Small-scale production of straight vegetable oil from rapeseed and its use as biofuel in the Spanish territory

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ABSTRACT

Biofuels nowadays are an important topic of study. The most significant point is the availability of bioethanol or biodiesel and their production from different raw materials. It is already known that large scale production of first-generation biodiesel cannot be seen as an alternative to fossil fuels due to land requirements, competition with food, increase in fertilizer requirements and pressure on tropical forests among others. This fact does not necessarily apply to second-generation biofuels or small scale niche productions. Straight vegetable oil (SVO) can be used directly in diesel engines with minor modifications. Our proposal is a small-scale SVO production system for self-supply in agricultural machinery. In this paper a model to provide SVO to local farmers in a specific area in Catalonia (Spain) is presented. We also present a discussion about the regulations to be changed in order to make possible the incorporation of SVO as engine fuel in diesel vehicles and a comparative analysis between the emissions of tractors fed with SVO and petrodiesel. Moreover a quantitative economic analysis of modifying diesel engines and long-term operability costs are shown and a first-run economic analysis comparing the actual crop rotation with the proposed one and some alternatives is studied.

Keywords: straight vegetable oil (SVO), rapeseed, cake meal, self-supply, biofuels

1. INTRODUCTION

The growing demand for energy, the depletion of petrol, the instability of world fuel prices and concerns about global warming are factors that focus the interest in renewable energy sources and in bioenergy, in particular (Morrone et al., 2008). Frequently bioenergy is presented as an environmentally friendly and locally available source of energy. Therefore bioenergy is emerging as a key factor in both developmental and environmental terms (FAO, 2005). Biofuels are an essential component of bioenergy because transport plays an important role in the world's total energy demand.

As pointed out by Russi (2008), biofuels are often presented as being "green" because of their contribution to reduce the greenhouse gas emissions. But their "greenness" depends greatly on diverse aspects such as agricultural techniques applied, fertilizer and pesticide use, intensive use of land, transportation requirements, and a possible competition with food, among others. As Russi argues, large scale production of first-generation biofuels is not sustainable because it would imply severe environmental and social impacts including enormous land requirements, increases in food import and fertilizer requirements and much less CO_2 savings than expected.

As an example of the enormous land requirements, the total energy consumption for transportation during 2007 in Spain is estimated in 42.1Mtoe (Eurostat database). Being the lower calorific value of

SVO approximately 0.9 toe/t and assuming an average production of 0.8 t/ha of SVO oil, 58.5 Mha of land would be necessary to produce this crude oil amount. This represents more than 3 times the arable land in Spain, and the same is applicable to many other European countries. Thus, in the current scenario it seems clear that only a little portion of the energy required to deal with transport in Spain can be provided by first-generation biofuels.

Additionally, the European Directive 2003/30/EC (2003) established that the share of energy from biofuels in the transport sector should be 2% by 2005 and 5.75% by 2010. The latest European energy strategy, agreed in March 2007 to increase the target to 10% within 2020, subject to production being sustainable, second-generation biofuels becoming commercially available and the Fuel Quality Directive being amended accordingly to allow adequate levels of blending. This measure among others will be in a directive on development by the European Parliament.

The targets for 2010 and 2020 would represent about one-fifth and one-third of the Spanish arable land respectively. Thus, since there is not enough available land to reach these targets, the needed biofuels will have to be imported from other countries, and likely from tropical countries with high productivity rates, which could increase the pressure on tropical forests as stated by Russi (2008).

Moreover, while some authors (Russi, 2008 and Resch et al., 2008) state that large-scale first-generation biofuels production is in direct competition with markets such as human food and animal feed, others authors (Goldemberg and Guardabassi, 2009) argue that such concerns are grossly exaggerated.

As argued, large-scale production of first-generation biofuels is not a sustainable option. However, this conclusion does not necessarily apply to small-scale production of locally selected biofuels for specific uses. Small scale bioenergy projects have been identified as a significant and promising contributor to renewable energy production and rural development (Han et al., 2008).

This paper presents a simple model for small-scale production and use of rapeseed SVO in diesel engines as a substitutive of petrodiesel. The goal of the presented model is two fold. First to enable farmers to self-consume a portion of the oil extracted from their seed production. Second, to feed farm animals with the appreciated cake meal. Thus, this is a small-scale model that requires neither large production facilities nor complex processes. It minimizes logistic requirements such as transportation and storage and does not generate wastes. Quality requirements of SVO play a very important role to assure an appropriate operation in diesel engines and are analyzed in the last section of the paper.

Additionally, a discussion on the policies that allow the use of SVO as engine fuel in diesel vehicles and a comparative emission analysis of tractors fuelled with SVO and petrodiesel are shown. Besides, an economic analysis of the modification of tractors to be fuelled with SVO and a first-run economic analysis of the cropping systems are studied.

The study presented here is focused in the Anoia area of Catalonia, Spain. In this area, rapeseed is a dry-farmed crop, as it is not necessary to irrigate the lands. Consequently, cultivation of rapeseed avoids putting pressure on the local water resources.

The main reasons for applying a small-scale oil production model can be summarized as:

- It allows local farmers to use rapeseed cake meal for feeding their own farm animals and/or the animals of the farms in the neighbourhood.
- It promotes local agriculture, contributing to generate wealth and jobs.
- It has a simple and environmentally-friendly design that avoids the use of chemicals in the oil processing, unlike biodiesel and bioethanol production. It is formed by just a screw press, some filters and pumps and its outputs are totally used (oil and rape cake).

- Appropriate use of renewable SVO as fuel, replacing fossil fuel, contributes to climate, water and soil protection and allows a reduction on greenhouse gas emissions.
- This proposal enables farmers to be partially independent from the fossil fuel industry.

2. PROPOSED MODEL AND PROCESSING OF THE RAPESEED

A small-scale SVO plant design is assumed, considering a minimum storage of the seed for the daily processing, a cold pressing facility and the oil and cake meal obtained being stored and used by the farmers or the fodder manufacturers of the surroundings. This means that there is no waste. Whereas the obtained SVO can be entirely used in the diesel engines of the agriculture machinery, the cake can be totally added to the animal fodder.

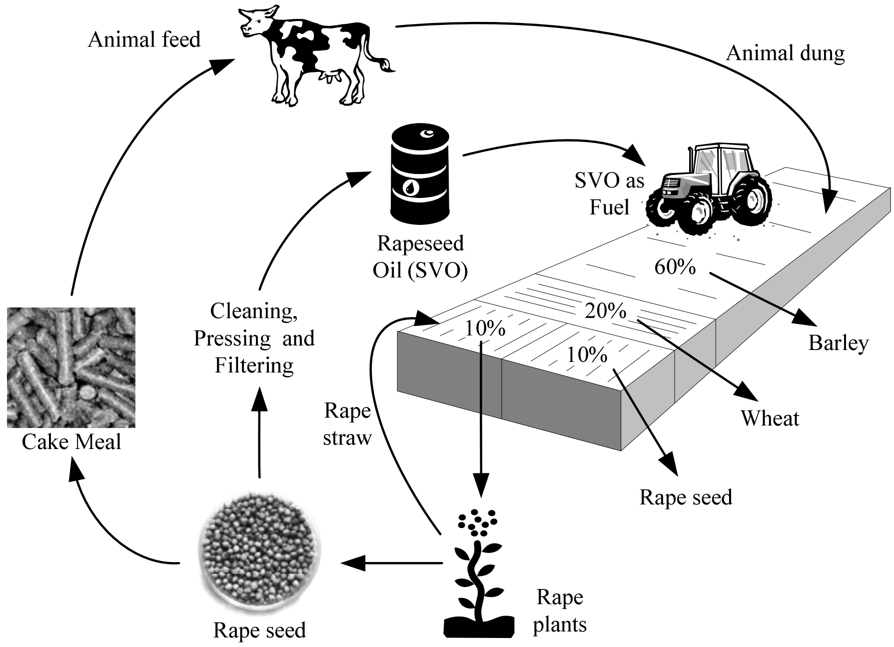
The proposed model is based on using a 10% of the arable land of a 100ha average exploitation to cultivate rapeseed and process the seeds to obtain SVO and cake meal. The SVO would be used to fuel the tractors that work in the exploitation and the cake meal would be used to feed farm animals. A 5-year rotation is assumed and the total arable land is divided into three parcels (20% rapeseed, 20% wheat and 60% barley). Thus, apart from the 10% of rapeseed destined to SVO and cake meal production, the rest of the seeds and the grains would be sold.

The processing of the rapeseed to obtain SVO to be used as engine fuel is made through three mechanical steps. The first step is cleaning the seeds from stones, metal pieces and straw. The second step is a cold pressing of the seed with a screw press to obtain oil. The oil yield should be between 28-36% of rapeseed mass (Ferchau, 2000). This range agrees to real production from Spanish cooperatives and from data provided by Reinartz manufacturer (Reinartz, 2008). So, for calculations it has been selected an average oil yield of 30%. As a final step, purification of raw oil obtained from the press using a press filter and a security filtration with a pore size of about 5 µm is required (Folkecenter, 2009)
Both the cake meal and the filter cake obtained in the process to obtain SVO have a high content of protein and are suitable for being incorporated as part of animal fodder. The introduction of rapeseed cake as part of the fodder has been largely studied – Gopfert et al. (2006), Simek et al. (2000), Brzoska (2008), Kracht et al. (2004) and Rinne et al. (1999).
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. Taking also into account the most representative groups of farm animals in the area and their characteristic intake (IDESCAT database), the fodder demand in the considered region could absorb completely the amount of rapeseed cake meal produced if a tenth of the arable land of Anoia Region (about 3,000ha) was dedicated to SVO and rapeseed cake production.

Rapeseed is a dry farming. 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 once 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 (FAS, 2000). Figure 1 shows a visual diagram of the model proposed.

HERE FIG.1

Fig. 1 – Rape seed oil and cake self-consuming cycle.



Taking into consideration a 10% of a mean farmer's land of 100ha, a mean production of 2,300kg/ha of rapeseed and a 30% of oil in weight obtained from the seeds (which contain 42% of oil), an SVO amount of 6,900kg (~7,500L) would be obtained. The data obtained from local farmers, leads to a diesel consumption of about 70L/ha for rapeseed direct seeding and of 65L/ha for wheat and barley. Thus, considering an increase of 10% in fuel consumption when consuming SVO, an area of approximately 104ha could be cultivated (20% rapeseed, 20% wheat and 60% barley) using the SVO production from 10ha of rapeseed (10%).

3. USE OF RAPESEED SVO IN DIESEL ENGINES

In this section the use of rapeseed SVO in standard diesel engines with modified intake is described.

The diesel engine was invented by Rudolf Diesel, who used peanut oil to fuel one of his engines at the Paris Exposition of 1900. Rudolf Diesel also suggested that vegetable oils would be the future fuel for diesel engines. However, petroleum, which replaced vegetable oils as engine fuel due to its abundant supply, was later discovered.

There are different varieties of oil fruits, such as soybean, rapeseed and sunflower, which are able to produce oil seeds. Thus, there are different SVOs that could replace diesel fuel. The lower heating values (LHVs) of SVOs are relatively high, around 37-39 MJ/kg (Altin et al., 2001), higher than coal (33 MJ/kg) but slightly lower than gasoline (42.5 MJ/kg), petrodiesel (43 MJ/kg) or petroleum (42 MJ/kg) (Demirbas, 2007). In consequence, the use of different types of SVOs in diesel engines is possible, but some technical modifications are necessary to be applied to the fuel system to get good runnability.

In Table 1 (Altin el al., 2001), the properties of diesel and of some vegetable oils are shown. Vegetable oils have comparable heat content, cetane number, heat of vaporization and stoichiometric air/fuel ratio with mineral diesel. The large molecular sizes of the triglycerides contained in oils, results in higher viscosity and lower volatility compared to petrodiesel. Proportion and location of double bonds affects cetane number of vegetable oils (Agarwal et al., 2008).

HERE TABLE1

Table 1 - Physical and chemical specifications of some vegetable oil fuels (Altin et al., 2001)

		Diesel fuel	Sunflower oil	Soybean oil	Rapeseed oil
LHV[a] (MJ/kg)		43.35	39.53	39.62	37.62
Density (kg/m^3)		815	918	914	914
Energy content (MJ/L)		35.33	36.28	36.22	34.38
Viscosity (mm^2/s)	27°C	4.3	58.0	65.0	39.5
	75°C	1.5	15.0	9,0	10,5
Cetane number		47	37.1	37.9	37.6
Flame point (°C)		58	220	230	275-290
Chemical formula		$C_{16}H_{34}$	$C_{57}H_{103}O_7$	$C_{56}H_{102}O_7$	$C_{57}H_{105}O_7$

[a] LHV: Lower Calorific Value

The straight use of SVOs in diesel engines entails some difficulties. These difficulties can be classified in two types, namely, operational and durability problems. Operational problems are related to starting ability, ignition, combustion and performance. Durability problems are related to deposit formation, carbonization of injector tip, ring sticking and lubricating oil dilution. It has been observed that the SVOs used during hours in a non-modified diesel motor, tend to choke the fuel filter because of their high viscosity and their content in insoluble substances. High viscosity of vegetable oils causes poor fuel atomization, large droplet size and thus high spray jet penetration. The jet tends to be a solid stream instead of a spray of small droplets. As a result, the fuel is not distributed or mixed with the air required for burning in the combustion chamber. This results in poor combustion accompanied by loss of power and economy (Agarwal et al., 2008).
As SVOs are too viscous for prolonged straight use in diesel engines, different methods are being investigated for reducing vegetable oil viscosity, such as fuel blending, fuel heating and esterification of vegetable oil (Nwafor, 2003). Oil heating before the fuel pump and before the injectors is the method suggested in this paper in order to reach the appropriate viscosity and to obtain good jet injection. Once heated, rapeseed oil becomes very similar to diesel in terms of physical properties – as seen in Table 2 (Nwafor, 2004) –, so no more changes are to be made in a diesel engine.

HERE TABLE2

Table 2 - Properties of diesel, unheated (room temperature) and heated (70ºC) rapeseed oil (Nwafor, 2004)

Fuel type	Diesel fuel	Unheated rapeseed oil	Heated rapeseed oil
HHV[a] (MJ/kg)	45.23	39.08	39.08
Density (kg/m^3)	844	918	884
Energy content (MJ/dm^3)	38.17	35.88	34.55
Viscosity (mm^2/s)	5.3	72.8	10.4

[a] HHV: Higher Calorific Value

There are many ways to implement a pre-heating of the SVO in a diesel vehicle –private cars, tractors and combine harvesters among others–, one of them being the use of the engine's own heat while running. This method requires a second fuel tank for the diesel with its own pump and filter connected just before the injection pump of the vehicle. In the main tank, the SVO would be stored. A pump and a heat exchanger need to be introduced in the primary fuel circuit, in order to pump the cold oil (more viscous than diesel) and to warm it up to 60-70ºC. With this modification, the vehicle should start up with diesel (for cold ignition) and once the engine is hot enough, the refrigerating water circuit can deal with the heating of the SVO. The stop must also be done with diesel in order to clean the fuel circuit and the injectors of SVO to be ready for the next cold start. The return system for unused fuel would be controlled by a valve system which ensures both fuels return to their respective tanks.

4. END-PIPE EMISSION CHARACTERISTICS

In recent years, diesel engines gained importance in the passenger car sector across Europe and it is likely that other markets will follow. Compared with very low-polluting spark ignition engines using efficient exhaust gas after-treatment systems, diesel engines have the disadvantage of emitting higher amounts of the critical components NO_x and particles. The well-known NO_x versus particle trade-off in diesel combustion leads to the need of either a NO_x or a particle exhaust gas after-treatment system if demanding exhaust gas emission limits have to be met. Future emission limits include, besides of strict particle mass limit values, also particle number limit values which will very likely enforce the use of combined NO_x and particle exhaust gas after-treatment systems (Soltic et al., 2009). The pollutant emissions are calculated according to Directive 2005/55/EC and its amendments. However, the limits are specified by different regulations, for example the Regulation 715/2007/EC, which refers to the light passenger and commercial vehicles Euro5 and Euro6 limits in g/km. The emissions limits for tractors, which are classified as non-road mobile machinery, are specified in Directive 97/68/EC and its amendments, mainly in Directive 2004/26/EC. These limits are defined in g/kWh and depend on the stages of application (I, II, III, etc.) and the engine power.

In Table 3, a comparative study of the end-pipe emissions of two tractors running on SVO and Diesel, according to Thuneke and Emberger (2007) are shown. Some adjustments must be done in the engine parameters to optimize the combustion of SVO, but even though the emissions are nearly to accomplish the actual regulation.

HERE TABLE3

Table 3 - End-pipe emissions according different references (Thuneke and Emberger, 2007)

	Engine characteristics				Stage[a] emission limits (category 75 kW ≤ P < 130 kW)		
	Deutz-Fahr (tractor) Agroton TTV 1160 6 cylinders, 1160 cm^3, 119 kW		Fendt (tractor) Farmer Vario 412 4 cylinders, 412 cm^3, 94 kW				
	SVO	Diesel	SVO	Diesel	Stage[1] I	Stage[1] II	Stage[1] IIIa
Emissions	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh
HC	0.1	0.21	0.2	0.1	1.3	1	0.2
CO	1	1.2	1	2	5	5	5
NO_x	6.5	6.2	7	6.4	9.2	6	4
PM	0.12	0.2	0.05	0.12	0.7	0.3	0.3

[a]Stage refers to the emission limits established by the EU legislation for off-road diesel engines

The stage limit values are introduced progressively and are mandatory for new tractor models to be sold in the EU community. Every new stage is more restrictive than the previous one. The tractors

shown in table 3 were manufactured in 2005 (Deutz-Fahr) and 2003 (Fendt) and should accomplish with stage II and I respectively.
When comparing the end-pipe emissions with the emission limits it is clear that both engines would be acceptable but for the amount of NO_x emitted. This leads to the need of adding exhaust gas after-treatment for the NO_x and adjusting the engine parameters to meet these limits for new engines.
Soltic et al. (2009) shows an experience with a heavy-duty on-road engine with exhaust gas after-treatment, running with SVO from rapeseed that meets the German pre-standard DIN V 51605. This work demonstrates that similar and even lower emissions for SVO compared to diesel can be achieved by engine parameter optimization for SVO and the use of an oxidation catalyst and a diesel particulate filter (DPF).
The emission limits for further stages are even lower, and especially for NO_x limit, which is reduced to 0.4g/kWh in stage IV. According to the lower NO_x limits, the need of selective catalytic reduction (SCR) systems to remove NO_x from diesel exhaust is required. SCR use urea solutions to provide ammonia, which is the reductant. These catalysts are already being used, quite easily fitted in industrial and agricultural vehicles (Steinbach et al., 2007 and der Wiesche, 2007). This means that once SCR systems are generalized in heavy duty and off-road diesel vehicles to deal with new NO_x emissions lower limits, the problems with this specific emission will be avoided. The CO_2 emissions from a vehicle associated to the combustion of 1 litre of petrodiesel are 2.84 kg CO_2/L (Flessa et al., 2002). According to the tractor fuel consumption for direct seeding already mentioned (65-70 L fuel/ha), the emitted CO_2 would be 198.8 kg CO_2/ha for rapeseed and 184.6 kg CO_2/ha for wheat and barley. The CO_2 emissions from a vehicle fuelled with SVO or other biofuels are frequently considered null, due to the fact that the amount of CO_2 emitted during combustion of these fuels has already been absorbed during the plant growth.
According to these results, the proposed system would avoid the emission of about 200 kg CO_2/ha due to combustion of the fuel. Even though, to develop an accurate comparison CO_2 emissions due to the use of fertilizers and oil processing among others should be also considered by means of a deep life cycle assessment study.
Therefore, in future studies, a life cycle assessment (LCA) of this model will be carried out in order to take into account all the emissions in the studied area. LCA would measure the emissions throughout all the bioenergy production chain, including all the factors involved in the cropping system.

5. OIL AS FUEL QUALITY CONTROL

The use of SVO as engine fuel is possible, but it must comply with some quality requirements. The most known standard for the use of rapeseed oil as fuel is the German prenorm DIN V 51605 (2006), which provides the limiting values and the testing methods to accept a SVO as fuel. The prenorm is divided in two parts, the characteristic properties for rapeseed oil and the variable properties.

The characteristic properties for rapeseed oil are: density (15ºC), flash point, calorific value, cinematic viscosity, low temperature behaviour, cetan number, carbon residue, iodine number and sulphur content. For cold pressed rapeseed oil, fulfilling the requirements of this prenorm is not a problem.

Variable properties are more demanding and indicate if the oil has been correctly transformed. From the author's several years experience analyzing rapeseed oils in the laboratory, the list of the most difficult-to-meet parameters –including the limit values according to DIN V 51605– and the reasons and consequences of their failure are summarized as follows:

Contamination: max. 24 mg/kg. This parameter depends on the filtration process. It is difficult to satisfy this quality requirement if the process filtration is not optimal. This parameter is important because it blocks filters and nozzles and is abrasive all over the fuel circuit.

Acid Value: max. 2.0 mg KOH/g. If high temperatures are developed during the pressing, the molecules of triglycerides are dissociated. The presence of these free fatty acids is negative for the engine. The oils with high acid values usually have a darker colour.

Oxidation stability: min. 6 hour. This index describes the pre-ageing. If its value is too low, it indicates that the oil degraded and viscosity increased. It has a negative influence in the lubrication of the engine.

Phosphorous content: max. 12 mg/kg. Phosphorous is normally fixed in the plant fibres thus if the filter process is not made correctly, this parameter is difficult to achieve. The phosphorus is dangerous for the engine because it is abrasive.

Magnesium and Calcium: max. 20mg/kg. The magnesium and calcium can cause reactions of polymerization, like making soap with the rapeseed oil. The presence of these elements in rapeseed oil only depends on the manufacturing process.

Ash content: max. 0.01 %. This concerns the content of oxide and raw ash. Ash is abrasive for the engine.

Water content: max. 0.075%. Water can cause an increase on the acid content, due to the hydrolysis produced (loss of emulsion stability) when the water is mixed with the oil. Normally water will cause problems anywhere in the fuel system.

6. ISSUES RELATED TO POLICY STRATEGIES TO BE ADOPTED

The proposed model will be greatly affected by policy strategies adopted to promote the use of biofuels. Policies can promote economic sustainability of bioenergy by rewarding those technologies and systems that perform appropriately in terms of social and environmental impacts, for instance net greenhouse gas reduction (FAO, 2008). These policies should deal with agricultural supervision, changes in legislation and financial measures, which are detailed below.

European Union (EU) crop production patterns have traditionally been heavily influenced by the Common Agricultural Policy (CAP) with its high support prices, planting restrictions, intervention buying, stock management, and rigid border controls. Actually, the CAP includes rules on agricultural land use, as well as a special payment for the production of crops dedicated to biofuels. A special aid for energy crops was introduced by the 2003 CAP reform (1782/2003/EC). A payment of 45 €/ha is available, with a maximum guaranteed area of 2 million hectares as the budgetary ceiling. In October 2007 the eligible area of 2 million hectares was exceeded and the aid per hectare of energy crops was proportionally reduced.

Also, policy strategies and legislation to reduce CO_2 emissions, like Directive 2003/96/EC, will affect the feasibility of the proposed model.

To make prices of SVOs similar to those of fossil fuels, SVOs need to be supported in two directions:

- Through the agricultural subsides of the Common Agricultural Policy of the European Union (Council Regulation 1782/2003/EC and its amendments).
- Exempting locally-produced SVOs of energy taxes according to the Energy Taxation Directive 2003/96/EC.

There is also the need for new specific legislation. The conversion of a diesel engine to run with SVO must fulfil some legal requirements. In Spain, the modification of a vehicle is regulated by RD 711/2006, RD 736/1988 and the modifications introduced by Orden CTE/3191/2002. In these regulations, the specific modifications permitted are defined and classified in different reform types. The addition of an alternative fuel system is typified as reform type number 4 (initially introduced to cover the use of gas as fuel). It implies making a technical project, a positive report from the manufacturer or the certified official laboratory and also the certification of the workshop where the reform is done. All or at least some of these steps can be avoided by installing an homologated kit to the vehicle, which would permit a quicker and cheaper procedure to make the modification to use SVO as fuel. Thus, the need for a change in legislation is needed to allow an easy and legally installation of these kits. Additionally, in order to minimize difficulties at the beginning of the proposed process, financial support for vehicle modification may be established.

Directive 2003/30/EC establishes the products to be considered biofuels and between them, we find the 'pure vegetable oil', defined as follows: "oil produced from oil plants through pressing, extraction or comparable procedures, crude or refined but chemically unmodified, when compatible with the type of engines involved and the corresponding emission requirements".

The Directive 2003/96/EC, transposed in Spain by law 22/2005 of 18 November, establishes the taxations to be imposed by member states on some of the therein defined energy products, which include in article 2 the CN 1514 group: rape, colza or mustard oil and fractions thereof, whether or not refined, but not chemically modified (as defined by Commission Regulation (EC) 1031/2008).

According to Directive 2003/96/EC, member States may apply an exemption or a reduced rate of taxation under fiscal control on the taxable products included in it. This Directive specifies that if an energy product other than those for which a level of taxation is specified in it, the product shall be taxed according to use, at the rate for the equivalent heating fuel or motor fuel. Thus, as the level of SVO taxation is not specifically included in the Spanish law 22/2005 of 18 November, the government shall tax it with the same amount as fossil diesel (which SVO substitutes). SVO should be included in the law at least as biodiesel is, promoting its use by a null taxation until 2013. This case is not unique in the EU. England is an example where SVO use is affected by the same tax as diesel due to the same lack of legislation.

Article 54 in the Spanish law 22/2005 of 18 November states that the use of fuels not specifically authorized is prohibited. This means that the use of SVO is out of the law until the Ministry authorizes it.

Moreover, according to Directive 2003/96/EC, paragraph 3 in article 18, the Kingdom of Spain can apply special reduced rates on commercial use of diesel used as propellant until 1 January 2010. This means than later than 2010 Spanish farmers will not have any more a reduced tax in petrodiesel, which implies the possibility to introduce SVO as a fuel due to economic reasons. Nowadays the Spanish government is applying an additional tax refund since fuel price increase on 2008, which will be maintained after the end of the period established by the EU directive.

Conversely, the use of rapeseed cake for livestock feed is simple, immediate and already being used. It has its specific legislation in Spain (Real Decreto 56/2002).

As long as some important fuel properties remain close to the values of mineral diesel fuel -e.g. cetane number, density, viscosity, heating value, lubricity, boiling behaviour-, when using SVO in diesel engines, only small modifications of the engine are required (Soltic et al., 2009). However, SVO has different chemical and physical properties compared to mineral diesel fuel which have to be considered and regulated. There is the need to establish a standard regulation for using SVO as fuel to control these fuel properties and to ensure its runnability as fuel. At the moment, no European standard exists.

7. TRACTOR MODIFICATION COSTS

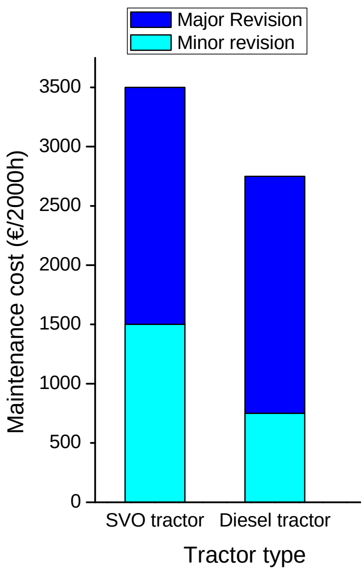
In this section the modification of tractors and their associated long term operability costs are studied. The proposed modification of the vehicle does not affect the engine, only the fuel line. The kits used to modify tractors cost between 3,300€ and 3,700€ (Elsbett, 2009), depending on the model. In this amount, the taxes, second fuel tank and installation are not included. The total cost is estimated of about 5,000€.

Currently, some agricultural machinery producers have already developed models specifically for its use with SVO with the double tank system. They are being commercialized and offering a two years warranty, so they accomplish with the legislation in some European countries. Considering the current price of a tractor of 170 to 200 CV (to cover a range between 150 and 200ha), the cost of such modifications would be of an average of 5% of the mean tractor cost (estimated to be of the order of 100,000€).

The mechanical revisions to be submitted would consist on a minor revision every 250 working hours and a major revision every 2,000 hours. The cost of these revisions are about 150€ and 1,000€ respectively according to local agricultural machinery workshop. In a diesel fuelled tractor, the minor revisions would be every 500 working hours and the major revision also every 2,000 hours. Thus, the increase in maintenance cost would not be very high, only of about 450€ every 2,000 hours, which represents about a 30% of maintenance cost increase compared to a diesel fuelled tractor as indicated in Figure 2. As seen, the increase in maintenance consists on reducing the time between revisions at its half in order to avoid any problem from contamination of the lubricating oil mostly. This will be avoided or reduced when new lubricants capable of accepting more SVO in its composition are developed.

HERE FIG.2

Figure 2 – Tractor maintenance cost



8. ECONOMIC ANALYSIS OF THE MODEL

In this section a first-run economic analysis of costs associated with substituting rapeseed crops for biofuel and feedcake purposes compared to other alternative crops is presented.

The mean crop yields considered in the area under study are 2,300kg/ha for rapeseed, 3,500kg/ha for wheat and 3,800kg/ha for barley according to data from local farmers. These yields can be increased or decreased due to climatic reasons, mainly rain and wind. The year after planting rapeseed, wheat and barley in the same field grow better in normal and rainy conditions whilst decreasing in yield in dry conditions. This is shown in table 4, where the usual cropping rotation and the rotation with rapeseed are shown.

HERE TABLE4

Table 4 – Crop yields variations based on crop rotation and climate conditions

	Year 1 Rapeseed	Year 2 Wheat	Year 3 Barley	Year 4 Barley	Year 5 Barley
Rainy years	△20%	△20%	△6%	△20%	△20%
Standard year[a]		△10%	△3%		
Dry years	▽20%	▽30%	▽3%	▽20%	▽20%

[a]Considered for the profit calculation in table 5.

As seen, the climatic conditions have a great effect on the yields. Barley requires less water than wheat, so it is recommended for the area of study and largely cultivated. However, barley should not be cultivated more than 3 consecutive years, due to diseases development and the consequently loss of yield. Additionally, fallow increases the yield of the next year crop in a 20% according to data from local farmers.

Taking into account the crop and its regional yield, the market price of the obtained products, the cultivation costs (work, machinery, fertilizers, herbicide, seed …), EU aids, storage facilities and the seed processing in the case of rapeseed crops the results obtained are shown in table 5.

The rapeseed cake, which represents 70% of the seed weight, is considered to be sold to farmers or fodder manufacturers of the area.

The use of diesel and its substitution for SVO on the land work of the tractors are considered with an increase of 10% of fuel consumption in SVO due to different energy density of the fuels.

Being a first-run analysis, the prices of raw materials and obtained products are considered stable in the complete time frame of the analysis and equal to the mean local market values of May 2009. There are some variables such as the diesel price for farmers, seed market price and oil market price which affect the results broadly and at the same time are very unstable. Table 5 contains various scenarios of crop rotation with its expected profit per year, which are shown in percentages related to the classical rotation scenario. The table also includes the information about each rotation (ha dedicated to each crop, rotation years and cropping parcels per year) as well as the fuel considered for the tractor. Three scenarios are considered: (1) scenario 1 (classical): 4-year rotation; total cultivated area of 25% wheat and 75% barley each year; thus a year of wheat in a parcel is followed by 3 years of barley. (2) Scenario 2 (proposed): 5-year rotation; total cultivated area of 20% rapeseed, 20% wheat and 60% barley each year; thus a year of rapeseed in a parcel is followed by 1 year of wheat and 3 years of barley. (3) Scenario 3 (classical fallow): 5-year rotation; total cultivated area of 20% wheat and 60% barley each year; thus a year of fallow in a parcel is followed by 1 year of wheat and 3 years of barley.

HERE TABLE5

Table 5 – 100ha exploitation gains using different crop rotations in standard year weather conditions

Scenario	Rotation type	Fallow/Rapeseed/Wheat/Barley (ha)[a]	Rotation (years)	Cropping parcels[b]	Tractor fuel	Profit per year (%)
1	classical	0/0/25/75	4	WBBB	Diesel	100.0%
2	proposed	0/20/20/60	5	RWBBB	SVO	116.5%
3	classical fallow	20/0/20/60	5	FWBBB	Diesel	84.4%

[a]ha corresponding to fallow and each crop type in the considered option.
[b]F: fallow, R: rapeseed, W: wheat and B: barley.

The proposed model (scenario 2) is a 5 years rotation and implies 20 ha of rapeseed to be cultivated. As only 10% of the exploitation (10ha) are necessary to cover the SVO as fuel needs, the rest of the rape seeds are sold at market price to the edible oil industry. This option is the most favourable with a 16.5% profit increase compared to the classical model. As seen, the actual prices and area conditions shows that classical fallow is not as profitable as the classical model used nowadays.
These results can change according to variations in yield and price. An increase or decrease in market price of an individual variable can result in an important variation in the obtained results. The increase in profits falls when cereal prices rise (especially barley) or fuel prices fall. When other variables as fertilizers or rapeseed market price rise, the proportion of profits increases. Additionally, when the variation in price affects market prices globally (diesel, cereals, seeds, fertilizers ...) the proportion of profit remains nearly unaltered.

The investment considered consists in modifying the tractor and constructing a plant for the processing of the seeds to obtain oil and cake. The installation is designed for 25 exploitations with an estimated lifetime of 20 years. The tractor is estimated to labour 300ha with an approximated lifetime of 18 years. The payback of the investment considering these conditions and scenario 2 is calculated of less than 3 years.

9. DISCUSSION AND CONCLUSIONS

As argued, large-scale production of first-generation biofuels cannot be seen as an alternative to fossil fuels due to land requirements, competition with food, increase in fertilizer requirements and pressure on tropical forests among others. On the other hand, in this paper a small-scale model for producing SVO has been presented and calculated. The proposed model is adequate in the studied area and has some environmental advantages including about 200 kg CO_2 emissions per hectare and year avoided due to fuel burning, biodegradability of the SVO fuel, no deforestation associated and simple production process with low energy requirement. Furthermore, small-scale production and consumption of SVO can revitalize rural economies and help them being less dependent on petrodiesel.

This model could be also useful in less developed countries, where petrodiesel might be scarce or difficult to obtain. 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 required.

The actual legislation has been studied and the possibility of using SVO as fuel is feasible, but has to be recognized and supported through specific Spanish laws according to the EU legislation as analyzed in section 4.

Modifications of tractors to use SVO are nowadays available and quite simple to be applied. The cost of such modifications has been rated and estimated of an average of 5% of the tractor cost.

The feasibility of the model greatly dependents on the market prices of grains, seeds and fuel. As detailed in section 8, first-run economic analysis has shown positive results when using the proposed model, achieving an additional 16% annual profit compared to the classical scenario. The payback of investment associated to the proposed model has been calculated in less than 3 years.

For all these reasons, the proposed model is economically and technically feasible and environmentally advisable. However, a detailed environmental study with a life cycle approach is required.

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