Environmental Assessments of Transportation Biofuels in Europe: A Survey

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Abstract

A substantial transportation biofuels sector is present in the EU-27 countries raising controversy about their environmental impacts. A survey of the literature regarding assessments of these impacts is presented, following a brief outline of the EU-27 biofuels production. The main assessments' results, based on extensive search in sources of scientific evidence and information related to the paper's topic, are cited and compared, combined with a discussion about these findings. Several conclusions are drawn and comments are made regarding, among others, the "splash and dash" system of European biodiesel, the uncertainty in the parameters related to LCIA of biofuels, the economic basis of their environmental impacts, the insufficient treatment of the land use impact category, etc.

Keywords: biodiesel, bioethanol, environmental impacts, LCIA

1 Introduction

Production of biofuels used for transportation in Europe has been rapidly increased in recent years. As Table 1 shows, biodiesel produced in EU-27 in 2007 was 5 713 000 tonnes increased from the level of 1 065 000 tonnes in 2002. EU's capacity for biodiesel production reached 10.2 million tonnes in 2007, compared to only 6.09 million tonnes in 2006 [7]. About 85% of the biodiesel produced in Europe is based on rapeseed oil, while the rest is based on other vegetable oils (soybean oil, palm oil, sunflower oil etc) produced in Europe or imported from third countries.

TABLE 1: MAIN BIODIESEL PRODUCERS IN EU-27 (000 tonnes)

	2002	2003	2004	2005	2006	2007
Germany	450	715	1 035	1 669	2 662	2 890
France	366	357	348	492	743	872
Italy	210	273	320	396	447	363
Austria	25	32	57	85	123	267
Denmark	10	40	70	71	80	85
UK	3	9	9	51	192	150
Czech Rep.	-	-	60	133	107	61
Greece	-	-	-	3	42	100
Others	1	8	34	284	494	925
Total	**1 065**	**1 434**	**1 933**	**3 184**	**4 890**	**5 713**

Source: [7]

According to EurObserver (Observatoire des ènergies renouvelables / Biofuel Barometer – June 2008) the EU-27 transportation biofuels consumption in the years 2006 and 2007 was as shown in Table 2 .

Given that biodiesel's net thermal value is 37.3 MJ/Kg, it is concluded that biodiesel's quantities consumed in EU-27 in the years 2006 and 2007 were 4 572 000 and 6 481 000 tonnes, respectively. That is, some 770 000 tonnes of biodiesel were imported in Europe in 2007. In addition, according to the European Biodiesel Board, 1.5 million tonnes of B99 (blend of 99% concentration in biodiesel) were imported in Europe from the US in 2008 [3]. The trend is obvious.

TABLE 2: TRANSPORTATION BIOFUELS CONSUMPTION IN EU-27 (2006-2007) (TOE)

	2006	2007
Biodiesel	4 073 904	5 774 207
Bioethanol	871 673	1 166 243
Other	656 141	753 617
Total	5 601 718	7 694 067

Source: [5]

Bioethanol production in years from 2004 to 2007 is shown in Table 3. It may be noticed that the rate of production increase between 2006 and 2007 was smaller than in previous years. Actually, in several cases the production decreased during these two years. Despite this trend, the 2007 bioethanol production capacity installed in EU-27 was 5.175 million litres [8], almost three times larger than the same year's actual produced quantity. On the other hand, substantial biofuels' imports in EU took place during this time.

TABLE 3: MAIN BIOETHANOL PRODUCERS IN EU27 (000 000 litres)

	2004	2005	2006	2007
France	101	144	293	539
Germany	25	165	431	394
Spain	254	303	396	348
Poland	48	64	161	155
Sweden	71	153	140	70
Italy	0	8	78	60
Czech Rep.	0	0	15	33
Others	27	76	79	132
Total	526	913	1 593	1 731

Source: [8]

Bioethanol's quantities consumed, as resulting from Table 2, were 1 730 million litres in 2006 and 2 315 million litres in 2007. Clearly the difference of 137 million litres in 2006 and 584 million litres in 2007 have been imported in Europe during this period. Bioethanol's feedstock includes sugar biomass, cereals and some other materials [8]. About 49% of the bioethanol production capacity installed in Europe is based on cereals while 31% on sugar biomass (sugar juice, sugar beet). Additionally, some serious efforts are in progress in Europe for bioethanol production from lignocellulosic materials in a feasible way. These efforts are mainly based on technology including stages such as biomass' pre-treatment with acid, enzymatic hydrolysis and distillation. As in the case of biodiesel,the increase rate of bioethanol production between 2006 and 2007 was decreased in relation with past years, as shown in Table 3, and in some cases it was negative.

Biofuels represent 2.6% of the energy content of all the fuels used in road transport in Europe in 2007. Nearly half of the target of 5.75% share in total energy consumed in road transport for 2010 set by the Directive 2003/96 on biofuels has thus been reached in four years time (2004-2007). To achieve the target of 5.75%, the European Union will have to increase its production and rely even more on imports of biofuels (and also raw materials for the production of biofuels, if the production capacity not used now is taken into account), at a time when biofuels are found at the core of the ecological and economic debate.The Industry, Research and Energy Committee of the European Parliament ('ITRE') voted on 16th September 2008 to require at least 10% of the energy used in road transport to be from renewable sources by 2020. In doing so, ITRE amended the Commission's original proposal. The main change is the establishment of an interim target of 5% by 2015 for renewables in road transport fuel, with at least 1% of the 5% coming from alternatives that "do not compete with food production". These alternatives include renewable electricity (used in battery-powered and plug-in hybrid vehicles) and hydrogen produced from renewable sources, as well as "second generation" biofuels like lignocellulosic ethanol. This percentage should increase to 4% (out of 10%) by 2020. According to market sources, it would be necessary to construct more than 500 ethanol plants in Europe to reach the 10% target by 2020.

2 Methodology

This is a survey paper, therefore the methodology used is based on extensive search in sources of scientific evidence and information related to the paper's topic, that is, environmental assessments of transportation biofuels in Europe. The scientific literature searched includes several individual researchers, whose main relevant findings, often conflicting, are cited in the paper (e.g. Tables 3-9). Also, data from several associations and governmental bodies have been searched and used, including the European Biodiesel Board, the European Bioethanol Fuel Association and DEFRA. The discussion and the conclusions section of the paper is based on the findings from the above sources, which substantiate the arguments. The references cited are only a small subset of the existing extensive literature on the topic.

3 Results and Discussion

According to several recent studies (e.g. [1]), the contribution of transportation biofuels to the reduction of the greenhouse effect and, therefore, to climate change is very doubtful. In some cases biodiesel and bioethanol production can lead to the increase of gases contributing to the greenhouse effect due to:

- The use of fossil transportation fuels in the complicated logistics needed for biomass collection and transportation and in biofuels distribution. Indeed, materials used for biofuels' production intended for transportation in Europe are often produced far away from biofuels' plants, thus creating the need for expensive logistics systems. More specifically, rapeseed is cultivated mainly in Northern European countries; both soybean oil and palm oil are imported from countries outside Europe, while biofuels production takes place in plants all over Europe. Biomass (seeds, seed oil etc) is transferred by trucks, trains and ships to every possible destination and it is often deposited for a while and shipped again for a new destination, where the market price is more attractive. For example the GHG (Greenhouse gases) emissions related to rapeseed oil transfer from Poland to Germany are lower than the corresponding from Poland to Italy or to Greece and, of course, even lower than in the case of import from an extra EU country (like the US). The extended import and export of biofuels (and the so-called "splash and dash" practice where biodiesel imported into the US -in most cases from Europe- to receive subsidies before being exported to European market) is contributing in general to the increase of GHG emissions.
- The deforestation of land in order to be used for biomass cultivation. This leads to emission of CO_2 captured in biomass and the soil into the atmosphere. The necessity for more biomass drives producers to deforest virgin forests or grasslands in order to exploit them as cultivation lands. This is the case in palm oil production in Southeast Asian countries. During the years 1990-2008 the land used for palm trees cultivation in Malaysia and Indonesia has increased by about 43%.

According to the European Biodiesel Board, the use of 1 kg of biodiesel leads to the reduction of some 3 kg of CO_2. Hence, the use of biodiesel results in a significant reduction in CO_2 emission (65%-90% less than conventional diesel), particulate emissions and other harmful emissions [6]. But many researchers doubt this value. Some indicated results about GHG emission savings for biodiesel and bioethanol are presented in Tables 4 and 5. As it may be seen, the range of these values is considerable and varies upon parameters such as the feedstock used, the country, the researcher etc.
There is also a big variation amongst LCIA results for the same biofuel. The following reasons contribute to this:

- The different way each system's limits are set
- The different biomass cultivation techniques
- The different biofuels' production methods and techniques
- Differences between local climates
- Direct or indirect changes in the use of land.

TABLE 4: BIODIESEL (FROM RAPESEED OIL) GHG EMISSIONS SAVINGS

Reference	Emissions (Kg GHG/l biodiesel)	Benchmarking (Kg GHG/l fossil diesel equivalent of 1 litre of biodiesel)	Saving (Kg GHG/l biodiesel)	% savings
Levington (2000)	1.2	3	1.8	60
ADEME (2002)	0.65		2.3	78
El Sayed (2003)	1.3		1.7	57
JRC (2003)	1.75		1.3	41
DEFRA (2003)	1.1		1.9	63

Source:[10]

TABLE 5: GHG EMISSIONS SAVINGS FOR VARIOUS BIOETHANOL CULTIVATION SYSTEMS

Raw material	Country	GHG emission savings (Kg CO_2/ha yr)
Bagasse	India	2 500
Wheat straw	Great Britain	3 000
Corn stover	USA	4 000
Molasses	South Africa	300
Molasses	India	2 500
Corn	USA	4 200
Sugar beet	Great Britain	10 500
Sugar cane	Brazil	28 000

Source:[1]

From a recent study about a bioethanol production system comes out that the GHG emissions from the biomass' cultivation needed are very much dependent on changes in the use of land [2]. Table 6 shows the total GHG emissions in the case of wheat cultivation in three different soil types. It is obvious that, in a certain type of land use, the GHG emissions due to cultivation climb to the 10-fold level of the normal case.

TABLE 6: EMISSIONS OF GREENHOUSE GASES IN THE CASE OF WHEAT (GRAIN) CULTIVATION

Kg CO2-equiv/GJ of harvested grain

Cultivation system	CO_2 fossil fuels	N_2O land	N_2O N fertiliser manufacturing	Total	CO_2 change of land-use	Total
Cultivation on "normal" arable land	10	9.2	5.7	25	0	25
Cultivation on grass-covered mineral soil				25	11	36
Cultivation on grass-covered peat soil				25	210	230

Source:[2]

Another conclusion of the same study is that current production of Swedish ethanol from wheat can be seen as "good" ethanol, reducing GHG emissions by some 80% compared to petrol. Ethanol based on sugarcane from Brazil leads to a reduction of 85% on average, while ethanol from maize in the USA leads to a reduction of only 20% on average. The reason for this is that fossil coal accounts, on average, for 25% of the fuel used in ethanol plants in the US and natural gas for the remaining 75%. Thus, there is a potential for improvement of current ethanol production systems especially in the US, but also worldwide, leading to increased GHG benefits.

Land use is rarely included as an impact category in biofuels LCIA studies. This is a problem, because the land use impact is related with the biomass production and, if it does not account to the total environmental performance of the biofuel, the LCIA study is obviously incomplete. Land use only recently has started to be assessed. Table 7 shows some LCIA cases and their impact categories studied. Clearly, resource depletion and global warming are the most studied categories while land use was not considered as an impact category in any of these studies. This means that land use impacts are not evaluated systematically in the biofuels systems. Some methods developed recently have facet methodological problems whereas some others contain promising indicators that might be used as such or be further elaborated into meaningful indicators. The main problems of these methods, according to the Institute of Environmental Sciences of the Leiden University (The Netherlands) [11], are related to the following topics:

- Definition of the system's boundary. The land quality can be judged by functional values for humans (economic values) and intrinsic values (environmental or ecological values). Changes in the land quality defined in functional terms have economic consequences and should ideally be internalised within the economic system. In LCA this means that changes in land quality that influence the present production (soil fertility) should not be assessed separately in the environmental impact assessment because the economic output (crop yield) is already defined in the functional unit. That is, the economic values of functions must not be involved in intrinsic values during the environmental and economic analysis.
- Inventory data. The following LCI data for land use must be distinguished:

✓Type of land use (e.g. forest, cropland, grassland etc)

✓Management activities (e.g. type and amount of fertiliser used, % surface sealed etc)

✓Area's size and location of land use

✓Duration of land use.

- Land use impacts in relation to other impact categories. Impacts of land use are often expressed using indicators for biodiversity or soil quality. However, conventional impact categories, like eutrophication, acidification and ecotoxicity, are also related to these -end and midpoint- indicators. So the impact of many of the land management activities like application of fertilisers, organic matter, lime and pesticides, are already accounted for in the environmental assessment. The link of the different indicators to the endpoints needs to be elaborated. This is necessary to avoid double counting, to get scientific basis to weight the different functions and to find relations with existing impact categories, like acidification, eutrophication and ecotoxicity.

• Normalisation. Most of the LCIA methods do not provide normalisation data. It must be noted that the reference situation for normalisation data is something different than the reference situation of the characterisation model. In normalisation the reference situation refers to the present land use situation in the region and year of reference. In the characterisation models for land use impacts the reference situation refers, in most cases, to the (past or future) natural climax vegetation for that region.

An overview of some indicative methods developed for land use impacts assessment is presented in Table 8.

TABLE 7: COMMON LIFE CYCLE IMPACT CATEGORIES FOR BIOFUELS ASSESSMENT

IMPACT CATEGORY	Kaltshmit 1997, ethanol, sugar beet, wheat, potato, Germany	Puppan 2001, ethanol, sugar beet, winter wheat, potato, Germany	Reinhardt 2002, ethanol, sugar beet, wheat, potato, Europe	Hu 2004, ethanol, Cassava, China	Kadam 2002, ethanol, waste bagasse, India	Sheehan 2004, ethanol, corn stover, U.S.A	Tan and Culuba 2002, ethanol, agricultural cellulosic waste, Philippines	Reinhardt and Jungk, 2001, biodiesel, rapeseed, Europe	Kim and Dale, 2005, ethanol and diesel, corn, soybean, USA
Resource depletion	X	X	x	X	x	X	x	x	x
global warming	X	x	x		x	X	x	x	x
CO2			x	X				x	x
Acidification	X	x	x		x	X	x	x	x
SO*x*	X		x						x
NO*x*	X		x	X				x	
eutrophication			x		x		x		x
human toxicity		x			x		x	x	
CO			x	X					
PM			x	X					
eco-toxicity		x							
photochemical			x			x	x		
HC			x	X					
solid waste					x				
land use									
water use									
ozone depletion	x	x				x		x	
Odor					x				

Source:[1],[12]

TABLE 8: OVERVIEW OF SOME INDICATIVE LAND USE IMPACT ASSESSMENT METHODS

Reference	**Inventory**			**Indicators**					**Operational**	
	Direct physical interventions	**Land types**	**Resources**	**Ecosystem health (biotic natural and man made environment)**					**Characterisation factors**	**Normalisation factors**
				Hemeroby	**Biodiversity**	**Soil fertility**	**Hydrology**	**Exergy**		
Brentrup *et al*., 2002		11 classes		Naturalness index					Yes	Yes
Lindeijer *et al.* (1998); Lindeijer (2000a, 2002); Weidema & Lindeijer 2001)					Vascular plant species density				Limited	
Lindeijer *et al.* (1998)		x								
Köllner, 2000; Goedkoop & Spriensma, 1999		x			Vascular plant species density				Limited	
Milà i Canals, 2003	4 types					Soil organic matter			No	No
Cowell & Clift, 2000	Loss of soil mass		Soil static reserve life						Preliminary	No
Cowell & Clift, 2000	Added organic Matter					Organic matter			No	No
Cowell & Clift, 2000	Vehicle operation on land					Soil compaction			No	No
Heuvelmans *et al*., 2005	Water use		Dynamic water reserve life						No	No
Heuvelmans *et al*., 2005	Land use type						Changes in regional water balance		No	No
Wagendorp *et al*., 2006								Cooling capacity of an ecosystem	No	No
Muys & Garcia Quijano,									No	No
Mattsson *et al*., 2000									No, mainly qualitative description	No

Source: [11]

4 Conclusion

As shown above, the capacity of biofuels production in Europe is large and could cover more or less the 5.75% target of EU for fossil transportation fuel substitution for 2010 even if the needed cultivated land is quite big. But for the achievement of the 2020 target of 10% substitution of fossil fuels, there is a strong need for a fuel produced easily and from a sustainable feedstock. There is a requirement for an easy industrialized biofuel's production process. Biodiesel from algae seems to be such a fuel since it has a high yearly productivity yield of 100 m^3/ha [4] (instead of 5 m^3/ha in the case of palmoil) and could cover the global demand for transportation fuels. It is produced from a nonfood biomass; therefore, it may have less social impacts than other systems using food products as a raw material. Nevertheless, it has some negative environmental impacts, such as ozone layer depletion, methane production, etc. These negative environmental impacts must be well studied before the commercialization of this technology system.CO2 emissions from road transportation fuels represent the 71% of the total CO_2 emissions from transportation fuels in EU-27 as Table 9 shows [9].The second in power contributor is navigation transports followed by civil aviation and railways. The till now efforts were –and correctly- to reduce the CO_2 emissions from road transportation because it was the main contributor. But as can be seen in Fig. 1 [9], the road transport and railway emissions are on descend pathway from 1990. Specifically during the 1990-2006 period, CO_2 emissions from road transport have dropped by about 15%, while civil aviation and navigation emissions have been increased by about 80% and 40%, respectively. Obviously, the introduction of biofuels' use in civil aviation and navigation could bring benefits in GHG emissions in Europe and globally.

TABLE 9: CO_2 EMISSIONS FROM TRANSPORT IN EU-27 (2006)

	Road transportation	Navigation	Civil Aviation	Railways	Other	Total Transportation
CO_2 emissions (million tonnes)	902.0	194.6	155.4	7.8	10.1	1 269.9
% Share of emissions of transportation fuels	71.0	15.3	12.2	0.6	0.8	100

Source:[9]

Transportation fuels (biodiesel and bioethanol or their feedstock) imported in EU incur increased GHG emissions. Especially in the "splash and dash" system of European biodiesel, GHG emissions connected with international transport are at least twice the corresponding GHG emission of a "real" imported biodiesel. They also incur "export" of some serious environmental negative impacts in the biofuels' (or biomass') countries of origin such as in the land use and ecotoxicity impact categories. For example, if a European country imports palm oil in order to produce biodiesel, in fact it gets benefits such as CO_2 emissions savings, while it "exports" deforestation and intensive cultivation techniques (fertilisation, pesticides) in the palm oil's country of origin. At the same time another study [13] concludes that biodiesel produced from imported palm oil provides higher gross and net energy compared to indigenous rapeseed. This is probably because oil palm residues are used to satisfy all thermal and electrical parasitic demands at a palm oil mill, while the typical system for rapeseed plugs into the electricity grid to generate power for the process.

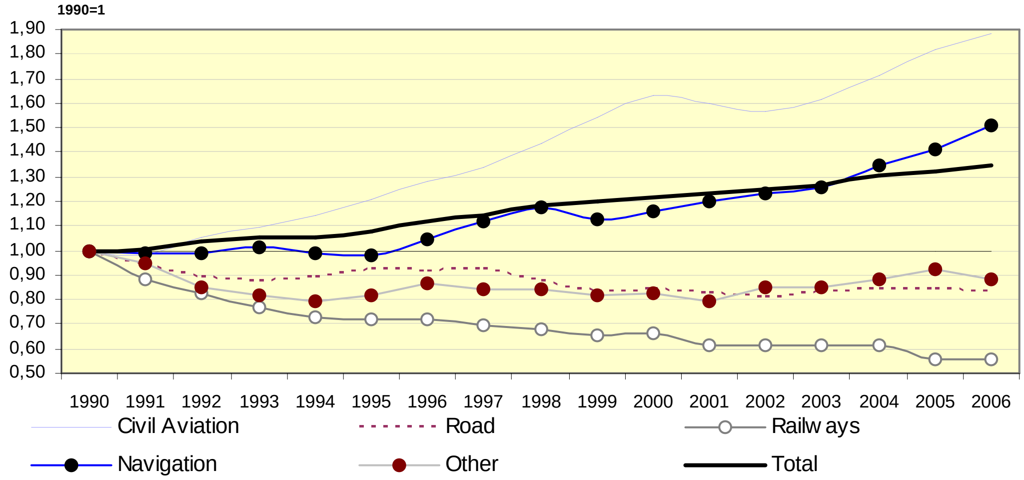

FIGURE 1: EVOLUTION OF CO_2 EMISSION IN EU-27

Source:[9]

The latter statement is another evidence that the more integrated a technological system of biofuels production the less the environmental impacts. This happens because the overall impact is subdivided and distributed to partial impacts for each product or by-product or process. In addition to the previous reference, some researchers (e.g., [14]) have shown that biofuels' production is more feasible if the operation occurs through small cooperative enterprises of biomass producers. This is because these cooperative enterprises can easily use all of the by-product quantities (e.g., for animal feed etc).

It is important to note that there is a significant uncertainty in the parameters related to LCIA of biofuels. Results for end indicators of impact categories such as GHG emissions, resource depletion, eco-toxicity, land use etc are characterized by considerable uncertainty. While internal uncertainty -due to the structure of the model used – does exist, the external uncertainty sources are the dominant ones. Such uncertainty may be a consequence of a lack of understanding or knowledge or it may derive from randomness inherent in processes. Examples of such uncertainty sources are cultivation techniques parameters (biomass productivity yield, fertilisers' and pest control data etc), stock market prices, climate parameters and many others. The most important and common internal uncertainty source of these types of LCIA is the way that each researcher sets the limits of each system. In some cases the limits include the entire biomass cultivation sector, the transportation system, the biofuel production and distribution system and their upstream and downstream supply chain, while in other cases they do not. These kinds of uncertainty incur confusion and many problems in decision-making issues concerning biofuels.

It is also important to note that all the environmental impacts of biofuels have an economic basis. For example, the use of raw materials produced in EU has different inventory parameters, such as the transportation means, their capacity, the average distance between biomass site and production plant, and the productivity of the plant. Due to this, produced biofuels have quite different impacts, such as GHG emissions, Net Energy Ratio etc. Therefore each biofuels' LCIA must take into account the each time different values for these parameters. When researchers choose values from existing data bases, they must do this with care, assuring that the values are the correct or the most representative ones. In the case of values' absence, research must be undertaken in order to obtain some appropriate of these. Use of food products, such as vegetables or seed oils, as fuels for power generation or as raw materials for the production of transportation

biofuels is unacceptable from an ethical and rational point of view, taking into account that billions of people in the world are suffering from starvation. Of course this is a political, not a market issue. The latter has led in the rise of market prices of food products, such as wheat, barley, corn, etc. In any case, certain limitation must be set by the global community to the use of food biomass for the production of transportation biofuels or, generally, for energy purposes.
Finally, the assessment of the land use impact category is insufficient, as has been shown in this paper. However, the examination of the sustainability of a technological system-such as the production and use of a biofuel- needs the evaluation of its performance in the land use category. So, future LCIA studies of transportation biofuels must include the system’s performance in this category, at least in relation to some basic subcategories, such as biodiversity.

5 References

Blottnitz, H., Curan, M. A. 2007. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. J. Cleaner Prod., 15 (7), 607–619.

Borjesson. P. 2009. Good or bad bioethanol from a greenhouse gas perspective – What determines this? Applied Energy, 86, 589–594.

Center for Renewable Energy Sources. Biodiesel. Reports. European Biodiesel Board. Biodiesel chains, Promoting favourable conditions to establish biodiesel market actions. http://www.cres.gr/biodiesel/downloads/reports/Other/EU27%20report.pdf. Last assessed March 2009

Chisti, Y. 2008. Biodiesel from microalgae beats bioethanol. Trends Biotechnol. 26 (3), 126–131.

Eurobserver. Biofuels Barometer. June 2008. http://www.eurobserv-er.org/pdf/baro185.pdf. Last assessed March 2009

European Bioediesel Board. Biodiesel http://www.ebb-eu.org/biodiesel.php. Last assessed March 2009

European Bioediesel Board. Statistics. http://www.ebb-eu.org/stats.php. Last assessed March 2009

European Bioethanol Fuel Association. Statistics. http://www.ebio.org/statistics.php. Last assessed March 2009

European Commission. Directorate-General for Energy and Transport.2008. EU energy and transport in figures. Statistical pocketbook
Frondel, M., Peters, J. 2007. Biodiesel: A new Oildorado? Energy Policy, 35 (3), 1675–1684.

Guinee, J., Oers, L., Koning, A., Tamis, W. 2006 Life cycle approaches for Conservation Agriculture. Part I: A definition study for data analysis Department of Industrial Ecology & Department of Environmental Biology. Institute of Environmental Sciences. University of Leiden..The Netherlands.
Kim, S., Dale, B. 2005. Life cycle assessment of various cropping systems utilized for producing biofuels: Bioethanol and biodiesel. Biomass and Bioenergy, 29, 426-439.

Thamsiriroj, T., Murphy, J.D. 2009. Is it better to import palm oil from Thailand to produce biodiesel in Ireland than to produce biodiesel from indigenous Irish rapeseed? Applied Energy, , 86, 595–604.

Weber, J. A., Van Dyne, D. L. 1996. Macroeconomic effects of a community-based biodiesel production system. Bioresource Technology. 56 (1), 1–6.