Environmental life cycle assessment of rapeseed straight vegetable oil as self-supply agricultural biofuel

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Abstract

Biofuels are nowadays considered a questionable environmental alternative to fossil fuels. In that context, this work analyses the environmental impacts when introducing rapeseed on the traditional and current wheat and barley agricultural rotation by means of a comparative life cycle assessment (LCA). The introduction of rapeseed, the correctness of its conversion to obtain straight vegetable oil and its use as self-consumption biofuel in tractors are evaluated. Life cycle assessment is used in this work to evaluate the impacts of different considered scenarios. A sensitivity analysis has also been conducted. The results presented show a modest environmental improvement (diminishment of 6 out of the 10 analyzed environmental impacts) when introducing rapeseed to local crop rotations and its partial conversion to oil to be used as fuel in existing diesel engines. Additionally, the ratio between the energy obtained and the total energy input shows moderate positive results when comparing the latter case with the current one. Results from this study can be used to support research and decision making to assess the convenience of introducing alternative fuels in agricultural exploitations.

Keywords

Straight vegetable oil, life cycle assessment, biofuel self-supply, small-scale biofuel production, rapeseed.

1. Introduction

The biofuels use has been discussed over the last years because of its environmental appropriateness, energy efficiency, competition with food and land-use impact (1,2). Many studies are focused on large-scale biofuel production aware of its environmental and social impacts (3-6).

Several authors have centered efforts on biofuel production techniques, which mostly involve the use of chemicals and high amounts of energy (7-10). Opposite to large-scale biofuel production, small-scale production of straight vegetable oil (SVO) is here considered, focusing its advantages on the reduction of the chemicals used in processing, the avoidance of long distances fuel transport and the independence that biofuel self-supply represents to farmers. SVO technology is based on a physical pressing and filtering of the oil seeds. Additionally, a refining stage using only water and energy is considered. The use of SVO as fuel is already studied and used in some European countries (11-16). However, only a German standard deals with legislation of rapeseed SVO used as fuel (17). Mediterranean Spanish traditional crops are considered in this work (18,19), as well as the introduction of rapeseed to classical crop rotation.

Life cycle assessment (LCA) methodology (20) is used for the environmental evaluation of different crop scenarios. Energy obtained from crops is considered as a target and used as a basis for the calculation and comparison of the impact categories.

An environmental comparison of different agricultural rotation options including the small-scale production and use of SVO as fuel are presented. The goals of this study are to evaluate the environmental benefits of introducing rapeseed in a wheat-barley based rotation area and to compare different possibilities for generating a specific amount of energy from an agricultural exploitation including SVO production and use.

2. Materials and methods

2.1. Methodology

The general framework for conducting an LCA is found in the 14040 and 14044 ISO standards which are followed in this work (21,22).

The present study models four different crop types and a rapeseed processing stage (to transform the seed into oil). The use of diesel fuel or straight vegetable oil as the tractor fuel is included in the model to take into account its consumption and the corresponding fuel emissions. Crop types are combined according to the crop rotation chosen for each scenario.

The model of the present work has been developed using GaBi 4 software (23). Data on crop works, fertilizing needs and yields were obtained for the Anoia region, a northeastern dry Mediterranean area in Spain. These data has been collected from local farmers and validated by Unió de Pagesos, a local agrarian cooperative. Results robustness is verified by means of a sensitivity analysis.

2.2. Goal and scope definition

The purpose of this work is to environmentally evaluate the conventional cropping system and the alternatives when introducing rapeseed in the crop rotation focused in a Spanish northeastern area. The use of rapeseed oil as alternative to diesel fuel is environmentally studied. Different cropping schemes are studied fixing the functional unit in 10^9kcal of energy obtained from the field products. This value is a rough approximation of the amount of energy produced in 100ha using the current crop rotation in the studied area. The functional unit is calculated depending on the final products use (see **Table 1**). Direct cropping technique is assumed.

Table 1. Energetic value of obtained products (kcal/kg)

	energy	source
Rapeseed for human consumption	4750	(24)
Rape oil for human consumption	8840	(24)
Rape oil as SVO	9029	(25)
Rape cake for animal consumption	2650	(26)
Wheat for human consumption	3400	(24)
Barley for human consumption	3520	(24)

2.3. System boundaries

The system boundary includes an agricultural exploitation where different crop types are considered (see **Figure 1**). The fate of the obtained products is not considered. The boundaries comprehend:

- Material inputs which take into account fertilizers, herbicides, insecticides, fungicides, diesel fuel and planting seeds.
- Cropping stages including fertilizing, herbicide, insecticide and fungicide treatments, sowing, harvesting and seed/grain transportation to cooperative installations.
- Rapeseed processing stage which includes transportation, pressing, filtering and degumming processes.

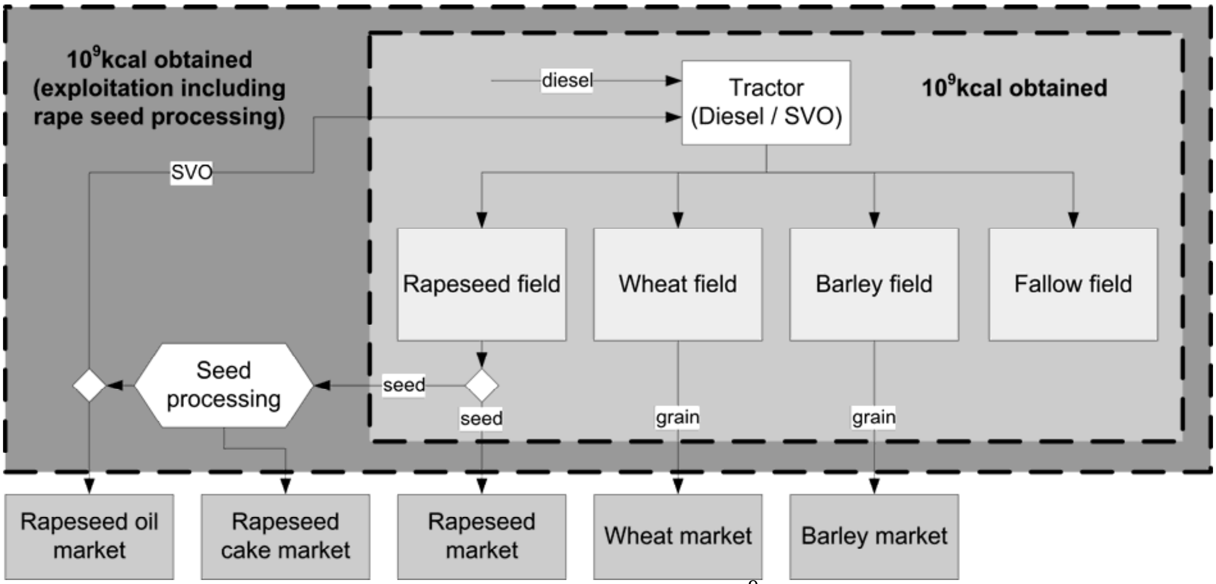

Figure 1. Crop types scheme and functional unit (10^9 kcal produced in an agricultural exploitation).

The base model is composed by grouping three crop types, namely barley, wheat and rapeseed. A fourth option, fallow, is also included. Barley, wheat and rapeseed crop types consist on the production of the grain and seed. Additionally, rapeseed model incorporates the seed processing, to obtain rapeseed oil that can be used as biofuel (SVO) in the exploitation. **Table 2** shows the 6 scenarios that have been evaluated according to different possibilities of agricultural exploitation in the considered region.

Table 2. Considered scenarios

	Rotation[1]	Fuel used	Rape seed fate	Rape seed oil fate
Diesel current scenario	WBBB	Diesel	-	-
Diesel classic scenario	WBBBF	Diesel	-	-
Diesel seed scenario	RWBBB	Diesel	All sold to the market	-
Diesel oil scenario	RWBBB	Diesel	All converted into oil	Sold to the market
SVO seed scenario	RWBBB	SVO	Some processed[2] and the rest sold to the market	Used as SVO
SVO oil scenario	RWBBB	SVO	All converted into oil	Some used as SVO[2] and the rest sold to the market

[1] R: Rapeseed; W: Wheat; B: Barley; F: Fallow.
[2] The amount needed as fuel is the processed one.

2.4. Impact assessment

CML method from the Environmental Sciences Institute of Leiden University is the method chosen in this study, because it is the one which generates more international consensus and avoids subjectivity (27,28).

Additionally to the ten CML2001 impact categories (28), land use and energy comsumption are analyzed. Land use stands for the amount of land required to obtain the functional unit.

An energy comparison is important to evaluate the process efficiency. The Energy Return on Investment (EROI) is used as a synthesizing concept for biofuel analyses (29). As the objective of any fuel is to provide energy, the ratio of energy produced to energy consumed during production is a mportant measure of process efficiency. However, the calculation of this ratio can lead to different results as pointed out by Russi (4) and Mulder (29). EROI is defined as the ratio between the energy obtained from a product and the energy used directly and indirectly in the processes involved to obtain this product.

In our study, the obtained products are not only biofuels, consequently, an adaptation is necessary. The energy input is calculated according to LCA methodology, taking into account all the energy inputs in the process. The **Crop energy ratio** used in this work is obtained dividing the energy obtained (functional unit) by the energy input.

3. Life cycle inventory (LCI)

In this section data and assumptions considered in this study are described.

3.1. Field system

The field is considered the same for the different crops. The field system (chemical and mechanical inputs to the on-field activities) is used for barley, wheat and rapeseed, with the appropriate inputs and outputs for each crop.

Fertilizers, *pesticides*, *planting seed* and *agricultural implement* quantities for each crop are detailed in **section 3.2** as well as the crops production according to its mean yield in the studied area.

Nitrous oxide (N_2O) emissions from agricultural soils are an important part of the total greenhouse gas emissions (30). These emissions depend on variables such as rainfall, humidity and temperature of the soil and fertilizer application method. The N_2O emissions associated to the agricultural field are considered according to IPCC 2006 method (31), considering direct and indirect emissions from the nitrogen applied. However, the direct emissions value (1%) has a high uncertainty degree as argued by several authors (32,33).

The emissions of *nitrogen oxides* (NO_x) are considered as a 10% of the N_2O emissions from the field, according to Ausdley (34).

Phosphorus (P) leached to freshwater is considered as an 11% of the P applied with the fertilizers according to Gasol (35).

The *planting seed* input is considered to take into account the production of this seed. From an environmental point of view, the planting seed is considered equal to the seed produced by the modeled field.

The *agricultural implement* input corresponds to the working tractor hours for the field operations, which is considered to be fueled either with diesel or with SVO.

3.2. Crop types

Barley, wheat and rapeseed are the crop types considered as well as fallow. Barley and wheat are greatly extended in the Mediterranean dry areas (18,19) and are also the most common in the studied area. Rapeseed can grow in the Mediterranean area; however, it has a lower yield than in areas as middle Europe wet areas.

Crop production and *fertilizers* are basic parameters that can greatly affect the model. Crop mean yields and the considered fertilization needs per hectare obtained from local farmers are used in this work. Considering the basic fertilizing elements, only N, P and K are considered due to the fact that S is considered enough in the NPK typical fertilization for the soils in the studied region.

Quantities of fertilizer products needed for each crop according to the fertilizer unit requirements and the abovementioned mean yields are shown in **Table 3**.

Table 3. Crop yield and fertilizer requirements

	Rapeseed	Wheat	Barley
Yield (kg/ha)	2300	3500	3800
Ammonium nitrate (kg/ha)	176	103	-
NPK 15-15-15 (kg/ha)	368	583	608
Potassium chloride (kg/ha)	-	58	-

These crops require appropriate pesticide application. Thus, insecticide, herbicide and fungicide treatment are considered for each crop. The types and amounts of pesticides used in the studied region are diverse, but due to lack of production data of each of them, the considered pesticides in the analysis are Alachlor (herbicide), Carbofuran (insecticide) and Benomyl (fungicide).

Fertilizers and pesticides environmental data is obtained from GaBi 4 database extension XII Renewable Materials (23) and includes overseas transport including rail and truck transport to and from major ports.

Planting seed. The amount of seed needed for each crop is 3.5 kg/ha for rapeseed, 200 kg/ha for wheat and 180 kg/ha for barley.

Agricultural implement. Another important factor when defining a crop system is the fuel consumption necessary to develop the different agricultural works. In this work, direct cropping system is considered. A mean diesel fuel consumption of 19 l/h is considered. The average time per hectare is considered according to the crop type (rapeseed: 3.75h/ha, wheat: 3.33h/ha, barley: 3.42h/ha and fallow: 0.67h/ha according to local farmers' experience in the studied area.

3.3. Crop rotation

Pathogens may build up in the soil when crops hosting the same pathogens are grown repeatedly in the same field (36). Crop rotation systems in agriculture are used to palliate the effect of pathogens, resulting in a natural pesticide treatment. Classically, fallow has been used in exploitations to allow the soil to recover some of the nutrients lost during recollection. Nowadays, the use of pesticides and fertilizers decreases the crop rotations need and the use of fallow. However, it is still very interesting to consider rotation as an exploitation yields enhancer. For example, rapeseed is considered a valuable crop that can reduce diseases in wheat and barley grain cultivation when preceding them (36).

In the considered area, 4 years rotation with 1 year of wheat (W) and 3 years of barley (B) is the most commonly used (WBBB rotation). The introduction of rapeseed in this rotation system brings many benefits, such as soil fluffing, plagues and diseases reduction and consequently an increase in the following crop yield.

The increase of crop yields due to rapeseed introduction depends on weather conditions and also on the crop sequence. In the considered region, wheat cultivated after rapeseed increases its production by 10% and barley after this wheat (2 years after rapeseed) has a 3% yield increase according to local farmers.

The traditional rotation in the studied area was WBBBF. However, the current rotation in the zone is WBBB, due to economical reasons and the availability of pesticides.

The crop rotation proposed in this work is based on the current rotation preceded by a rapeseed crop (R), thus being a 5 years rotation: RWBBB.

3.4. Harvested crops processing and rapeseed co-products

The harvested seeds and grains need to be screened and sometimes dried before storage or further processing.

Screening is the process used to separate the seeds and grains from impurities taken from the field. Impurities usually tend to be crop residues and little stones. They represent about 2% of the total weight processed according to local cooperatives (37).

The drying step is performed to reduce the water content of the seeds (rapeseed in this case) when needed. Initially, the harvested seeds have generally a mean moisture water content of about 13%, being usually dried to a moisture content of 7.5% for its conservation and to keep the seed at optimum moisture for pressing. However, farmers of the studied area remark that the drying stage is usually unnecessary thanks to climate conditions of the studied area. Thus, no drying is considered in the study.

Once the rapeseed has been screened and dried, different co-products are obtained, mainly rape seeds and straw. The straw is returned to the field as it is a valuable fertilizer complement, helping the growth of the next crop. The rape seeds can have different fates. They can be straightly sold to the market or can be processed to obtain oil and rape cake.

The process to obtain oil from the seed is different according to the production scale and final use. In the small-scale SVO production, the seeds are processed in a screw press, with an oil extraction efficiency of approximately 70%, which leads to a high oil content in the cake meal. Large-scale processing includes not only pressing but also hexane extraction of the oil, with an overall yield of about 95%. This method decreases the properties of the oil for its straight use as biofuel and requires the use of chemical compounds, larger facilities and more energy.

The proposed processing to obtain SVO is done with a pressing plant composed by a cold pressing stage (screw press) followed by filtering and water degumming stages. The latter is performed to remove hydratable gums from the oil. Along with the gums, this process also decreases the phosphorus content, which is a critical parameter to meet the current standard of SVO as fuel (38). Water degumming consists of mixing a little amount of water with the oil while stirring, followed by a decantation. Thus, the process to obtain SVO only consumes electrical energy and a few amount of water.

The whole processing requires 0.55MJ of electrical energy per kg of pressed seed. This value is calculated from the electrical power consumption of a 500kg/h selected screw press (39,40). Water degumming is considered to consume 0.09MJ of electrical energy and 0.02kg of water per kg of seed processed (41).

3.5. SVO technology and tractor emissions

There are many references in literature related to the use of SVO in diesel engines (11-13,25,42,43). However, the use of SVO in a current diesel engine without modification of at least the fuel system to heat the oil can lead to problems in the combustion chamber (14,15). There are various possible modifications to enable a diesel engine to run with SVO. In this work a double tank system with a heat exchanger is considered.

In the double tank system, to avoid fuel system blockage and difficulties on next cold start, some diesel is used when starting and stopping the engine. The considered diesel consumption is 3% of the total SVO consumption.

SVO consumption is approximately 10% higher than diesel, due to the different energy contents (LHV and densities of the fuels).

Data from diesel considered in this work is taken from GaBi database (23) and the average European fuel transportation of 100km is considered (44).

As long as the consumption is considered as explained for diesel and SVO, tractor emissions are also considered according to each fuel type. Diesel tractor emissions are according to GaBi database (23) universal tractor process. SVO emissions have been calculated using the proportions calculated from Thuneke (13).

In order to comply with new European emission standards, the tractor is considered to be equipped with a selective catalytic reduction (SCR) to treat the vehicle exhaust gases. This catalyst (AdBlue) works by injecting a solution of urea in the exhaust gases to reduce some of the NO_x emitted into N_2 and H_2O (45). In this study, the production of urea and the tractor consumption have been considered. The volume of urea solution consumed is considered to be 4.14% of the fuel used (46).

CO_2 emissions for SVO have been considered null because they are compensated by the amount of this gas absorbed during the growth of the rapeseed plant (CO_2 neutral balance) (47). SO_2 emissions are also considered null in the case of biofuels due to its low sulphur content (48).

4. Results and discussion

In this section, the LCA results and a sensitivity analysis of these results are presented.

4.1 Impact assessment

The results in this section are calculated according to the scenarios described in section 2.3. The different crop types in an exploitation are Barley, Barley-2, Fallow, Rapeseed, Wheat and Wheat-1; where Barley-2 and Wheat-1 stand, respectively, for barley 2 years after rapeseed production and wheat 1 year after rapeseed.

The comparisons of ten **CML2001 impact categories**, energy consumption and land use for each scenario based on *diesel current* scenario are shown in **Figure 3**

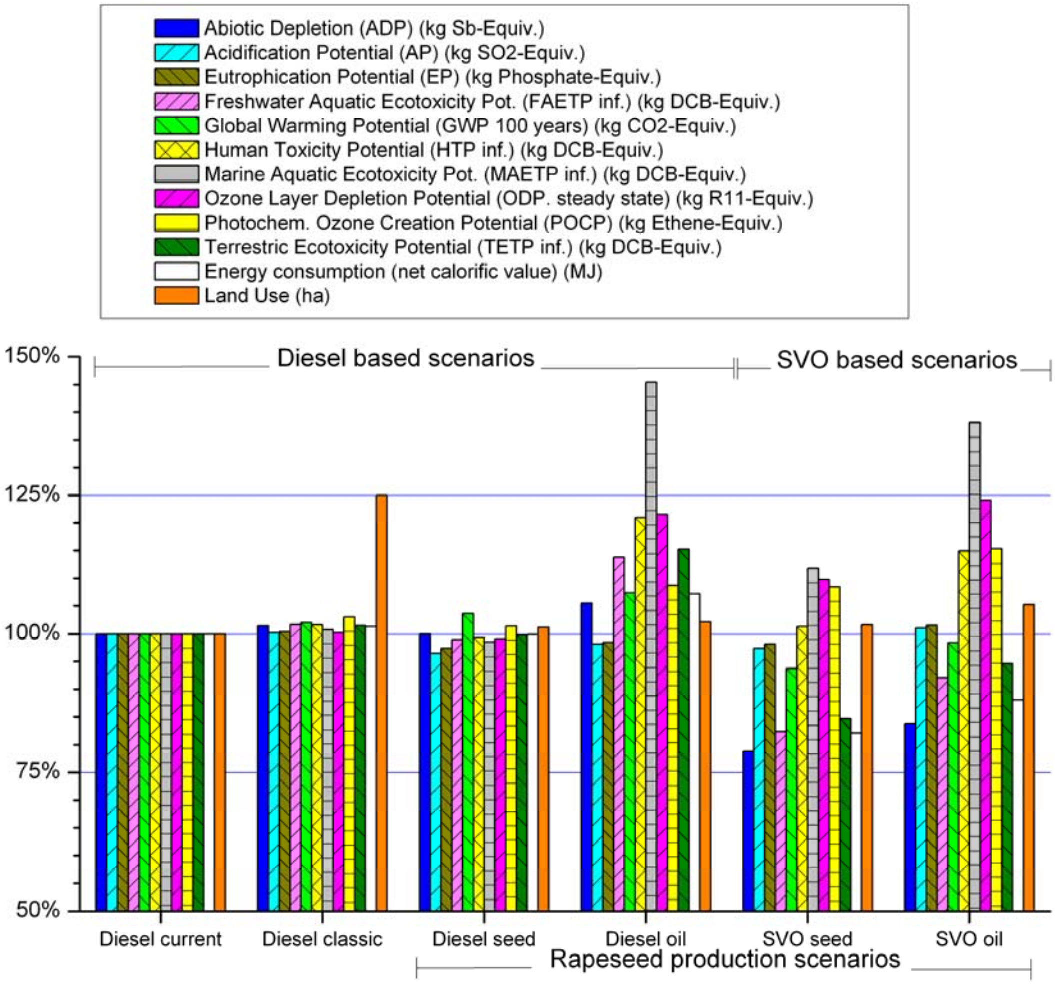

Figure 2. Environmental results and land requirement comparison for the considered scenarios.

Figure 2 shows that the *diesel classic* scenario is slightly worse from an environmental point of view than the *diesel current* scenario due to the lack of production from fallow field zone.

The scenarios involving rapeseed cultivation are also shown in **Figure 2**. The two scenarios using SVO as biofuel have lower impact results comparing to the corresponding two scenarios using diesel in most of the impact categories. Scenarios where the whole production of rapeseed is processed into oil are environmentally worse than where no seed or just a part of it is processed (e.g., *diesel oil* is worse than *diesel seed* scenario). This was already expected due to addition of a new process (pressing step) with its consumptions (mainly electricity) and emissions. The efficiency of the pressing stage is low due to current technology of the press. Thus, this efficiency could be enhanced, therefore improving the results for SVO.

ADP, FAETP and energy consumption are clearly lower in SVO based scenarios. On the other hand, MAETP, ODP and POCP are better in diesel based scenarios. Land requirement is calculated according to the functional unit and the crop rotation of each scenario, showing a clear disadvantage for *diesel classic* scenario, as it includes fallow which doesn't produce any product. A slight land requirement increase in *diesel seed* and *SVO seed* scenarios is obtained, but not much representative, being lower that 1.7%. This increase is due to the lower energy content of rapeseed compared to barley. This land requirement can be lowered if a greater rapeseed crop yield is obtained (for example in more rainy regions).

The comparison of scenarios shall be centered in *diesel current*, *diesel seed* and *SVO seed* scenarios to determine the influence of the introduction of rapeseed and the use of SVO as self-supply fuel. **Figure 3** shows the results of these 3 scenarios and the contribution of the different crop types in each impact category**.**

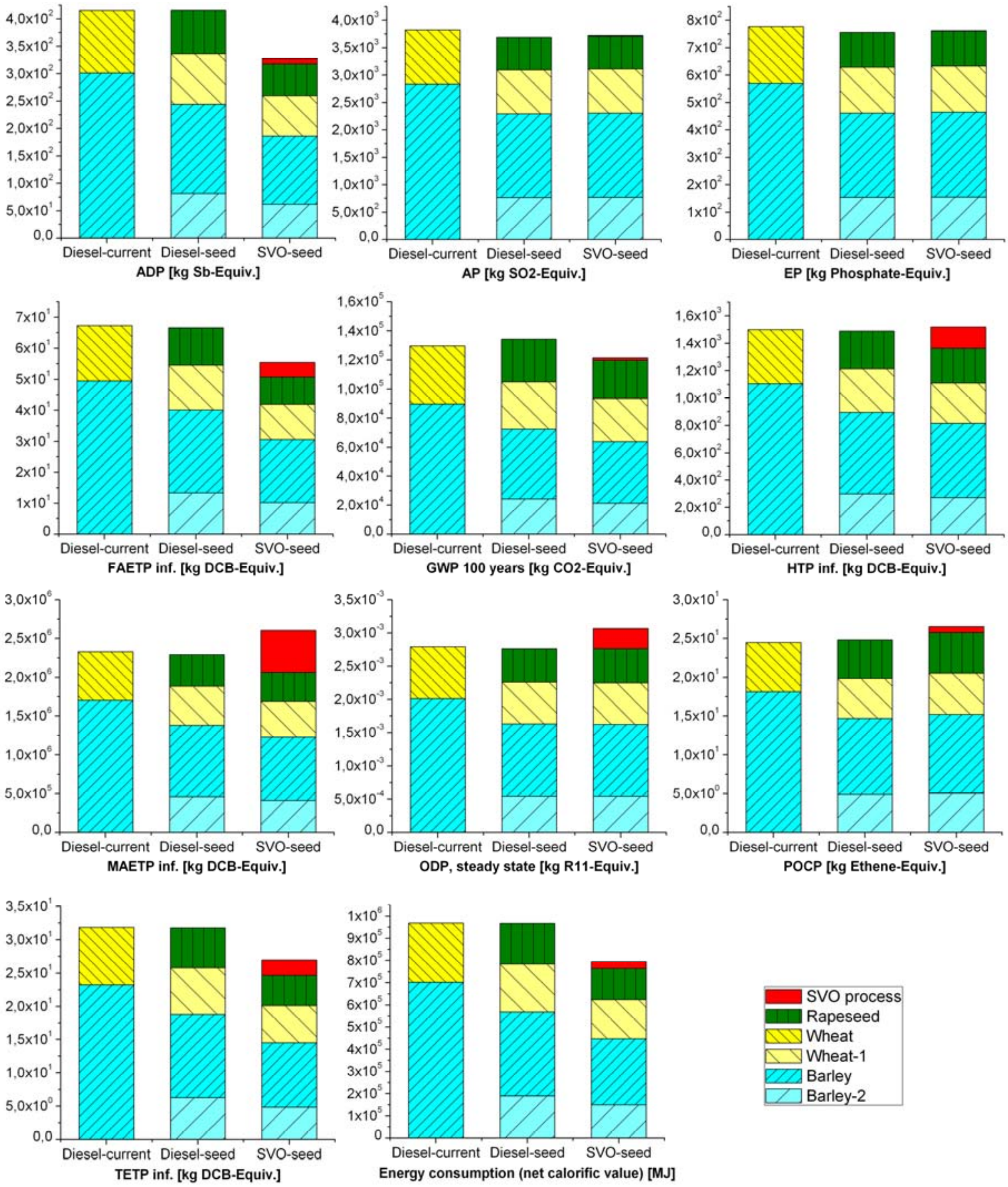

Figure 3. CML2001 impact categories results and energy input for *diesel current, diesel seed* and *SVO seed* scenarios.

The two diesel scenarios are very similar according to the results shown in **Figure 3**. The scenario using SVO as fuel (*SVO seed* scenario) is better than diesel seed scenarios in all impact categories except for MAETP, ODP and POCP. Thus, the use of SVO for agricultural self-consumption is generally better than using diesel, particularly if the seed processing impact is reduced by increasing its efficiency. Moreover, if the tractors are specifically designed or completely adapted for SVO consumption, the SVO based scenario will achieve better results.

Electrical power used in SVO processing (mainly pressing) affects negatively HTP, MAETP and ODP results compared to diesel. Electricity consumption affects also FAETP, POCP and TETP, but this effect doesn't change the comparison between *diesel seed* and *SVO seed* scenarios.

It is clear that *SVO seed* scenario is worse than *diesel current* scenario in only three impact categories: MAETP, ODP and POCP. MAETP and ODP are worse due to the electricity consumption during the conversion of seed into oil. The results of POCP impact category are worse due to the tractor emissions and the AdBlue (SCR) production. SVO fueled tractor emissions lead to 6.9% increase in POCP compared to diesel fueled tractor (the increase of NO_x and NMVOC effect is higher than the decrease in CO and SO_2). AdBlue consumption in SVO fueled tractors increases due to the fuel consumption increase. Better performance in SVO fueled tractors can be achieved adjusting engine parameters and design. These changes in the current engines can reduce this impact difference in the results.

4.2 Energy consumption

The **Crop energy ratio**, calculated dividing the energy obtained by the energy input, is clearly higher in *SVO seed* scenario compared to the other scenarios here presented, as shown in **Table 4**. Thus, even not being very high, there is a moderate advantage for the scenarios using SVO as fuel, and predominantly for *SVO seed* scenario with a 21.6% higher *crop energy ratio* than *diesel seed* scenario.

Table 4. Crop energy ratio

Diesel-current	4,32
Diesel-classic	4,26
Diesel-seed	4,32
Diesel-oil	4,03
SVO-seed	5,26
SVO-oil	4,90

4.3 Sensitivity analysis

To validate the results, a sensitivity analysis has been carried out. The major contributor to most of the impact categories is the NPK fertilizer production and transport, except for POCP (tractor emissions) and AP and EP (N_2O and mostly NH_3 field emissions). Moreover, GWP is also affected by field emissions when considering just the rapeseed field. Electricity consumption in rapeseed pressing step is the major contributor to toxicity categories and ODP.

A variation of ±20% has been considered for the abovementioned major contributors to evaluate their effect on the different impact categories. Analysis for N_2O shows less than 1% variation for all parameters except for GWP, which shows about 6% variation for both *diesel current* and *SVO seed* scenarios, so the comparison is not affected. NH_3 analysis shows an AP and EP impact variation for both scenarios of about 18.5%. Press electricity consumption sensitivity analysis shows less than 2% variation for all impact categories but MAETP (4.1% difference), affecting only *SVO seed* scenario, in which the press is used. However, this difference does not change the tendency of the results. On the other hand, NPK fertilizer quantity analysis, which is the most contributing, shows a slight improvement for SVO scenario, but without changing the conclusions of this work. Thus, the sensitivity analysis proves the validity of the selected data for the presented model.

Moreover, one of the hypotheses in this work that could affect the results is the discarding of the seeds and grains drying step. When considering drying for all products or drying just for rapeseed, the compared results show no significant difference.

5. Conclusions

The overall conclusion is that the introduction of rapeseed in the classical rotation whereas and its use to produce SVO for fuel self-consumption slightly lessens most of the environmental impacts considered. Crop energy ratio indicator shows a preference for SVO fueled scenarios, being the ratio 21.6% superior for *SVO seed* scenario compared to the current and the diesel seed one. Additionally, adverse environmental impacts to *SVO seed* scenario (MAETP, ODP and POCP) are just between 8.5% and 11.9% worse than reference scenario. Nevertheless, the possibility of greener electrical energy consumption shall be considered to lower the three impacts due to the seed processing step. Adjusting the engine parameters for SVO fueled tractors can reduce POCP and other tractor emissions. Moreover, the land requirement is increased by only 1.7%, which can be reduced by a greater rapeseed crop yield.

The environmental profile of this model is useful for research and decision making. Like in any other LCA studies, the results show which impact categories improve, which ones worsen and the most significant affecting factors.

The major strength of this agricultural model is the avoidance of diesel and the use of a self produced alternative fuel. A further advantage is the chance of using either diesel or SVO as fuel and processing the rapeseed seed or selling it according to the seed and diesel market prices, which provides independence from the market and flexibility to the farmers.

References

[1] W.M.J. Achten, P. Vandenbempt, J. Almeida, E. Mathijs, B. Muys, Life Cycle Assessment of a Palm Oil System with Simultaneous Production of Biodiesel and Cooking Oil in Cameroon, Environmental Science & Technology 44(12) (2010) 4809-4815.

[2] I. Gelfand, S.S. Snapp, G.P. Robertson, Energy Efficiency of Conventional, Organic, and Alternative Cropping Systems for Food and Fuel at a Site in the US Midwest, Environmental Science & Technology 44(10) (2010) 4006-4011.

[3] G. Gopalakrishnan, M.C. Negri, M. Wang, M. Wu, S.W. Snyder, L. Lafreniere, Biofuels, Land, and Water: A Systems Approach to Sustainability, Environmental Science & Technology 43(15) (2009) 6094-6100.

[4] D. Russi, An integrated assessment of a large-scale biodiesel production in Italy: Killing several birds with one stone?, Energy Policy 36(3) (2008) 1169-1180.

[5] P.S. Bindraban, E.H. Bulte, S.G. Conijn, Can large-scale biofuels production be sustainable by 2020?, Agricultural Systems 101(3) (2009) 197-199.

[6] J. Goldemberg, P. Guardabassi, Are biofuels a feasible option?, Energy Policy 37(1) (2009) 10-14.

[7] D.D. Hsu, D. Inman, G.A. Heath, E.J. Wolfrum, M.K. Mann, A. Aden, Life Cycle Environmental Impacts of Selected US Ethanol Production and Use Pathways in 2022, Environmental Science & Technology 44(13) (2010) 5289-5297.

[8] H. Huo, M. Wang, C. Bloyd, V. Putsche, Life-Cycle Assessment of Energy Use and Greenhouse Gas Emissions of Soybean-Derived Biodiesel and Renewable Fuels, Environmental Science & Technology 43(3) (2009) 750-756.
[9] L. Lardon, A. Helias, B. Sialve, J.P. Stayer, O. Bernard, Life-Cycle Assessment of Biodiesel Production from Microalgae, Environmental Science & Technology 43(17) (2009) 6475-6481.
[10] S.P. de Souza, S. Pacca, M.T. de Avila, J.L.B. Borges, Greenhouse gas emissions and energy balance of palm oil biofuel, Renewable Energy 35(11) (2010) 2552-2561.
[11] Y. He, Y.D. Bao, Study on rapeseed oil as alternative fuel for a single-cylinder diesel engine, Renewable Energy 28(9) (2003) 1447-1453.
[12] O.M.I. Nwafor, Emission characteristics of diesel engine running on vegetable oil with elevated fuel inlet temperature, Biomass & Bioenergy 27(5) (2004) 507-511.
[13] K. Thuneke, P. Emberger, Exhaust gas emission characteristics of rapeseed oil fuelled tractors - Investigations at a test stand, Conference: Agricultural Engineering 2007. 2001 (2007) 47-52.
[14] G. Labeckas, S. Slavinskas, Performance of direct-injection off-road diesel engine on rapeseed oil, Renewable Energy 31(6) (2006) 849-863.
[15] G. Labeckas, S. Slavinskas, Comparative performance of direct injection diesel engine operating on ethanol, petrol and rapeseed oil blends, Energy Conversion and Management 50(3) (2009) 792-801.
[16] A.K. Hossain, P.A. Davies, Plant oils as fuels for compression ignition engines: A technical review and life-cycle analysis, Renewable Energy 35(1) (2010) 1-13.
[17] DIN-51605, Fuels for vegetable oil compatible combustion engines - Fuel from rapeseed oil - Requirements and test methods, Germany, (2010) 16.
[18] J. Alvaro-Fuentes, J. Lampurlanes, C. Cantero-Martinez, Alternative Crop Rotations under Mediterranean No-Tillage Conditions: Biomass, Grain Yield, and Water-Use Efficiency, Agronomy Journal 101(5) (2009) 1227-1233.
[19] E. Madejon, J.M. Murillo, F. Moreno, M.V. Lopez, J.L. Arrue, J. Alvaro-Fuentes, C. Cantero, Effect of long-term conservation tillage on soil biochemical properties in Mediterranean Spanish areas, Soil & Tillage Research 105(1) (2009) 55-62.
[20] F. Cherubini, GHG balances of bioenergy systems - Overview of key steps in the production chain and methodological concerns, Renewable Energy 35(7) (2010) 1565-1573.
[21] ISO_14044, Environmental management - Life cycle assessment - Requirements and guidelines, Geneve, Switzerland, EN ISO 14044 (2006).
[22] ISO_14040, Environmental management - Life cycle assessment - Priciples and framework, Geneve, Switzerland, EN ISO 14040 (2006).
[23] PE_International, GaBi 4, Institut für Kunststoffprüfung und Kunststoffkunde, Stuttgart, Echterdingen (2010).
[24] USDA, United States Department of Agriculture National Nutrient Database, www.nal.usda.gov (2009), accessed: 2010
[25] B. Grau, E. Bernat, R. Antoni, R. Jordi-Roger, P. Rita, Small-scale production of straight vegetable oil from rapeseed and its use as biofuel in the Spanish territory, Energy Policy 38(1) (2010) 189-196.

[26] FEDNA, Fundación Española para el Desarrollo de la Nutrición Animal. Tablas de ingredientes para piensos, http://www.etsia.upm.es/fedna/tablas.htm (2003), accessed: 2010
[27] E. Martinez, F. Sanz, S. Pellegrini, E. Jimenez, J. Blanco, Life-cycle assessment of a 2-MW rated power wind turbine: CML method, International Journal of Life Cycle Assessment 14(1) (2009) 52-63.
[28] G. Guinée JB., M., Heijungs, R., Huppes, G., Kleijn R, van Oers, L., Wegener Sleeswijk, A., Suh, S., Udo de Haes HA., de Bruijn, JA., Ivan Duin R. and Huijbregts MAJ., Life cycle assessment: an operational guide to the ISO standards, 2009 (2001).
[29] K. Mulder, N.J. Hagens, Energy return on investment: Toward a consistent framework, Ambio 37(2) (2008) 74-79.
[30] Y. Li, D.L. Chen, F. Barker-Reid, R. Eckard, Simulation of N2O emissions from rain-fed wheat and the impact of climate variation in southeastern Australia, Plant and Soil 309(1-2) (2008) 239-251.
[31] IPCC, Guidelines for National Greenhouse Gas Inventories, prepared by the National Greenhouse Gas Inventories Programme, Chapter 11, N2O emissions from managed soils, and CO2 emissions from lime and urea application, www.ipcc-nggip.iges.or.jp/public/2006gl/index.html (2006), accessed: 2010
[32] P.J. Crutzen, A.R. Mosier, K.A. Smith, W. Winiwarter, N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels, Atmospheric Chemistry and Physics 8(2) (2008) 389-395.
[33] L. Reijnders, M.A.J. Huijbregts, Biogenic greenhouse gas emissions linked to the life cycles of biodiesel derived from European rapeseed and Brazilian soybeans, Journal of Cleaner Production 16(18) (2008) 1943-1948.
[34] E. Audsley, Harmonisation of environmental life cycle assessment, Final Report Concerted action AIR3-CT94-2028. European Commission. DG VI Agriculture, (1997).
[35] C.M. Gasol, X. Gabarrell, A. Anton, M. Rigola, J. Carrasco, P. Ciria, M.L. Solano, J. Rieradevall, Life cycle assessment of a Brassica carinata bioenergy cropping system in southern Europe, Biomass & Bioenergy 31(8) (2007) 543-555.
[36] B. Mattsson, C. Cederberg, L. Blix, Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops, Journal of Cleaner Production 8(4) (2000) 283-292.
[37] C. de_la_Peña, Harvested crops processing and rapeseed conversion to oil, Cooperativa del Campo de San Gregorio, Pina de Ebro. Personal communication June 2009 (2009).
[38] DIN-V-51605, Fuels for vegetable oil compatible combustion engines - Fuel from rapeseed oil - Requirements and test methods, Germany, (2006).
[39] A. Bosquet, Electronic communication with sales manager of La Mécanique Moderne, (2009).
[40] F. Braack, Electronic communication with sales agent of Maschinenfabrik Reinartz GmbH&Co. KG., (2009).
[41] Y. Lechón, H. Cabal, C.d.l. Rúa, C. Lago, L. Izquierdo, R.M. Sáez, M.F.S. Miguel, LCA de combustibles alternativos para el transporte. Fase II: LCA comparativo del biodiésel y del diésel., Energía y Cambio Climático, www.ciemat.es (2006), accessed: 2008

[42] R. Altin, S. Cetinkaya, H.S. Yucesu, The potential of using vegetable oil fuels as fuel for diesel engines, Energy Conversion and Management 42(5) (2001) 529-538.
[43] O.M.I. Nwafor, The effect of elevated fuel inlet temperature on performance of diesel engine running on neat vegetable oil at constant speed conditions, Renewable Energy 28(2) (2003) 171-181.
[44] C.A. Lewis, Fuel and energy production emission factors, MEET Project: Methodologies for Estimating Air Pollutant Emissions from Transport (Task No. 3.4), (1997).
[45] F. Klingstedt, K. Arve, K. Eranen, D.Y. Murzin, Toward improved catalytic low-temperature NOx removal in diesel-powered vehicles, Accounts of Chemical Research 39(4) (2006) 273-282.
[46] BlueCat, How much AdBlue will a vehicles use http://www.bluecat.ie/FAQ/AdBlue_FAQ/How_much_AdBlue_will_a_vehicles_use.html (2005), accessed: 2009
[47] C.M. Gasol, X. Gabarrell, A. Anton, M. Rigola, J. Carrasco, P. Ciria, J. Rieradevall, LCA of poplar bioenergy system compared with Brassica carinata energy crop and natural gas in regional scenario, Biomass & Bioenergy 33(1) (2009) 119-129.
[48] G. Vaitilingom, C. Perilhon, A. Liennard, M. Gandon, Development of rape seed oil burners for drying and heating, Industrial Crops and Products 7(2-3) (1998) 273-279.