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Use of Rapeseed Straight Vegetable Oil as Fuel Produced in Small-Scale Exploitations

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1. Introduction

The current dependence on oil in most industrial sectors and mainly in the transport sector is unsustainable neither in short nor in long term. This encourages to consider alternatives in most industrial sectors and incentivises to promote renewable energy use. In addition, the EU is promoting or even forcing the use of renewable energies in order to accomplish the commitments under the Kyoto Protocol.

In Europe the most common biofuels in transport are biodiesel and bioethanol. These biofuels are mostly obtained from large-scale plants and its production involves serious environmental and social problems as shown by several authors (Russi, 2008; Galan et al., 2009). In this scenario it is necessary to implement other biofuels currently not present in the Spanish market.

Straight vegetable oil (SVO) is a biofuel that can be small-scale produced from rapeseed planted in dry Mediterranean areas. The small-scale production presents several advantages and is more sustainable than large-scale production as cited by several authors (Baquero et al., 2010).

This chapter presents a method to produce rapeseed and process it to obtain rapeseed oil and rapeseed cake meal from a small-scale point of view. It also shows how rapeseed oil can be used as fuel in diesel engines for agriculture self-consumption. A production, processing and use-as-fuel model for rapeseed oil is also presented, analysing environmentally and economically the use of rapeseed oil as fuel compared to other agricultural production alternatives. The results are evaluated for dry Mediterranean area conditions.

2. Rapeseed production

Rapeseed is an oleaginous plant widely distributed all around the world. It has the capacity to grow and develop under temperate climate. Rapeseed is adapted to many soils, being the fertile and well-drained soils the more advantageous, as it has low tolerance to floods. The best are loamy soils, composed of clay, silt and sand. The desirable pH is from 5.5 to 7, but it also withstands some alkalinity, up to 8.3. It is resistant to periods of drought due to its deep taproot and the fibrous near-surface root system and has a good recovery after the drought (Sattell et al., 1998). An image of the rapeseed flower is shown in Figure 1.

In the studied zone the rapeseed is a dry farming plant. Thanks to its deep roots, rapeseed can gain access to subterranean water resources better than wheat and barley, grains usually grown in the area studied. The recommended field rotation for rapeseed is planting every five years in rotation with wheat (1 year) and barley (3 years). If there were strong price expectations, producers might keep rapeseed in the same field for two or even three years at the risk of the crop developing fungal diseases (Provance et al., 2000).

Fig. 1. Image of the flower and siliqua of rape (Photo J.F. Marti).

In order to select the rapeseed variety better adapted to the area of study (Anoia area in Catalonia, Spain, selected as a dry Mediterranean area) a test has been carried out in an experimental and representative field. The yield and the oil content of 9 rapeseed varieties were studied during the harvest of 2006. The experimental field was divided into 36 rectangular divisions, this is to say, 4 replicas of each one of the 9 studied rapeseed varieties were performed.
This study is still being carried out in order to average the results obtained in various years. Table 1 shows the preliminary results obtained in the harvest of 2006. The results obtained in 2008 were unusable because of the hard drought suffered in the autumn of 2007 and the winter of 2007-2008.

Variety	Supplier	Average oil content (%)	Rapeseed yield (kg/ha)
Bellini	Aceites Borges Pont	41.6	3636
Pacific	Limagrain Iberica	42.6	4645
Madrigal	Koipesol semillas	39.1	4525
Aviso	Aceites Borges Pont	40.5	4348
Sun	Agrusa	41.5	5251
Potomac	Limagrain Iberica	38.7	5251
Bambin	Agrusa	42.0	-
Royal	Koipesol semillas	39.5	5110
Standing	S.A. Marisa	40.3	4722

Table 1. Studied varieties of rapeseed. Average oil content and yield.

The average oil content of the 9 varieties and rapeseed yield are presented in Table 1 with an average content of humidity of 9.0% in the harvest of 2006. The analysis was carried out by applying the method described by EUETII-UPC (2006).
It should be pointed out that edge effects associated to experimental small rectangular divisions results in higher experimental yields than those found in real arable fields. From

Table 1 it seems clear that the rapeseed variety with more oil content is the Pacific, but the varieties with higher yield are Sun and Potomac. Thus, the Sun rapeseed variety maximized the rapeseed oil yield in the study of the harvest of 2006.

As a ground fertilization, the application was 450 kg/ha of a fertilizer of 15% nitrogen, 0 % phosphorus, and 15% potassium oxide. Additionally, 260 kg/ha of ammonium nitrosulphate of 27% nitrogen was spread out as a fertilizer coverage.

Before sowing, an herbicide treatment consistent in Trifluralin (48%, 2.5 l/ha), Glyphosate (36%, 1.0 l/ha) and Metazachlor (50%, 3.5 l/ha) was applied. The insecticide treatment was an application of Deltamethrin 2.5% of 0.4 l/ha.

Rapeseed agricultural production includes the use of different products (fertilizers, pesticides, herbicides, fungicides, rapeseed seed to plant) for its cultivation as long as the agricultural work done (mainly tractor work). Considering the studied region, dry farming conditions for rapeseed are taken into account. The yields in Table 1 are very high because they are obtained from an experimental study, where the edge effect and other variables increase this production value. In this study, the rapeseed yield mean value considered is 2300 kg/ha. The use of 3 kg/ha of fertilizer and 2kg/ha of herbicide are considered. In the area of study, the straw from the collected seeds is usually left in the field as fertilizer, so the straw is considered a co-product used as fertilizer for next year.

3. Rapeseed processing

The processing of the rapeseed to obtain SVO to be used as engine fuel is made through three mechanical steps: cleaning of seed, pressing and purification (see Fig. 2). The first step consists of cleaning the seeds from stones, metal pieces and straw. In this process it is very important to reduce the risk of damaging the press.

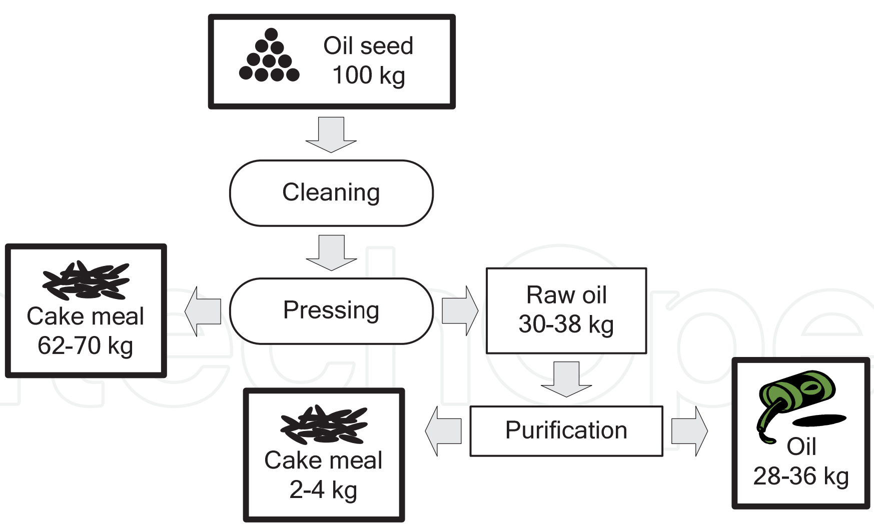

Fig. 2. Rape seed oil processing.

The second step is a cold pressing of the oil seed with the screw press to obtain oil. This step must be done carefully to reduce the incorporation of undesirable materials from the solid by-product (rapeseed cake) The pressing process influences the content of phosphorus, calcium and magnesium as well as the content and dimension of the particles. The variability of those elements depends on the speed and the pressing temperature. A low speed (low throughput) increases the oil yield and the content of particles. A high speed (high throughput), produces the opposite effect, decreasing the oil yield and also the particles. It is possible to find an optimal compromise according to the necessities of production and capacity of filtering. The oil yield should be between 32-36% of rapeseed mass, due to the amount of undesirable particles obtained in the oil if the pressure is too high or if a second pressing is done (Ferchau, 2000).

As a final step, purification of raw oil obtained from the press is needed. It is recommended to use a press filter and to perform a security filtration after a decantation. A general filtration procedure must be done after decantation in order to remove the suspended particles from the oil. Usually a pressure filter is used, either a chamber filter or a vertical one. As a final step, a security filtration of a defined pore size (between 1 and 5 µm) is recommended to remove the finest particles that still remain in the oil. In this step is very important to pass the quality control exposed in section 4.5. After this final step and after complying with the quality control, the oil is prepared for combustion in a modified diesel engine.

The cake meal and the filter cake obtained in the process to obtain SVO both have a high content of protein and are suitable for being incorporated as part of animal fodder

There is a variation of this process to extract more oil from the seed using a solvent. The abovementioned process is the first step. About 70% of oil from the seed is extracted, leaving 30% in cake meal. The next stage is a process of extraction using hexane as solvent. It reaches up to 95% extraction of the seed oil. In this stage, a solvent (hexane) is mixed with rapeseed cake. The solvent dissolves the oil remaining in the rapeseed cake. After its evaporation, the solvent is recovered for its use. The outline of the process is shown in Figure 3. In case of hexane extraction, the cake meal obtained has less protein than when just pressing the seed. Even though, there is no problem to use it as animal food.

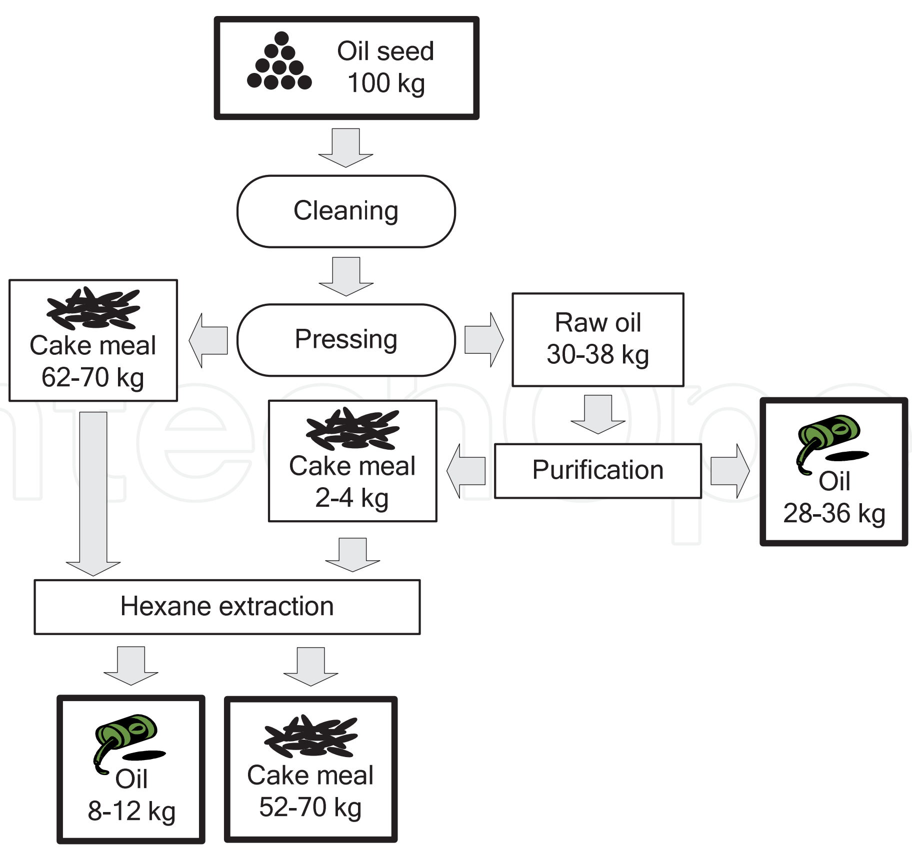

Fig. 3. Rapeseed oil hexane extraction process.

4. Use of rapeseed oil as fuel

4.1 Use of rapeseed SVO in diesel engines

Rapeseed oil can be used as fuel in diesel engines. Other vegetable oils can also be used as SVO to fuel diesel engines because they have similar properties. In Table 2 the properties of different oils are shown. The differences in the oil properties are small. However, to replace diesel fuel, some modifications are required to adjust the physical properties of the oil to be pumped to the engine and pulverized in diesel common injectors.

Fuel type		Diesel fuel	Rapeseed oil	Corn oil	Soybean oil
LHV[a] (MJ/kg)[b]		43.35	37.62	37.83	39.62
Density 20°C (kg/m^3)[c]		828	915	920	920
Energy content (MJ/l)[b,c]		35.81	34.42	34.80	36.45
Viscosity (mm^2/s)[c]	20°C	4.64	75.27	70.8	64.37
	80°C	1.64	12.27	11.65	11.29
Cetane number[b]		47	37.6	37.6	37.9
Flame point (°C)[b]		58	275-290	270-295	230
Chemical formula[b]		$C_{16}H_{34}$	$C_{57}H_{105}O_6$	$C_{56}H_{103}O_6$	$C_{56}H_{102}O_6$
[a]LHV: Lower Calorific Value; [b](Altin et al., 2001); [c](Riba et al., 2010)					

Table 2. Physical and chemical specifications of some vegetable oil fuels.

The modifications are aimed to heat the rapeseed oil to reduce its viscosity and density. During start-up, the vehicle runs with diesel to avoid the engine working at low temperatures with straight vegetable oil. Once the engine has warmed, it will be able to heat and use SVO. Note that the engine shouldn't be stopped for a long time when using SVO, otherwise it will be complicated to cold start the engine with SVO.

The components that need to be installed in the fuel supply system:

- an additional deposit for the start-up diesel
- a water-oil heat exchanger
- a temperature sensor
- two solenoid valves to select the fuel to be used
- filters for oil and diesel fuels

The use of vegetable oil as fuel started long ago. Rudolf Diesel used peanut oil to run a diesel engine at the World Exhibition in Paris in 1900 (Baquero et al., 2010). He also suggested that vegetable oils could be the future fuel for diesel engines, but diesel fuel from oil substituted vegetable oil due to its abundance and price.

The use of SVO in diesel engines carries also some difficulties, namely:

- difficulties in operating the motor itself because of the different ignition temperatures of the two fuels. These difficulties can be solved just by preheating the vegetable oil.

- problems of engine durability due to deposit formation in the combustion chamber and mix of the vegetable oil with the engine lubricating oil. The first problem is solved by increasing the vegetable oil temperature, so it decreases its viscosity and density, which allows a correct injection and burning of the vegetable oil. The second problem is solved by reducing the life of the engine lubricant, (Agarwal et al., 2008; Vaitilingom et al., 2008).

Despite these difficulties, it is noteworthy that both fuels have very similar energy content: 34.42 MJ/l for rapeseed SVO and 35.81 MJ/l for diesel fuel. This makes the engine performance and consumption very similar for both fuels. If we compare the performance of both fuels in the same engine, experimental results show that the performance of a vehicle running on diesel is optimal at low loads, whereas working with vegetable oil is optimal at high loads.

4.2 Oil as fuel quality control

In order to use rapeseed oil as fuel, some physical and chemical properties of the oil must be met. The description of these properties as well as its effect on the diesel engine should be taken into account. Thus, the German norm DIN 51605 is to be followed.
This norm establishes the maximum and minimum values for the parameters selected to accept a rapeseed vegetable oil as appropriate biofuel to substitute diesel in modified engines. The parameters include some intrinsic rapeseed oil properties and some which are variable and indicate if the oil has been correctly processed. Between these properties, acid value, iodine index and oxidation time are the ones which indicate the vegetable oil degradation.

4.3 Use of SVO as fuel

The authors experience in the use of a car with a modified diesel engine is described in this section. The car which engine was adapted to run with SVO is a VW Caddy 2.0 SDI using the parts described in section 4.1.
Table 3 presents the results of a test performed by the authors of this paper with the modified VW Caddy 2.0 SDI after 45000 km of trial. The consumption of this vehicle using diesel is nearly the same as with SVO, as the calorific value of both fuels are almost the same.

Own average consumption (l/100km)	7.54
Total distance (km)	45000
Fuel consumption (l)	3393
Average rate oil/total (%)	91.36%
SVO consumption (l)	3100

Table 3. SVO consumption as fuel.

From the technical data available from Volkswagen, the urban consumption for this vehicle is 7.5 l/100km, the extra-urban is 5.3 l/100km and the combined consumption is 6.1 l/100km. The test carried out with the above-mentioned 70 HP vehicle shows that maintaining an average speed of 70-80 km/h leads to an average consumption of about 6 l/100km. Driving faster, maintaining 120 km/h during long periods of the ride, leads to a consumption of about 9 l/100km.

5. Use of rapeseed cake for animal feeding

Due to its high content of protein, it is interesting to consider the use of rapeseed cake for animal feeding. The incorporation of cake meal in animal fodder is studied in many works, which support the fact that cake meal is suitable as animal fodder complement.
The introduction of rapeseed cake as part of the fodder has been largely studied. A lot of studies have been carried out and the results show that the introduction of rapeseed cake in

little proportions in the fodder (until 10-15%) entails no significant changes in parameters such as nitrogen, lipid and mineral metabolism and also for the health status of the animals (Gopfert et al., 2006). Even in cow milk, no significant differences were found in fat, protein, casein, solids and non-solids fat content in the milk from cows fed with 15% of rape cake in fodder (Simek et al., 2000). Other studies of rapeseed used in different forms (Brzoska, 2008; Kracht et al., 2004) and (Rinne et al., 1999) show no negative effects on animal neither to their meat nor the milk obtained.
Rapeseed is nowadays used as a component in the fodder of many animals. The limit proportion is not determined by law in Spain, but some recommendations have been given by the Spanish Animal Nutritional Foundation (FEDNA, 2003) for the different species and ages. In Table 4 the mean chemical composition of rapeseed meal is shown (Moss & Givens, 1994).

Crude protein (g/kg DM[a])	397
Crude fiber (g/kg DM[a])	106
Cellulose (g/kg DM[a])	177
Starch (g/kg DM[a])	45
Water-soluble carbohydrates (g/kg DM[a])	115
Gross Energy (MJ/kg DM[a])	19.7
[a]DM: Dry matter	

Table 4. Mean chemical composition of rapeseed meal.

The most representative groups of farm animals in the studied area are cattle, pigs and poultry (IDESCAT, 2008). Using the total number of animals and the characteristic intake of each species, the potential fodder demand is calculated. In Table 5 the values of fodder consumption in the Anoia region are shown for these representative groups. The proportion of cake meal in fodder was calculated using FEDNA (2003) recommendations. The cake meal yield (1500 kg_{cake}/ha) is calculated based on the yield of rapeseed in the regions –2300 kg/ha as detailed in section 2– and the amount of oil extracted through pressing –35% from rapeseed w/w as seen in section 3–.

Animal group	**Bovines**	**Pigs**	**Poultries**	**Total**
Number of livestock per year	6779	89439	607491	-
Fodder (t/year)	16321.8	62093.2	22958.4	-
Maximum cake meal in fodder (%)	17%	7%	5%	-
Maximal cake meal consumption (t/year)	2774.7	4346.5	1147.9	8269.2
Cake meal yield (kg/ha)	1500	1500	1500	-
Rapeseed land (ha)	1849.8	2897.7	765.3	5512.8

Table 5. Rapeseed land requirement.

The fodder demand in the considered region could absorb completely the amount of rapeseed cake meal produced if a tenth of the arable land (about 3000 ha) was dedicated to rapeseed production. As seen in Table 5, the amount of land requirement for rapeseed cultivation to cover the maximal cake meal consumption of the studied area is about 5500 ha.

6. Proposed cropping model and agricultural exploitation

The previous sections show the rapeseed production, the rapeseed processing to obtain oil and the use of the cake meal obtained from the seed processing. This information can be used to develop a cropping model that comprises the introduction of rapeseed to the current agricultural rotation based on wheat and barley (WBBB, where W stands for wheat and B for barley). The proposed rotation would preserve the 3 years of barley after one year of wheat in each field portion adding on year rapeseed prior to wheat (RWBBB). The introduction of rapeseed increases the two next following crop yields by 10% (wheat) and 3% (barley) for normal weather conditions. Additionally to the introduction of rapeseed to the rotation, the processing of the seed into oil and cake meal would allow its use as straight vegetable oil to fuel the exploitation tractor.

The proposed model for small-scale biofuel self consumption exploitations is graphically represented in Fig. 4, where the basis model, the rapeseed processing and the fate of the different products obtained are shown.

In order to design this model some hypotheses have to be made. First of all, small-scale producers are considered. The mean farmer is supposed to work an arable land of about 100 ha. The proposal involves using approximately 10% of the arable land for self-supply. In the studied area, as a dry Mediterranean zone, irrigated lands are nearly inexistent, being the traditional sowed crops wheat and barley. It is proposed to cultivate rapeseed as a dry crop in order to avoid putting pressure on water resources. Secondly, the system of crop-rotation jointly with direct seeding is going to be applied. Thus, rapeseed can be seeded in the same land one out of five years. Only the seeds are extracted whereas the rest of the plant is crushed while gathering the seed and left on the fields to be rot. Doing so, the soil recovers part of the nutrients contained in the straw from the plant, thus avoiding the use of some amount of fertilizer. Finally, the farmers bring the harvest to the farmer's cooperative, which is located near their lands and where there is an industrial press for extracting the oil of the rapeseed harvest.

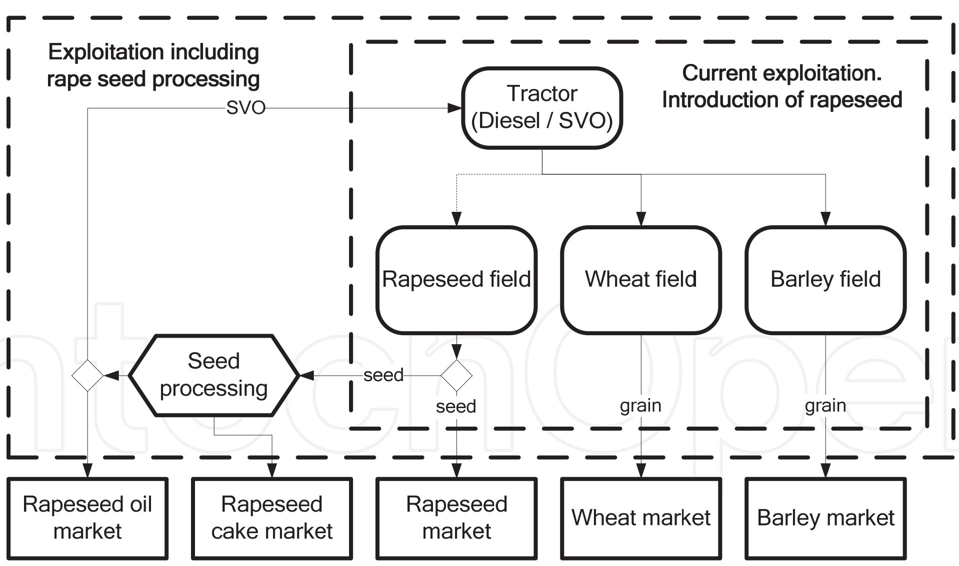

Fig. 4. Exploitation model and products fate.

Important institutions such as the Food and Agriculture Organization (FAO) of the United Nations support good agricultural practices to mitigate negative impacts, in particular on carbon, soil and water resources. Among such practices we find no tillage and direct seeding, retention of soil cover, multiple cropping, appropriate crop choice and crop rotations. There are mainly three systems of harvest namely traditional seeding, minimum cultivation and direct seeding that nowadays coexist in the studied area, being direct seeding the chosen one for its lower impact, better carbon retention in soil and reduced fuel consumption.

General assumptions are made in this model. For example, the press is assumed to extract in average 80-85% of the total oil content from the seeds. This means that after pressing, seeds are converted in a 35%of oil and a 65%of meal cake. Additionally, according to a survey answered by farmers in the Anoia area (EUETII-UPC, 2010), the average yield of the rapeseed harvest in this area is a minimum of about 2300 kg of rapeseed/ha.

Supposing a direct harvesting system of cultivation, the fuel consumption would be about 7000 l per 100 ha. As explained, the production of rapeseed SVO is supposed to be 875 l per ha. Therefore, dedicating 10% of the arable land to cultivating rapeseed is enough for self fuel supply. Also there is a small excess of SVO that could be sold for other needs. Vegetable oils can be also used in the production of additives that are useful for various industrial purposes as pointed out by (Hancsok et al., 2008). The 15000 kg of rapeseed cake per 10 ha would be used to feed the animals in this area as calculated in section 5.

7. Environmental and economic analyses

Life cycle assessment (LCA) is a methodology widely used to evaluate environmentally all kind of processes and products production (Hsu et al., 2010; Huo et al., 2009; Lardon., 2009; Schmidt, 2010). Economic assessment based on LCA methodology is also being used in literature (Lee et al., 2009; Huppes et al., 2010; Ouyang et al., 2009; Nassen., et al 2008).

7.1 Environmental analysis

As FAO indicates (FAO, 2008), a policy objective by many countries entails mitigating climate change by means of bioenergy promotion. Conversely, life-cycle analyses -which measure emissions all over the bioenergy production chain- points toward a wide divergence in carbon balances according to technologies used, locations and production paths. Thus, more research should be carried out in this field. As FAO suggests, important sources of emissions seem to be land conversion, mechanization and fertilizer use at the feedstock production stage, as well as the use of non-renewable energy in processing and transport.

To evaluate the environmental impact of the model suggested in this work, a general analysis of different topics can be done: energy and water requirements, biodegradability, equivalent CO_2 emissions (global warming), tailpipe engine emissions and deforestation. Moreover, LCA methodology (Schmidt, 2010) is used to comparatively evaluate environmental impacts.

Regarding to the use of energy, the proposed method nearly eliminates the impacts related to fuel processing and transport, which allows minimizing energy requirements. Fossil fuels, on the contrary, are transported from remote countries as well as raw materials to produce large-scale first-generation biofuels. Furthermore, both fossil fuels and first-generation biofuels need complex processing, which requires significant amounts of energy. Therefore, the proposed model reduces significantly energy consumption. Additionally, rapeseed cultivation helps crop rotation and direct seeding. This is highly recommended as it reduces the steps of land working, thus minimizing power requirements. This results in less use of fuel for each crop, which is a desirable way to reduce emissions.

As for water requirements, as (FAO., 2008) states, many feedstocks are highly water intensive, meaning that their expansion is likely to create even greater competition for this limited resource, depending upon location and production methods. The method proposed here, moves towards a dry land use, as rapeseed is able to grow in the same conditions as replaced cereals would do. On the other hand, water requirements of SVO production are null whereas as stated by (Pate et al., 2007), water requirements of bioethanol with the current technology are about 4 litres of water per litre of bioethanol produced. Consumptive water use in petroleum refining is about 1.5 l/l and biodiesel refining requires about 1 litre of fresh water per litre of biodiesel produced.

Additionally, concerning biodegradability, commonly used SVOs including rapeseed oil are biodegradable and non-toxic, making them useful for transportation applications in highly sensitive environments, such as marine ecosystems and mining enclosures for example (West et al., 2008). This implies less risk when storing the fuel and less impact to biodiversity if accidentally spoiled.

To compare the CO_2 emissions from both models, their differences have to be considered. As long as use of machinery, fertilizer and herbicide requirements are similar, the main variation between the two systems is the use of SVO instead of petrodiesel.

Emissions associated to transport, production and combustion of 1 litre of petrodiesel are 3.16 kg CO_2/l (Flessa et al., 2002). Approximately a 10% of these emissions result from the extraction, production and transport of the diesel fuel and the remaining 90% are due to its combustion. The fuel consumption for direct seeding and for traditional seeding, according to local farmers, are respectively 70 and 140 l fuel/ha. Thus, the emitted CO_2 due to tractor diesel consumption when using traditional seeding doubles the direct seeding method.

On the other hand, the CO_2 emitted when burning SVO in a diesel engine was absorbed by the crop during growth (CO_2 neutral). Consequently, these emissions are compensated by the photosynthesis absorption. SVO production is very simple and has a low energy requirement, as already seen. Thus, the CO_2 associated emissions of this stage are much lower than the ones from petrodiesel.

According to these results, the proposed system avoids the emission of more than 200 kg CO_2/ha. In future studies, a life-cycle assessment of this model will be carried out in order to take into account all the emissions in the studied area. Life-cycle analyses would measure the emissions throughout all the bioenergy production chain.

Regarding tailpipe engine emissions, diverging results are found (Krahl et al., 2007; Thuneke & Emberger, 2007). As concerns CO, CO_2 or Particulate Matter (PM) emissions, the SVO is clearly better than petrodiesel. Meanwhile, looking at NOx and HC it is not clear if the use of SVO reduces or increases its emissions. Thus, more research is needed to study this field in greater depth.

In relation to deforestation, the high demands of productive soil in large-scale production of biofuels would produce deforestation especially in tropical forests (Russi, 2008). On the other hand, the small scale production plant presented here deals with a small portion of the amount of available land to produce biofuel, thus avoiding the abovementioned impact.

In order to achieve representative results, the general framework for conducting an LCA is followed in this work (ISO 14040, 2006; ISO 14044, 2006). Taking the cropping model presented in section 6, Gabi 4 software (PE International 2010) has been used to carry out the LCA impact assessment.

The use of diesel or straight vegetable oil (SVO) as the tractor fuel is also included to take into account the consumption and the corresponding fuel emissions. Crop types are considered depending on the crop rotation chosen for each scenario. Data on crop works, fertilizing needs and yields were obtained from the Anoia region, a northeastern dry Mediterranean area in Spain.

Different cropping schemes are studied fixing the functional unit in 10^9kcal of energy produced, because this is the energy obtained from approximately 100ha of land. Direct cropping technique is assumed. An energy functional unit is the most suitable to evaluate a system where different outputs are found, namely barley grain, wheat grain, rapeseed seed, cake and oil.

The system boundary includes an agricultural exploitation where different crop types are considered. The fate of the obtained products is not considered, only the energy that each obtained product represents. The boundaries comprehend (i) materials inputs which take into account fertilizers, herbicides, insecticides, fungicides, diesel fuel and planting seeds, (ii) cropping stages including fertilizing, herbicide, insecticide and fungicide treatments, sowing, harvesting and seed/grain transportation to cooperative installations, and (iii) rapeseed processing stage which includes transportation, pressing, filtering and degumming processes.

Three scenarios are considered for this environmental assessment, based on grouping three crop types, namely barley, wheat and rapeseed. Barley, wheat and rapeseed models 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. The use of SVO as fuel is also considered in one scenario. Thus, the first scenario is the current exploitation method (**current scenario**). The second incorporates rapeseed into crop rotation but uses only diesel fuel (**diesel scenario**). The third additionally includes rapeseed processing and SVO fuel use (**SVO scenario**).

Emissions of the considered model are aggregated into impact categories according to an international accepted method in the impact assessment phase. 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 (Guinée et al., 2001; Alvaro-Fuentes et al., 2009). It is a cause-effect method that limits the uncertainty in groups according to impact categories (Dreyer et al., 2003). It calculates the increase of damage and quantifies its effects (Garraín, 2009).

Fig. 5 shows the environmental impact category results using 6 CML non-toxicological impact categories, energy consumption and land use for each scenario taking the current one as a basis. The introduction of rapeseed in the classical rotation and its use to produce SVO for fuel self-consumption slightly lessens some of the environmental impacts considered. Crop energy ratio indicator shows a preference for SVO fuelled scenarios, being the ratio 21.6% superior for SVO scenario compared to the current and the diesel seed one. Adverse environmental impacts to SVO scenario (ODP and POCP) are just 8.5% and 9.8% worse than reference scenario. A slight land requirement increase in both diesel and SVO scenarios is obtained, but not much representative, being lower that 1.7%. Favourable environmental impacts to SVO scenario (ADP and GWP) are down to 21.2% and 6.2% lower than reference scenario. AP and EP are 2.7% and 1.9% lower than reference scenario, not being much representative. On the other hand, diesel scenario impacts compared to reference scenario varies less than 4%, being practically the same. The higher diesel scenario impact is global warming potential (GWP), which increases 3.7% whereas in SVO scenario lessens 6.2%. Sensitivity analysis carried out show practically no variation in tendency, however, the impact of the electrical energy use in SVO scenario can be reduced if renewable electrical energy is used.

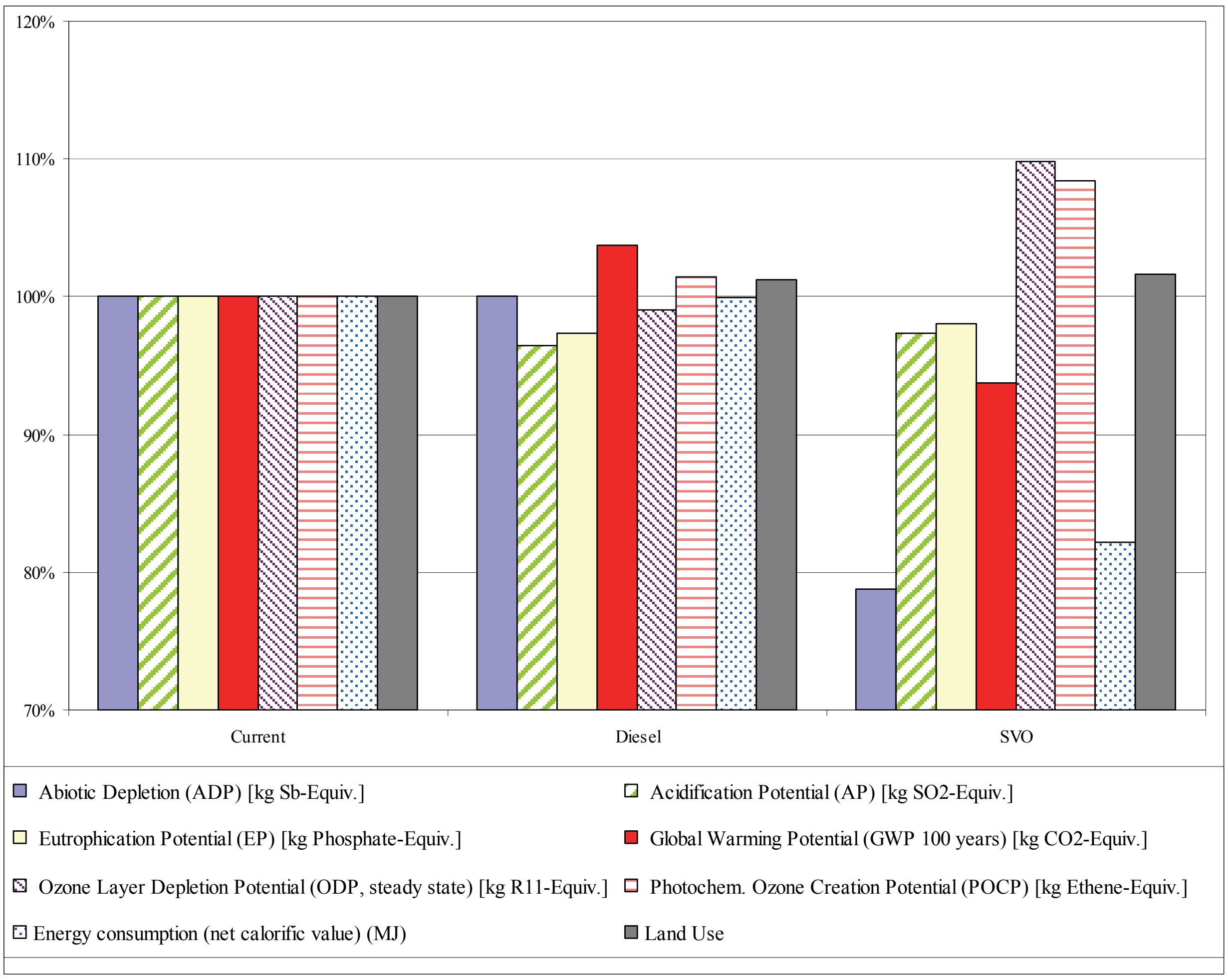

Fig. 5. Environmental impact category results

7.2 Economic analysis

Following the same model as in the environmental analysis, an economic assessment is done to evaluate the different cropping alternatives considered for the region. Thus, a comparative economic result can be achieved. Life cycle costing (LCC) methodology enables the compilation and evaluation of the inputs, outputs and the potential economic benefit of a product system throughout its life cycle (Lee et al., 2009). There are different LCC approaches, depending on their target, the costs involved and the context of the LCC itself. LCC is used in many fields, such as building techniques and rebuilding (Nassen et al., 2008; Ouyang et al., 2009) and also military equipment (Huppes et al., 2004). However as a product oriented method is hardly used for agricultural processes.

Costs include investments linearly distributed during the years of use, as this study pretends to give a mean economic benefit for an exploitation period of a year (a complete season). The benefit is shown as a representative parameter of the viability of each scenario.

Fig. 6 shows a simple diagram of the rapeseed processing and co-products use. This figure also shows schematically the production of rapeseed with the different inputs and its processing. The same input scheme is applied to wheat and barley.

Following the LCA-based LCC methodology, this analysis takes into account all the process stages. The benefit calculation is developed by modelling each crop type as well as the rapeseed processing stage. Each crop type requires its particular fertilization and crop protection products. Rapeseed processing stage is only considered when transformation of seed is required (SVO scenario). The use of diesel or SVO in the tractor is also considered to take the consumption and the corresponding fuel emissions into account.

Each scenario is obtained by the combination of different crop partitions, each one with its own conditions, as already explained. The different partitions are Barley, Barley-2, Fallow, Rapeseed, Wheat and Wheat-1; where Barley-2 and Wheat-1 stand for barley 2 years after rapeseed and wheat 1 year after rapeseed. The benefits obtained in each scenario are shown in Fig. 7.

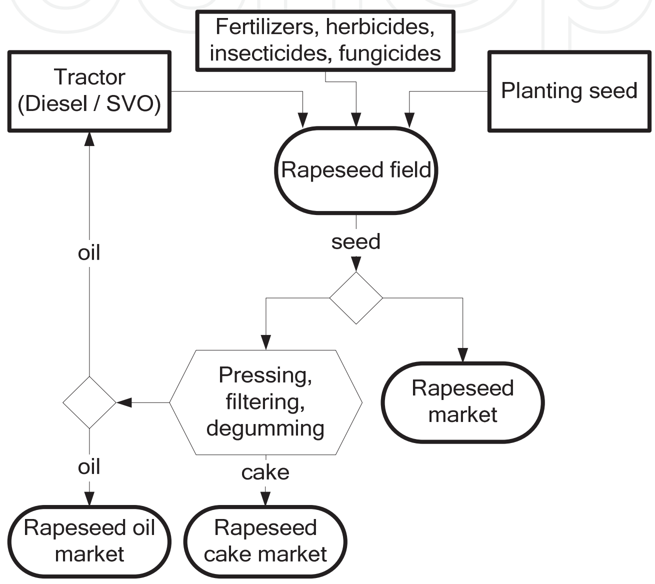

Fig. 6. Rapeseed production scheme

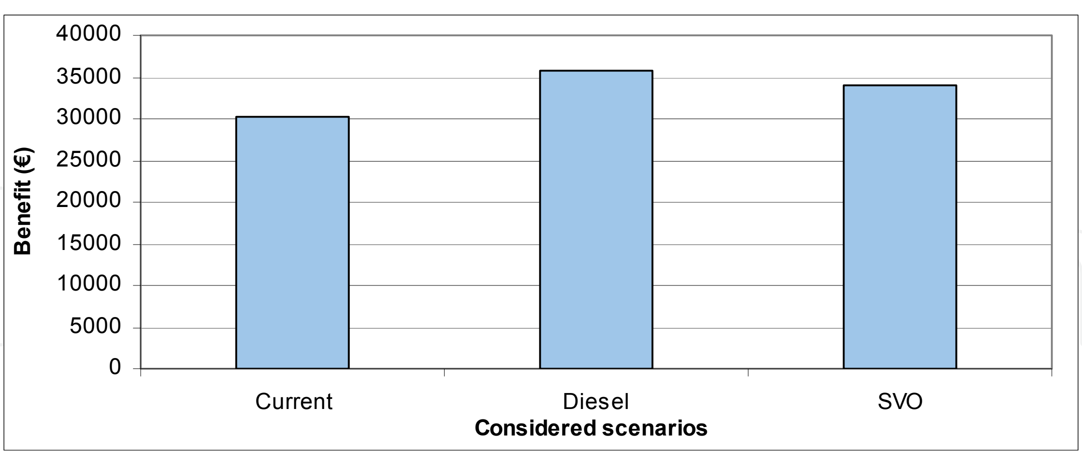

Fig. 7. Economic benefit results for each scenario

Contributions to the benefit are higher or lower according the proportion of each crop partition. Rapeseed –when not processed– gives a higher benefit per ha than the other crop types. It is clear from the results that small scale processing of the rapeseed to sell the oil is not as economically feasible as direct rapeseed sell.

Using diesel or SVO as fuel options have been analyzed, performing a diesel price and taxes sensitivity analysis. Results of these analyses show that the Spanish granted diesel for agriculture is preventing SVO to be introduced as a fuel for agricultural exploitations. Current policies do not support specifically self-supply fuels for agriculture, thus being unable to compete with already implemented diesel exploitations.

It is clear that in the current economic conditions, applying crop rotation RWBBB with diesel as fuel (diesel seed scenario) is currently the best option. Very close to this option is the SVO seed scenario, which uses the same rotation scheme but destines part of the seed harvested to produce fuel for the agricultural machinery. Thus, it reduces the amount of diesel used in the exploitation. Diesel and SVO scenarios benefit is 15% and 11% respectively higher than reference scenario (current scenario).

8. Conclusions

This chapter explains the production and use of rapeseed oil as self-produced agricultural biofuel and analyzes its use in the study area. It also evaluates from an environmental and economic point of view the presented model.

The first three sections show the small-scale production technology to obtain rapeseed oil and analyse the best rapeseed variety for a specific zone. Similar studies are necessary to analyse the most appropriate variety for each region under study. The fourth section is a summary of the necessary modifications in diesel engines to work with straight vegetable oil, as long as showing real consumption data from an adapted vehicle. It also shows the use of rapeseed cake as animal food. In section 6 an exploitation model is presented, introducing rapeseed to the traditional crop rotation of wheat and barley and incorporating the seed processing and oil use. Section 7 and 8 show the environmental and economic results of the proposed model compared to the traditional rotation and the sole use of diesel in the proposed rotation.

In the proposed exploitation model, all co-products obtained from the rapeseed plant processing (straw, rapeseed cake, oil and seed) have a clear target (field, animal feed, biofuel and seeds market) and a defined market price. Thus, no waste products are generated. Furthermore, the SVO obtaining process is more sustainable than biodiesel production thanks to its lower energy consumption and the avoidance of chemicals use like methanol.

Results for SVO and diesel fuel use in the proposed rotation with rapeseed are compared to current rotation. Life cycle assessment show the environmental impact category results using 6 CML non-toxicological impact categories. The environmental evaluation shows the preference for SVO in most categories, however some others show adverse results. The implementation of this exploitation model should take the latter into account to minimize them. On the other hand, economic feasibility is not clear in the current economic context. However, it might be feasible in future scenarios where the access to fossil fuels was limited. Moreover, small-scale production and consumption of SVO can revitalize rural economies and help them being less dependent on diesel fuel. Furthermore, this model can also be useful in less developed countries, where diesel fuel might be scarce or difficult to obtain. Additionally, research in fields such as crop sustainability, crop emissions and new varieties of plants, diesel engines modifications and new type of lubricants among others is promoted. More research is especially needed in the sustainability assessment of the proposed model along the whole life cycle.

Thus, the use of SVO in diesel engines is a real possibility that can be taken into account when considering small-scale biofuel production.

9. References

Agarwal, D. & Agarwal, A. K. (2007). Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Appl. Therm. Eng., Vol.27, No.13, (September 2007) pp. 2314-2323, ISSN 1359-4311

Altin, R.; Cetinkaya, S. & Yucesu, H. S. (2001). The potential of using vegetable oil fuels as fuel for diesel engines. Energy Conversion and Management, Vol.42, No.5, (March 2001) pp. 529-538, ISSN 0196-8904

Alvaro-Fuentes, J.; Lopez, M. V.; Arrue, J. L.; Moret, D. & Paustian, K. (2009). Tillage and cropping effects on soil organic carbon in Mediterranean semiarid agroecosystems: Testing the Century model. Agriculture Ecosystems & Environment, Vol.134, No.3-4, (2009) pp. 211-217, ISSN 0167-8809

Baquero, G.; Esteban, B.; Rius, A.; Riba, JR. & Puig, R. (2010). Small-scale production of straight vegetable oil from rapeseed and its use as biofuel in the Spanish territory. Energy Polic, Vol.38, No.1, (2009) pp. 189-196, ISSN 0301-4215

Brzoska, F. (2008). Milk production and composition as influenced by soybean meal, rapeseed meal or rapeseed cake in concentrates for dairy cows. Annals of Animal Science, Vol.8, No.2, (March 2008) pp. 133-143, ISSN 1642-3402

Dreyer, L. C.; Niemann, A. L. & Hauschild, M. Z. (2003). Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99 -Does it matter which one you choose? International Journal of Life Cycle Assessment, Vol.8, No.4, (2003) pp. 191-200, ISSN 0948-3349

Esteban, B.; Baquero, G.; Puig, R.; Riba J-R. & Rius A. (2011) Is it environmentally advantageous to use vegetable oil directly as biofuel instead of converting it to biodiesel? Biomass & Bioenergy, Vol.35, No.3, (March 2011), pp. 1317-1328, ISSN 0961-9534

EUETII-UPC. PNT GRA 105, Normalised working procedure: Determination of the total amount of oil extractable from rape seed. (2006) Escola d'Enginyeria d'Igualada. Igualada, Spain

EUETII-UPC. Survey conducted between 2009-2010 in the Anoia region, to the farmers of Unio de Pagesos and Coperal agriculture cooperatives. (2010) Escola d'Enginyeria d'Igualada. Igualada, Spain

FAO. Reports on international commodity prices. Food and Agricultures Organization of the United Nations 2.03.2011, Available from: Available from: www.fao.org/es/esc/prices/WeeklyPricesServlet.jsp

FEDNA. (2003) Fundación española para el desarrollo de la nutrición animal, Tables of composition for animal food and quality control, In Fundación Española el Desarrollo de la Nutrición Animal. 2.03.2011, Available from: http://www1.etsia.upm.es/fedna/introtabla.htm

Ferchau, E., (2000) Equipment for decentralised cold pressing of oil seeds, In: Folkecenter for Renewable Energy, 2.03.2011, Available from: http://www.folkecenter.net/mediafiles/folkecenter/pdf/dk/efdcpos_ef.pdf

Flessa, H.; Ruser, R.; Dorsch, P.; Kamp, T.; Jimenez, M. A.; Munch, J. C. & Beese, F. (2002). Integrated evaluation of greenhouse gas emissions (CO2,CH4, N2O) from two farming systems in southern Germany. Agriculture Ecosystems & Environment, Vol.91, No.1-3, (2002) pp. 175-189, ISSN 0167-8809

Galan, M. I.; Bonet, J.; Sire, R.; Reneaume, & J. M.; Plesu, A. E. (2009). From residual to useful oil: Revalorization of glycerine from the biodiesel synthesis. Bioresour. Technol, Vol.100, No.15, (August 2009), pp. 3775-3778, ISS 0960-8524

Garraín, D. (2009) Desarrollo y aplicación de las categorías de impacto ambiental de ruido y de uso de suelo en la metodología de análisis de ciclo de vida. In Universitat Jaume I. 2.03.2011, Available from: http://www.tdr.cesca.es/TESIS_UJI/AVAILABLE/TDX-0630109-01132//garrain.pdf

Gopfert, E.; Trckova, M. & Dvorak, R. (2006). The use of treated rape cake in a calf starter diet, Czech J of Anim Sci, Vol.51, No.11, (August 2006), pp. 491-501, ISSN 1212-1819

Guinée, J. B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; Koning, A. d.; Oers, L. v.; Sleeswijk, A. W.; Suh, S.; Haes, H. A. U. d.; Bruijn, H. d.; Duin, R. v. & Huijbregts, M. A. J. (2001) Life cycle assessment: an operational guide to the ISO standards, Center of Enviromental Science- Leiden University 2.03.2011, Available from: http://media.leidenuniv.nl/legacy/new-dutch-lca-guide-part-1.pdf

Hancsok, J.; Bubalik, M.; Beck, A. & Baladincz, J. (2008). Development of multifunctional additives based on vegetable oils for high quality diesel and biodiesel. Chemical Engineering Research & Design, Vol.86, No.7A, (September 2007) pp. 793-799, ISSN 0263-8762

Hsu, D. D.; Inman, D.; Heath, G. A.; Wolfrum, E. J.; Mann, M. K. & Aden, A. (2010) Life Cycle Environmental Impacts of Selected US Ethanol Production and Use Pathways in 2022. Environmental Science & Technology, Vol.44, No.13, (June 2010) pp. 5289-5297, ISSN 0013-936X

Huo, H.; Wang, M.; Bloyd, C. & Putsche, V. (2008). Life-Cycle Assessment of Energy Use and Greenhouse Gas Emissions of Soybean-Derived Biodiesel and Renewable Fuels. Environmental Science &Technology, Vol.43, No.3, (February 2009) pp. 750-756, ISSN 0013-936X

Huppes, G.; Rooijen, M. v.; Kleijn, R.; Heijungs, R.; Koning, A. d. & Oers, L. (2004) ; Life Cycle Costing and the Environment. Report of a project commissioned by the Ministry of VROM-DGM for the RIVM Expertise Centre LCA. 2.03.2011, Available from: http://www.rivm.nl/milieuportaal/images/Report%20LCC%20April%20%202004%20final.pdf

ISO 14040: Environmental management -- Life cycle assessment -- Principles and framework. (2006) International Organization for Standardization Geneve, Switzerland

ISO 14044: Environmental Manangement—Life Cycle Assessment—Requirements and guidelines. (2006) International Organization for Standardization Geneve, Switzerland

IDESCAT database, Agricultural census, 1999. Institut d'Estadística de Catalunya, 2.03.2011, Available from: http://www.idescat.cat/

Kracht, W.; Danicke, S.; Kluge, H.; Keller, K.; Matzke, W.; Hennig, U. & Schumann, W. (2004). Effect of dehulling of rapeseed on feed value and nutrient digestibility of rape products in pigs. Archives of Animal Nutrition, Vol.58, No.5, (August 2006) pp. 389-404, ISSN 0003-942

Krahl, J.; Munack, A. & Bünger, J. (2007) Emissions of Biodiesel and Vegetable Oil, In: UFOP, 2.03.2011, Available from: http://www.ufop.de/downloads/report.pdf

Lardon, L.; Helias, A.; Sialve, B.; Stayer, J. P. & Bernard, O. (2009). Life-Cycle Assessment of Biodiesel Production from Microalgae. Environmental Science & Technology, Vol.43, No.17, (2009) pp. 6475-6481, ISSN 0013-936X

Lee, J. Y.; Yoo, M.; Cha, K.; Lim, T. W. & Hur, T. (2009). Life cycle cost analysis to examine the economical feasibility of hydrogen as an alternative fuel. International Journal of Hydrogen Energy, Vol.34, No.10, (2009) pp.4243-4255, ISSN 0360-3199

Moss, A. R. & Givens, D. I. (1994). The Chemical-Composition, Digestibility, Metabolizable Energy Content and Nitrogen Degradability of Some Protein-Concentrates. Animal Feed Science and Technology, Vol.47, No.3-4, (June 1994) pp. 335-351, ISSN 0377-8401

Nassen, J.; Sprei, F. & Holmberg, J. (2008). Stagnating energy efficiency in the Swedish building sector-Economic and organisational explanations. Energy Policy, Vol.36, No.10, (2008) pp. 3814-3822, ISSN 0301-4215

Ouyang, J. L.; Ge, J. & Hokao, K. (2009). Economic analysis of energy-saving renovation measures for urban existing residential buildings in China based on thermal simulation and site investigation. Energy Policy, Vol.37, No.1, (2009) pp. 140-149, ISSN 0301-4215

Pate, R., M. Hightower, C. Cameron, & W. Einfeld, (2007). Overview of Energy-Water Interdependencies and the Emerging Energy Demands on Water Resources, Report SAND 2007-1349C, 2.03.2011, Available from:http://www.sandia.gov/energy-water/

PE_International (2010) In Institut für Kunststoffprüfung und Kunststoffkunde; GMBH, P. E., Ed. Stuttgart, Echterdingen, 2010.

Provance, P.; Suzanne, M.; Crutchifield, J. & Sandene, P. (March 2000). World Rapeseed Production in 2000/01 Likely to Fall Below Record 1999/2000 Levels, In: Feature commodotity articles, 2.03.2011, Available from:
http://ffas.usda.gov/wap/circular/2000/00-03/wap2.htm

Riba, J.; Esteban, B.; Baquero, G.; Puig, R.; & Rius, A. (2010) Characterization of physical properties of vegetable oils to be used as fuel in diesel engines. Afinidad Vol.67, No.546, (2010), pp. 100-106,

Rinne, M.; Jaakkola, S.; Varvikko, T. & Huhtanen, P. (1999). Effects of type and amount of rapeseed feed on milk production. Acta Agriculturae Scandinavica Section a-Animal Science, Vol.49, No.3, (September 1999), pp. 137-148, ISSN 0906-4702

Russi, D. (2008). An integrated assessment of a large-scale biodiesel production in Italy: Killing several birds with one stone? Energy Policy, Vol.36, No.3, (March 2008), pp. 1169-1180, ISS 0301-4215

Sattell, R.; Dick, R.; Ingham, R.; Karow, R.; Kaufman, D. & McGrath, D. (January 1998) Rapeseed (Brassica campestris/Brassica napus), In: 2.03.2011, Available from: http://extension.oregonstate.edu/catalog/html/em/em8700

Schmidt, J. H. (2010). Comparative life cycle assessment of rapeseed oil and palm oil. International Journal of Life Cycle Assessment, Vol.15, No.2, (2010), pp. 183-197, ISSN 0948-3349

Simek, M.; Sustala, M.; Vrzalova, D. & Trinacty, J. (2000). The effect of rape cakes in feed mixtures on the content parameters of cow milk. Czech Journal of Animal Science, Vol.45, No.4, (April 2000) pp. 161-167, ISSN 1212-1819

Thuneke, K. & Emberger, P. (2007). Exhaust gas emission characteristics of rapeseed oil fuelled tractors - Investigations at a test stand. Conference: Agricultural Engineering 2007, Vol.2001, (2007) pp. 47-52, ISSN 0083-5560

Vaitilingom, G.; Perilhon, C.; Liennard, A. & Gandon, M. (1998). Development of rape seed oil burners for drying and heating. Industrial Crops and Products, Vol.7, No.2-3, (January 1998), pp. 273-279, ISS 0926-6690

West, A. H.; Posarac, D. & Ellis, N. (2008). Assessment of four biodiesel production processes using HYSYS. Plant. Bioresour. Technol., Vol.99, No.14, (2008), pp. 6587-6601, ISSN 0960-8524

Biofuel's Engineering Process Technology

Edited by Dr. Marco Aurelio Dos Santos Bernardes

ISBN 978-953-307-480-1
Hard cover, 742 pages
Publisher InTech
Published online 01, August, 2011
Published in print edition August, 2011

This book aspires to be a comprehensive summary of current biofuels issues and thereby contribute to the understanding of this important topic. Readers will find themes including biofuels development efforts, their implications for the food industry, current and future biofuels crops, the successful Brazilian ethanol program, insights of the first, second, third and fourth biofuel generations, advanced biofuel production techniques, related waste treatment, emissions and environmental impacts, water consumption, produced allergens and toxins. Additionally, the biofuel policy discussion is expected to be continuing in the foreseeable future and the reading of the biofuels features dealt with in this book, are recommended for anyone interested in understanding this diverse and developing theme.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Grau Baquero, Bernat Esteban, Jordi-Roger Riba, Rita Puig and Antoni Rius (2011). Use of Rapeseed Straight Vegetable Oil as Fuel Produced in Small-Scale Exploitations, Biofuel's Engineering Process Technology, Dr. Marco Aurelio Dos Santos Bernardes (Ed.), ISBN: 978-953-307-480-1, InTech, Available from: http://www.intechopen.com/books/biofuel-s-engineering-process-technology/use-of-rapeseed-straight-vegetable-oil-as-fuel-produced-in-small-scale-exploitations

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