1}$ can be saved.

***Keywords*—**Biodiesel, carbon footprint, rapeseed.

I. Introduction

According to the Directive 2009/28/EC [1] on the promotion of the use of energy from renewable sources, the share of biofuel in the fuel used in transportation sector rises to a minimum 10% in every Member State by 2020. The directive wants to ensure that by expanding 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 for diesel engines produced in Romania.

Brassica napus – also known as Canola –is an ideal raw material (oil) with regard to combustion characteristics, oxidative stability and cold temperature behavior in producing biodiesel [3]; the oil can also be used as it is in not very pretentious engines. It is a popular crop in Romania with an annual production rather constant.

In this study we assess the environmental performance of rapeseed oil (RO) and rapeseed methyl ester (RME) as fuels for diesel engines.

The study compares the CO_2 eq. emissions 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.

With this purpose we compiled agricultural production data for winter rape cultivated on 150 ha. from eastern Romania (Moldavia) in the agricultural year 2011-2012.

II. Methodology

The selected methodology to calculate greenhouse gas emissions (GHG) during production of RO and RME is Life Cycle Assessment (LCA). Life cycle assessment (LCA) is an appropriate tool to assess the environmental performance of the studied systems [4]. LCA is a methodology that follows the ISO 14040 guidelines [5], [6] and is divided into four steps: 1. Definition of goal and scope, 2. Inventory analysis, 3. Impact assessment, 4. Interpretation. In this study we only considered CO_2 and $CO_{2eq.}$emissions.

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

A. Goal, Scope and System Boundaries

The aim of the study was to calculate the CO_2 eq. emissions 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 performance of RME and to compare the results with fossil diesel.

The functional unit is the production of 1.15 kg of RO and 1.10 kg. of RME by means of transesterification of rapeseed oil produced in Romania. The results obtained by the two biofuels are compared with the results of fossil diesel.

The vegetable oil system studied includes agricultural production of winter rape, transport of inputs/outputs and oil extraction. The biodiesel system studied includes also the reaction of transesterification. The main stages analyzed for both biofuel and conventional diesel are represented in Fig. 1. The system includes all agricultural inputs and outputs, and their corresponding emissions, during the agricultural stage

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[2], [7]. Inputs are: all agricultural machinery, seeds, fertilizers with their corresponding emissions, insecticides, herbicides, water for irrigation, methanol and energy. 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 considered as an input. Farmer transport stage includes a total number of 10 round trips [7]. To obtain the final product, we have to consider the extraction of the vegetable oil phase and its refining. For biodiesel production is also considered the reaction of transesterification.

B. Allocation Procedure

The oil extraction yield is considered 97% taking into account the seed's oil content of 41% [8]–[10], and the outputs are meal and rapeseed oil (1.48 kg•kg-1) [11]. In this study meal and glycerin are considered co-products of RO and RME production and their impact is subtracted from the systems total impact. From the rapeseed oil system it has been subtracted the impact of soymeal production [10] and from the biodiesel system it has been subtracted the impact of glycerin produced from propane gas [10], [12].

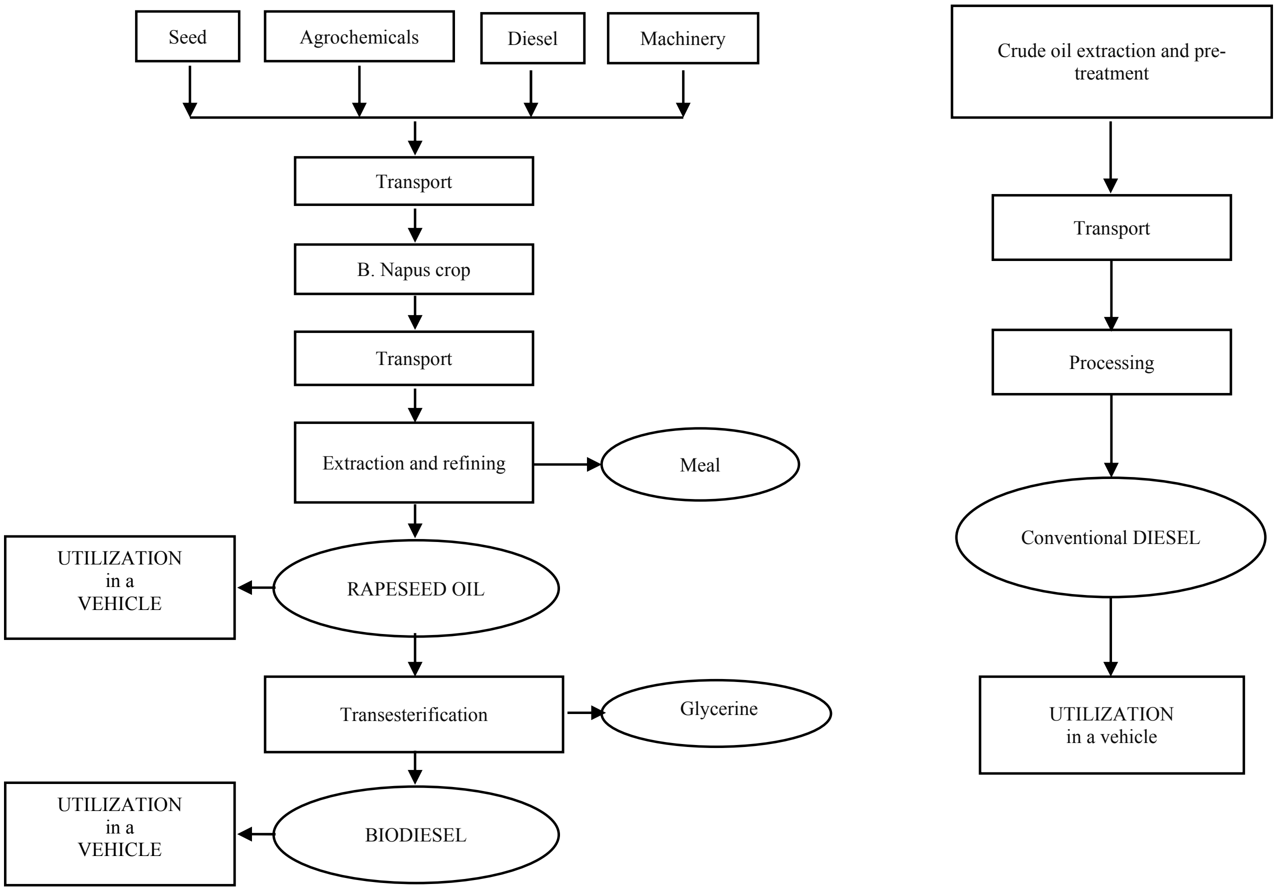

Fig. 1 Boundaries of the rapeseed oil production system, biodiesel production system and conventional diesel

In Table I is presented the information used for the compilation of the agricultural inventory.

The methods used in the life cycle inventory phase were mainly based on the Life Cycle Inventories of Agricultural Production Systems methodology [13] and on the EU Concerted Action AIR-CT94-2028 "Harmonization of Environmental Life Cycle Assessment for Agriculture" [14].

III. Input Calculation

A. 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.

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TABLE I
FIELD OPERATION EXPERIMENTAL DATA USED IN THE ASSESSMENT

Operation	Tractor	Implement				Inputs
	Weight [kg.]		Weight [kg.]	Operating rate [$h \cdot ha^{-1}$]	Fuel [$l \cdot ha^{-1} \cdot y^{-1}$]	
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 $kg \cdot ha^{-1} \cdot y^{-1}$ NPK 15-15-15
Sowing	9.000	seeder	800	0.75	7.50	3.500 $kg \cdot ha^{-1} \cdot y^{-1}$rape seeds
Irrigation						600 $m^3 \cdot ha^{-1}$ water
Herbicide application	4.000	Boom sprayer	3.000	0.25	2	1 $kg \cdot ha^{-1} \cdot y^{-1}$Fusilade Forte
Insecticide application	4.000	Boom sprayer	3.000	0.25	2	0.15 $kg \cdot ha^{-1} \cdot y^{-1}$Karate-Zeon
Harvesting	10.000			1	10	

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·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·FU-1);
LT=life time of the tractors or implements (h) (12.000 h. for tractors and 800 – 3.000 h. for implements) [15], [16].

The material used in tractors and implements maintenance and repair during their lifetime was calculated using specific parameters from specialized bibliography [17], [18] 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 [18].

B. Fuel Consumption and Emissions

Fuel consumption and emissions associated to the use of agricultural machinery and transportation of the two biofuels – 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 [19], [20].

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

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).

C. 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 [21].

D. Production of Herbicides

Data related to the energy use and the emissions associated to pesticides production were taken from Ecoinvent database [22].

E. 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 [23].

F. 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 [24].

G. 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 [25]–[30].

IV. COMPARATIVE EVALUATION OF CO_{2EQ}. FOR RO, RME AND CONVENTIONAL DIESEL

Considering the LHV of the three fuels studied, when compared the results show clear benefits of rapeseed oil and rapeseed methyl ester production and use against diesel fuel.

As it is shown in Table II, the activity with the greatest impact in biofuels production in Romania consists of oil extraction and refining and is of about 56%. All the activities included in the agricultural stage also have an important contribution to the final result, of around 35% of the total global warming potential. Regarding the transesterification reaction, in the case of biodiesel production, it is the activity with the least impact in GWP of RME production, of 7%.

TABLE II
RO, RME AND CONVENTIONAL DIESELCO_2EQ.EMISSIONS

RO		**RME**		**Diesel**	
Production	Use	Production	Use	Production	Use
1.193	**3.229**	1.145	3.088	0.471	3.156
-2.036		-1.943		3.627	

When compared to conventional diesel, both RO and RME seem to be worse than diesel fuel as the combustion process is not considered. To demonstrate the benefits of the biofuels, the quantity the CO_2 emitted from the equivalent quantity of diesel used in a car is subtracted from the rapeseed oil and rapeseed methyl ester GWP category.

The contribution of the RO system is, in this case, of -2,036 kg. CO_2 eq. and the contribution of the RME system is of -1,943 kg. CO_2 eq.

By substituting diesel fuel with this vegetable oil a total quantity of 5,663 kg. CO_2 eq. ·42.8 MJ^{-1} can be saved and by using biodiesel the reduction would be of 5,560 kg. CO_2 eq. ·42.8 MJ^{-1}.

V. CONCLUSIONS

In terms of global warming potential both rapeseed oil and biodiesel production systems present a bigger contribution than conventional diesel. However, when the usage phase is included in the calculation, a lower contribution to GWP is distinguished.

These impacts are mainly associated to oil extraction and refining and 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.

This study helps us draw another conclusion that of the use of co-products from biofuels production processes (rape flour, glycerin and rape meal) help improve their results in Global Warming Potential category.

Furthermore, the environmental performance of the systems could be improved by changing the fertilizers used to alternative ones from agriculture, agribusiness, livestock waste, etc. [7] and by reducing the energy-intensive demand of the industrial process to obtain biofuels.

Another important impact has the irrigation stage, also needed to increase crop production.

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

ACKNOWLEDGMENT

The authors would like to thank Dan Ciuhureanu, rape producer, for his support during data collection process and also the Project SOP HRD - TOP ACADEMIC 76822 for supporting this research and the paper publishing.

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