A feasibility study of using biodiesel in recreational boats in the UK

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Abstract

The paper presents a feasibility study of applying biodiesel in recreational boats in the UK for the purposes of rational utilisation of energy resources and environmental protection.

Biodiesel has been widely used to fuel diesel engines for onshore vehicles, particularly, for agriculture machinery. Application of biodiesel for merchant ships' propulsion in a large scale has been seen a non-near future option due to the lack of availability and supply chains of the fuel. However, powering recreational boats with biodiesel has shown some market in pursuing marine environmental protection.

The study reviews the current status of using biodiesel on recreational boats and analyses the market in the UK. Results on fuel availability for the sector, economic aspects and environmental benefits are presented.

Key word
Renewable energy, bio-fuel, diesel engine, environmental performance, recreational boat, eco-efficiency

List of notation

Biodiesel	Bio-D
Fossil diesel	Fos-D
Global warming potential	GWP
Polyaromatic hydrocarbons	PAH

Neat rapeseed oil	NRO
Rapeseed methyl ester	RME
Ultra low sulphur diesel	ULSD
Life cycle emissions	LCE

1 Introduction

Biodiesel is a collective terminology describing alkyl monoesters of fatty acids from vegetable oils and animal fats. The idea of using vegetable oils in diesel engines is far from new. As early as the 1900, at the World Exhibition in Paris, only five years after Rudolph Diesel patented his engine, it was demonstrated running on groundnut oil.

However, the ready supply of cheap fossil fuel oil from then and up to now has to a large extent prevented any greater efforts on utilising biodiesel. The fact that fuel from vegetable oils can never replace the world's current fossil fuel consumption has also prevented biodiesel from being regarded as a realistic alternative fuel. But with increasing concerns on global pollution and the limited fossil fuel oil reserves, renewable fuels are becoming more and more important energy resources.

The main advantage with use of biodiesel, compared to other alternative fuels, is that it can be used almost straightaway in diesel engines, requiring only minor modifications. The fuel can be made from virtually any plant with the right structure of fatty acids. In the European climate however, rapeseed is a favoured source as a main oilseed crop grown in Europe.

Although crude rapeseed oil can be used to fuel diesel engines, it is largely unsuitable for modern DI (Direct Injection) engines. The high viscosity of the neat biodiesel is a problem, especially in cold weather. This has led to the necessity of a transesterification process to transfer the fuel properties to match with fossil diesel, a process which adds significantly to the total production costs. This process does, however, give the fuel viscosity and other properties similar to those of ordinary petroleum diesel.

Biodiesel has been successfully marketed and sold to recreational boaters in several areas in the USA where the term of e-diesel is used for a mixture of ethanol and diesel used on boats. Market surveys [1, 2] have indicated that the main users of biodiesel are sailboat owners for the following main reasons:

- Environment: cleaner emissions, less pollution, less toxic, biodegradable.
- Aesthetics: less soot, less smoke, less odour, pleasant to handle, safety.
- Mechanical: high lubricity, smoother operation, complete combustion.

2 State of the art of using biodiesel on diesel engines

Austria has been one of the pioneers in biodiesel production and utilisation due to lack of oil resources in the country. Farmers in the village of Mureck were the first to start a co-operative for commercial biodiesel production in Austria. In 1990, a capacity of 500 tonnes per annual plant was specifically set up in operation to produce biodiesel from rapeseed and sunflower crops for the farmers' own consumption. It has since been used as a model to convince their politicians of the merits of biodiesel. In the same year, a large fleet test of all major brands of tractors was carried out at Wieselburg. This successful test led to engine warranties from most of the tractor producers, including John Deere, Ford, Massey-Ferguson and others. In the following year (1991), the first fuel standard for biodiesel, i.e. ON C 1190, was established by the Austrian Standardisation Institute [3].

Examples of using biodiesel in the UK include: a) Reading Buses conducted a biodiesel project in 1992, where three of their buses were fuelled with rapeseed methyl ester (RME) for three months, in an attempt to persuading the Government to support the production of biodiesel; b) Camelot Crafts operated their small boats with biodiesel on the Norfolk Broads [4]; c). A new product, e-diesel, has just entered the market. It is a diesel substitute manufactured from waste frying oils by Stephen Whittaker and Ebony Solutions in Northwich. The product has so far been tested on some 75 vehicles, ranging from private cars to a fleet of heavy duty vehicles [5].

Biodiesel, in the form of soybean methyl ester, has been available to boaters in certain areas of the USA since 1994. Among the areas served are the Chesapeake Bay [1] and the San Francisco Bay [2]. Big marketing campaigns, funded partly by the National Biodiesel Board (NBB), have been carried out to get boaters' attention to the benefits of using biodiesel. As a common practice in the States, biodiesel has been marketed as a 20% blend with petroleum diesel. This blend ratio was set based on a cost analysis compromising emissions, price competitiveness, minimised modifications of engines, etc. However, on individual basis, very high blends or 100% of biodiesel have been used in fuelling boats. The most remarkable example is Bryan Peterson, who motored a 28 ft rescue boat travelling 35,000 miles around the world during 1992-1994, consumed 18,000 gallons of 100 % biodiesel supplied by NBB [2].

3 Advantages of biodiesel over fossil diesel

Table 1 lists the properties of neat rapeseed oil (NRO), rapeseed methyl ester (RME) and fossil diesel (Fos-D) fuel. It can be seen that biodiesel after transesterification has very similar properties with diesel. Thus, it can be used on existing diesel engines almost straightaway.

In detail, compared with diesel fuel, RME has higher values on cetane number, flash point and viscosity. However, the parameters of calorific value, carbon content are lower. It has an extremely low sulphur concentration and considerable amount of oxygen, whereas, zero or neglectable for diesel fuel.

3.1 Engine combustion and performance

The high cetane number of RME offers good cold start of engines. Studies [6, 7] showed that the high viscosity of RME affects its atomisation quality slightly. Thus, in general, it has little influence on the combustion. Although the calorific value of RME is about 10% less than that of diesel due to the lower carbon concentration, tests [8, 9] illustrated that engines fuelled with RME have increased specific fuel consumption by only about 2% compared when diesel fuelled. This may be contributed to the high content of oxygen improves the combustion efficiency which compensates the lower calorific value.

One of the most important concerns when using alternative fuels on diesel engines is the lubricity properties of fuels, as it has an effect on long term engine wear, particularly with respect to those components normally lubricated by the fuel itself, such as fuel pumps and injectors. Tests [9] showed that biodiesel has a clear advantage of being a superior lubricant over diesel.

3.2 Engine emissions

Combustion emissions of biodiesel vary with fuel supplies. The properties of biodiesel, particularly the animal fat, are affected by geographical locations and weather conditions where oil seeds grow and the process of fuel production. The properties also depend very much on the type of the oil seeds. Thus, engine emission results reported by different researchers vary. In general, emissions of biodiesel combustion have much less environmental impact compared with that of fossil diesel fuel.

Less composition of carbon and high for oxygen inherently reduces carbon monoxide and carbon dioxide emissions. It was observed [8, 9] that CO and CO_2 emissions are reduced by 28-37% and 4-5%, respectively. 72-94% of total hydrocarbon emission reduction has been obtained [10, 11]. Carbon soot from fuel combustion can be reduced in the order of 60-70% as shown in figure 1 [11]. As a result, particulate matters and smoke capacity are dropped significantly.

The lack of toxic and carcinogenic aromatics (benzene, toluene and xylene, 25% wt in low sulphur light diesel) in biodiesel brings a dramatic reduction in polyaromatic hydrocarbons (PAHs) emissions. A 74% PAHs reduction was reported [10].

Unlike other “clean fuels” which has reduced harmful emission species in the exhaust, but not carbon dioxide emissions, the carbon dioxide released from burning biodiesel will be recaptured by crops growing. Thus, the net effect of CO_2 emission is zero. This will reduce substantially the accumulation of CO_2, a green house effect gas, in the atmosphere. Another major benefit of using biodiesel is its zero or near zero sulphur oxides (SOx) emissions. SOx emitted from engine combustion come from sulphur content in fuel. The extremely low sulphur concentration in biodiesel makes its SOx emissions undetectable [8].

[Figure 1]

All the above indicate that the exhaust gases from the combustion of biodiesel have reduced impact on human health and the environment. However, tests [8, 12] showed that NOx emissions from burning biodiesel is slightly increased compared with diesel fuels due to the increased combustion efficiency leading to a high combustion temperature. The increased scale of NOx emission can be easily reduced by engine technology, such as retarded fuel injection.

3.3 Boating environment

Apart from those general benefits brought by using biodiesel on diesel engines, other advantages specified to recreational boats applications are:

Biodiesel has less impact to water pollution due to its insolubility and high biodegradation rate. Vegetable oils after transesterification are quite insoluble in fresh water and seawater, with a saturation rate of 17 ppm (sea) and 14 ppm (fresh) at a normal temperature [4], whereas petroleum diesel can partition aromatics into water at a rate of hundreds ppm. The biodegradation rate of biodiesel ester is about twice as high as for diesel fuels. For example, RME can be decomposed by 98.3% in 21 days [4]. The half-life for the biodegradation is with the first 4 days. The toxicity of biodiesel to marine plants and animals is significantly low compared with diesel. Tests with larval forms of fish and shell fish showed that the toxicity of biodiesel is, depending on the types of larval forms, 20-40 times less than that of fossil diesel fuels.

The low solubility and high biodegradation rate of biodiesel is absolutely an advantage for the boating environment since accidental spills of fuel is sometimes inevitable. However, a large spill still imposes a risk to the environment. Seabirds, mammals and fish that get coated with vegetable oils can die from hypothermia and illness or become victims of predators.

3.4 Other advantages

Biodiesel is a user-friendly fuel, in terms of handling, safety and storage. The product has no noxious odours and is considered as harmless to handle as a salad oil. It has no volatile organic compounds, no existence of any aromatic hydrocarbons that minimise the risk of releasing poisonous fumes, harmful or corrosive gases. Its non-volatility and high flashpoint pose no risk of explosion.

4 Biodiesel market and availability

Virtually, any plant oil can be utilised as biodiesel. Since rapeseed is a main source for biodiesel production in Europe, particularly, Northern Europe and the UK due to climate conditions there are in favour to grow rapeseed, the following discussion on biodiesel refers mainly to RME. Actually, rapeseed is one of the crops which have high percentage of oil (about 45% in rapeseed). In other continents, a variety of crops have been used as the raw materials of biodiesel, like in America, biodiesel is produced mainly from soybeans, with an oil yield rate of about 20%.

Currently, 10% of arable land in the UK and Europe must be set aside from food production under Common Agricultural Policy regulations (Agenda 2000). However, some non-food crops (including energy crops) are eligible to be grown on set aside land. The EC has proposed that biodiesel should account for a 5% share of the motor vehicle fuel market by the year 2005. A policy of subsidisation has been proposed to encourage the implementation of this plan.

In the UK biodiesel production and application have not been explored adequately to a level they should be, compared with other European countries and the States due to the high price of the fuel or lack of support from Government's taxation policy. The UK is committed to 10% of electricity (7000 MW) generation coming from renewable energy by 2010, which is currently 2.8%. It is seen that this target is going to be mainly achieved by using crops mainly from miscanthus. Renewables in the UK, 70% used for electricity generation, account currently hydro, wind and different forms of biofuels, but excluding oils from plants.

It is estimated that about 6% of the UK's current usage of diesel fuel could be replaced by RME from rapeseed grown on set aside land. The area of set aside land in the UK is 497,764 ha (1999). It is unlikely that all set aside land is to be used for growing rapeseed for biodiesel production. If they were, the following estimate (table 2) of biodiesel productivity in the UK could be realised.

It is necessary to mention that waste cooking oils from restaurant have been used to power diesel cars [5]. Although these oils can be used for fuelling boats directly, it is not considered in this paper.

5 Boating fuel consumption in the UK

Using biodiesel in merchant vessels as a propulsion fuel is obviously not a near future option due to its high price, small productivity and lack of supply chains compared with marine bunker fuels. However, powering recreational boats where fuel consumption of engines is small and they often operate in environment sensitive areas. This may show a small but attractive market for biodiesel.

Table 3 shows that the annual fuel consumption of recreational boats in the UK is about 430,478 tonnes. This is more or less in consistency with the figure in the States where there are 1.1 million recreational boats with an annual fuel consumption of 306,358 tonnes. Considering that the specific fuel consumption of biodiesel is 3% higher than that of fossil diesel, this gives that the boating fuel consumption accounts 48.2% of the total annual rapeseed oil production from the set aside lands in the UK. This simply means that it requires for about half of the set aside land in the UK to grow rapeseed crop.

Whether it is feasible to grow rapeseed crop with 48.2% of the set aside land in the UK to fuel all its recreational boats is questionable. However, powering one or two types of boats with biodiesel is seen quite possible (table 4), such as sailing yachts, where actually some sailing yachts in the UK are being fuelled with biodiesel imported from Europe. If only sailing yacht sector is considered, it only accounts 4.5% of the total rapeseed oil production if all the set aside land was used for growing rapeseed.

6 Economic aspects

The price of biodiesel varies with many factors, such as, seed price, scale of production, processing technique, sales of by-products (mainly glycerine and meal) and government taxes. A large scale of production is a main factor of reducing the price. Recent development in crushing technique has contributed to the price reduction. Biodiesel price is also very sensitive to the sales of its by-products as the by-products are of high values to chemical industry. Long distance transportation, for both seed to be crushed and distribution of processed oil, will have considerable effects to the total economy.

The current state is that biodiesel is more expensive than fossil diesel fuel. In USA, boat owners pay about 5 times as much as diesel price for biodiesel. In Europe, most countries have an untaxed policy for biodiesel, which makes the biodiesel price competitive to taxed diesel fuel. In the UK, the government has recently introduced a new tax rate on biodiesel by 20 pence per litre reduction from that of ultra low sulphur diesel (ULSD) fuel [14]. The price of biodiesel is still not attractive to boaters compared with fossil diesel.

Currently, recreational boats in the UK use red diesel (normal diesel with red dye) fuel where a special tax rate is applied. The retail price of the red diesel is about 35 pence per litre. Whereas, with the new tax rate, price for biodiesel made from used oil is about 80 pence per litre and around 1 pound for fuel made from fresh seeds [15].

Obviously, to make biodiesel a viable option for fuelling recreational boats, even motor vehicles, a measure of tax duty free, or further tax reduction, or governmental subsidy is required. Thus, the current incentives of using biodiesel will mainly come from environmental performance, rather an economical option.

7 Environmental performance and eco-efficiency

To evaluate the environment performance of using biodiesel fuel instead of fossil fuel on recreational boats, life cycle emissions (LCE) of the two types of fuels concerned should be considered. However, for comparison purpose, the analysis concentrates on emissions contributed from fuel user-end chains, i.e. emission inventories from engine manufacture and decommissioning are excluded. Previous studies have also shown that these emissions give an insignificant contribution to the overall life cycle emissions [17]. Table 5 illustrates life cycle stages included in the analysis for both biodiesel and fossil diesel fuel. Also for reasons given in section 3, the following discussion will focus on sailing yachts only.

Table 6 illustrates the emissions from sailing yachts and their contribution to the different environmental impact categories. Data presented in Table 6 should not be compared with those stated in section 3.2 where discussion was focused on emissions from engine operation only.

The emission values are derived by calculations from engine emission raw data [16], with consideration of the fact that sailing yacht number in the UK is 380,000, average sailing time is 39 hours per year and average power of boats is 20 kW. The normalisation factors used are total emissions per year in the UK [18]. For the impact category acidification the acidic potential of the two compounds is used as characterisation factor. The normalised values for diesel and biodiesel are then determined by equation 1 [19]

$$\text{Normalised value impact category} = \sum_{i=1}^{n} \frac{\text{total emission}_{compound\ i} \times \text{characterisation factor}_{compound\ i}}{\text{normalisation factor}_{compound\ i}} \quad (1)$$

Emissions of CO could also be included in the impact category of photo oxidant formation, but the contribution is insignificant if characterisation factors [20] are used. Other impacts categories, i.e. ozone layer depletion, and other substances in the selected impact categories are not included due to lack of reliable data. The chosen impact categories and substances are however sufficient to illustrate the method. From the state of the art knowledge in environmental performance study, it is safe to assume that missing emission substances have little effect on the total results as presented in Figure 2. This is however an area that needs further investigations for improvement of the method.

Figure 2 shows the characterised and normalised environmental profile from sailing yachts in the UK fuelled by fossil diesel and biodiesel based on the figures in Table 6. The y-axis shows the relative contribution from each impact category. The results show that the use of biodiesel offers the best result within each impact category except for eutrophication, while the difference in acidification is insignificant. The adverse effect of eutrophication and acidification is due to the higher values of NO_X emissions of biodiesel. There is a clear advantage in the contribution to climate change by using biodiesel (76.4 percent reduction), photo oxidant formation (48.2 percent reduction) and local air pollution (35.5 percent reduction).

[Figure 2]

However, there is a debate on how environmentally friendly the use of biodiesel is if the whole value chain of the fuel is taken into account. By examining the fuel consumption of agricultural machinery for seeding and harvesting, and the energy consumption for the processes of oil production, a great amount of the energy output is consumed during the production. However, the production efficiency is increasing (50% at present) [16]. This is anyway higher compared to that of fossil diesel where approximately 8% of the energy is consumed during extraction, refinery and distribution [21]. Our results do however show that even when this is taken into account, biodiesel brings greater environmental improvements for most impact categories.

Different impact categories could be weighted according to political priorities or based on weighting by expert panels. Some possible weighting factors are shown in Table 8. The weighted results are shown in Figure 3 and Figure 4.

[Figure 3 and Figure 4]

As seen from these diagrams, according to the weight factors used, the use of fossil fuel results in the most significant environmental impacts changes from global warming to local pollution. However, for both weight models biodiesel application produces worse effect on eutrophication. This is due to the increased NO_x emissions from biodiesel combustion.

8 Eco-efficiency

Another important aspect related to the choice of fuel is the price. Table 7 gives an overview of fuel cost per year by sail yacht in UK [15]. Information about economic and ecological performance is often represented by means of eco-efficiency indicators. The objective of eco-efficiency is to maximise value while minimising resource used and adverse environmental impacts. The method developed by the WBCSD [22] on eco-efficiency analysis is employed in this study, which integrates value and ecological aspects into an efficiency ratio:

Eco-efficiency = product or service value per environmental influence (2)

In order to calculate the eco-efficiency, it is necessary to evaluate the value created by sailing activity. However, it is difficult to put value on recreational activities, and one way to resolve it could be to measure it as the inverse of costs. The costs can be expressed by the fuel price (see Table 7). Different taxation systems could also be built into the model. The environmental influence can be expressed by the impact categories as shown in Table 6. The eco-efficiency of sailing yachts in UK on a yearly basis could then be calculated by:

Eco-efficiency =(1/ yearly costs) / environmental impact (3)

Applying equation 3, the eco-efficiencies using biodiesel and fossil diesel are 2.4×10^{-4} and 3.8×10^{-4} per Global Warming Potential (GWP), respectively. Figure 5 shows the eco-efficiency for the two types of fuel for the selected impact categories. The y-axis shows the service value (1/yearly cost) per relative environmental impact from each category. It shows that the eco-efficiency of biodiesel is the best for the impact categories climate change. For the other impact categories, fossil diesel has the best eco-efficiency. By comparing Figure 2 and 5 the influence of costs on the eco-efficiency can be derived. However, the use of cost-factors is just for the purpose of demonstrating the method. Other price mechanisms and taxation systems could be included here. This is a subject for further studies.

[Figure 5]

The use of eco-efficiency analysis is considered as an instrument for e.g. political planning.

Figure 6 and 7 present results of the eco-efficiency for the “political weighted” and for the “expert panel weighted”.

[Figure 6 and Figure 7]

The results show that fossil diesel has the best eco-efficiency values for most of the impact categories. However, with a reduction in biodiesel price or by taxation on emissions from fossil fuel, the eco-efficiency indicator will be a good measurement instrument for finding the crossing points between the best alternatives in accordance with e.g. relevant political goals.

9. Summary and conclusions

The paper discusses feasibility of fuelling recreational boats in the UK, with detailed analysis and illustration of fuel properties, benefits of using biodiesel for both engines, cost factors and the environment.

Application of biodiesel on recreational boats has been recognised as a viable option for environmental protection and rational use of energy resources. Incentives of using biodiesel on recreational boats are: a) The importance of clean and environmentally friendly operation, especially on lakes and inland waterways; b) The property of bio-degradation of biodiesel makes it suitable for waterborne application. This study indicated that fuelling recreational boats with biodiesel is feasible in the UK, in terms of resources to grow the required rapeseed plant.

This is the first attempt to study analysis methods and results of environmental performance and eco-efficiency of using biodiesel on recreational boats in the UK. Although changes on fuel prices and government taxation policy will affect the results of the eco-efficiency of the two types of fuel, eco-efficiency is probably a useful instrument in the future for both political purposes and taxation planning. However, methodologies applied in this study require further improvement and standardisation, including system description, methods of allocation, weighting principles and the calculations of value creation. There is also a need for an investigation on which impact categories to be considered as the most important to include in the inventories. Further research should be done to come up with more data and examples on this subject.

The most obvious obstacle for using biodiesel is its high price. To make biodiesel as an economical fuel for recreational boats, government assistance with low or no taxation on the fuel is highly demanded. Meanwhile, promotion of large-scale production, standardisation of fuel, transportation and supply are also important factors in making biodiesel an economically viable fuel.

References

[1] National Biodiesel Board, USA: *"Marketing Biodiesel On The Chesapeake"*, executive summary of 1997 Outreach Program.

[2] National Renewable Energy Laboratory / US Department of Energy Research Project: *"Survey of 100 Recreational Boaters Using Biodiesel, 1994-1997"*, CytoCulture International Inc., USA.

[3] Körbitz, W.: *"The Biodiesel Market Today and its Future Potential"*. Proceedings of the *Plant Oils as Fuels – Present State of Science and Future Developments* Symposium held in Potsdam, Germany, February 16-18, 1997, pp. 3-12.

[4] *"Biodiesel Production in the UK"*. A report prepared by the East Durham Biodiesel Working Group, 1993.

[5] The e-diesel homepage, Ebony Solutions, Norwich, Cheshire. www.ebony-solutions.co.uk/e-diesel1.htm

[6] PL Zhou, YW Wang, T Roskilly, "An Investigation Of Droplet Size And Distribution In Direct Injection Diesel Sprays Using Phase Doppler Anemometer Measurement", Transaction of the Institute of Marine Engineers, V112 Part 3-4, Nov. 2000

[7] YW Wang, PL Zhou, T Roskilly, "An investigation of diesel and rapeseed methyl ester droplet evaporation", SAE 2000-01-2045, CEC/SAE Fuel and Lubricants, June 2000

[8] 8 K Polydakis, "Engine emission reduction with use of REM", MSc Dissertation, Dept. of Marine Technology, University of Newcastle upon Tyne, Sept. 1997

[9] Von Wedel, Randall: *"Technical Handbook for Marine Biodiesel in Recreational Boats"*, CytoCulture International Inc., USA. 2nd edition, April 1999. www.cytoculture.com

[10] NF0403-Miscanthus, Agronomy (for Fuel and Industrial Uses", MAFF Scientific Report, 2000, www.maff.gov.uk/farm/acu/acu.htm

[11] Sams, T., Technical University Graz, Institute for Internal Combustion Engines and Thermodynamics: *"Exhaust Components of Biofuels under Real World Engine Conditions"*. Proceedings of the *Plant Oils as Fuels – Present State of Science and Future Developments* Symposium held in Potsdam, Germany, February 16-18, 1997, pp. 64-77.

[12] PL Zhou, YW Wang, T Roskilly, "Application and development of biofuel on diesel engines", 2nd European liquid biofuels conference, Athens, 5-7 May 1997.

[13] K Fet, The Use of Biodiesel in Recreational Boats, Final Year Project for BEng in Marine Technology, the University of Newcastle upon Tyne, May 2000.

[14] Budget 2002, Chapter 7.30, http://www.hm-treasury.gov.uk/

[15] Author's conversation with Mr. TL De Winne, British Association for Bio Fuels and Oils (BABFO), May 2002.

[16] BABSO report,http://www.biodiesel.co.uk

[17] T Johnsen, AM Fet, "Screening Life Cycle Assessment of M/V Color Festival", Report no. 10/B101/R-98/009/00, Aalesund College, 1999

[18] "Digest of United Kingdom Energy Statistics 2000", Department of Trade and Industry, London Stationery Office, July 2000, ISBN 011 5154973

[19] Fet, A. M., Michelsen, O., Johnsen, T., "Environmental performance of transport –A comparative study." Norwegian University of Science and Technology – IOT, NTNU, Norway, 2000.

[20] MZ Hauschild, H Wenzel, "Fotokemisk ozondannelse som vurderingskriterium ved miljøvurdering af produkter", in M Hauschild (ed.), "Baggrund for miljøvurdering af produkter", Miljøstyrelsen og Dansk Industri, København, 1996 (in Danish)

[21] PRé Consultants, "Eco-indicator 99 Methodology Report", The Netherlands, 2000.

[22] WBCSD, "Measuring eco-efficiency, a guide to reporting company performance", Verfaille, H.A., Bidwell, R., June 2000.

TABLES

Table 1. Properties of biodiesel and fossil diesel

Property	NRO	RME	Fos-D
Cetane number	42.6	54.4	47.8
Flash point (°C)	274	>110	80
Cloud point (°C)	-11	-2.2	-12.2
Pour point (°C)	–	-9.4	-28.9
Viscosity (cs) @40°C Viscosity (cs) @100°C	46.68 –	6.2 2.4	3.2 1.3
Specific heat (kJ/kgK @100°C)	2.43	2.47	1.7
Conductivity (W/mK @100°C)	0.15	0.17	0.11
Surface tension (mN/m^2 @100°C)	28.1	25.4	22.5
Lower heating value (kJ/kg)	40,400	40,600	45,300
Density (kg/m^3)	906	874	852
Sulphur content (%wt)	0.022	0.031	0.32
Carbon (%wt)		77.20± 5%	87.26± 5%
Hydrogen (%wt)		12.64± 5%	13.44± 5%
Oxygen (%wt)		10.9	0.00

Table 2. Annual rapeseed oil production in the UK

Total set aside land in the UK (ha)	497,764
Average plant yield (t/ha)	4.25
Harvested seed (t/y)	2,115,497
Average oil content (%wt)	43.5
Rapeseed oil productivity (t/y)	**920,241**

Table 3. Annual diesel fuel consumption by boats in the UK

Boat type	Number (x 1000)	Ave. power (kW)	Season length (month)	Sailing time (h/y per boat)	Fuel cons.* (t/y)	Remarks**
Sailing Dinghy	460	8	7	39	19,674	1.5 times per fortnight at 1 hours per time
Sailing	380	20	7	39	40,632	1.5 times per fortnight at

Yacht						1 hours per time
Motor Cruiser	340	8	12	365	233,308	1/3 of year's usage at 3 hours per day
Canoe	200	N/A			0	
Sports	160	120	7	52	136,864	1 time per fortnight at 2 hours per time
Total	**1,540**				**430,478**	

* On the basis of diesel fuel and take engine specific fuel consumption as 0.235 kg/kWh

** Remarks are based on a survey to 50 yacht clubs in the UK [13]

Table 4. Fuel consumption by different type of boats

Boat Type	Sailing Dinghy	Sailing Yacht	Motor Cruiser	Sport	Total
Fuel consumption (%)*	2.2	4.5	26.2	15.3	48.2

*Percentage of rapeseed oil production from the set aside land in the UK

Table 5: Life cycle stages included in the LCE.

Fos-D	Extraction	Transport	Refinery	Distribution	Engine operation	
Bio-D	Fertiliser production	Fertiliser application	Agricultural machinery	Oil production/ processing	Transport	Engine operation

Table 6: The emissions from Sailing Yachts (in UK) fuelled by diesel (Fos-D) and on biodiesel (Bio-D) (kg/year)

Impact category	Substances	Fuelled by Fos-D [16]	Fuelled by Bio-D [16]	Charac-terisa-tion	Norma-lisation factors [18]	Normalised values petrol	Normalised values biodiesel
Climate change	CO_2	1.4×10^8	3.4×10^7	1	4.16×10^{11}	3.46×10^{-4}	8.17×10^{-5}
Acidifi-cation	SO_X	1.5×10^5	2.9×10^4	1,0	1.62×10^9	3.40×10^{-4}	3.45×10^{-4}
	NO_X	6.2×10^5	8.2×10^5	0,7	1.75×10^9		
Local air pollution	Particulars / soot	5.2×10^5	3.1×10^5	1	0.44×10^9	1.28×10^{-3}	8.26×10^{-4}
	CO	4.8×10^5	5.8×10^5	1	4.76×10^9		
Photo oxidant formation	NMVOC	2.9×10^5	1.5×10^5	1	1.96×10^9	1.48×10^{-4}	7.66×10^{-5}

Eutrophi-cation	NO_X	6.2×10^5	8.2×10^5	1	1.75×10^9	3.54×10^{-4}	4.68×10^{-4}

Table 7: Fuel cost per year by sail yacht [15]

	A*	B	C	**D**
Bio-D	40632	90.2	874	**32032156**
Red Diesel	40632	34.79	852	**12043764**

*A = fuel consumption (t/y)
B = average fuel cost pence per litre
C= density of fuel (kg/m^3)
D = total fuel cost per year (GBP/y)

Table 8: Political weight factors [19]

Impact Category	**Weight factor, political goals**	**Weight factors, expert panels**
Climate change	1	19
Ozone depletion	1	12
Acidification	1,5	4
Photo oxidant formation	1,8	5
Local air pollution	1,5	4
Eutrophication	2	7

FIGURES

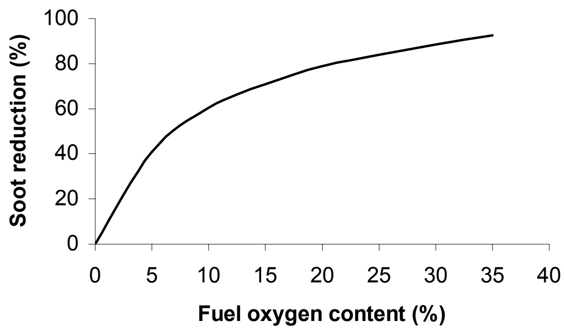

Figure 1. Soot reduction due to fuel oxygen content

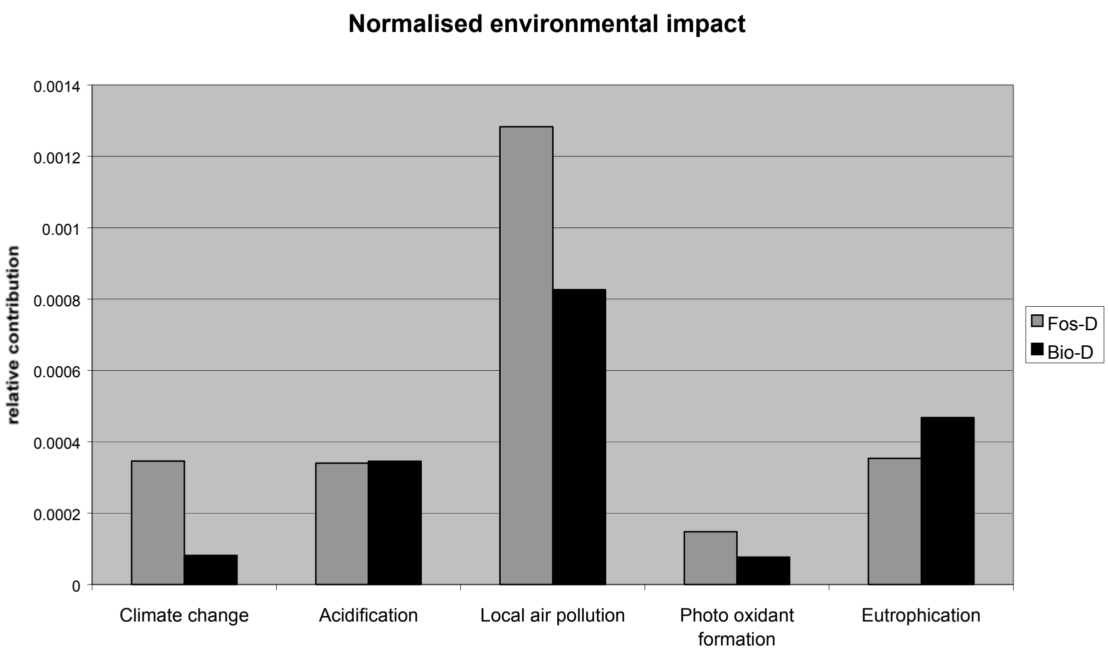

Figure 2: Characterised and normalised inventory results from sailing yachts in UK, use of petroleum diesel compared with biodiesel

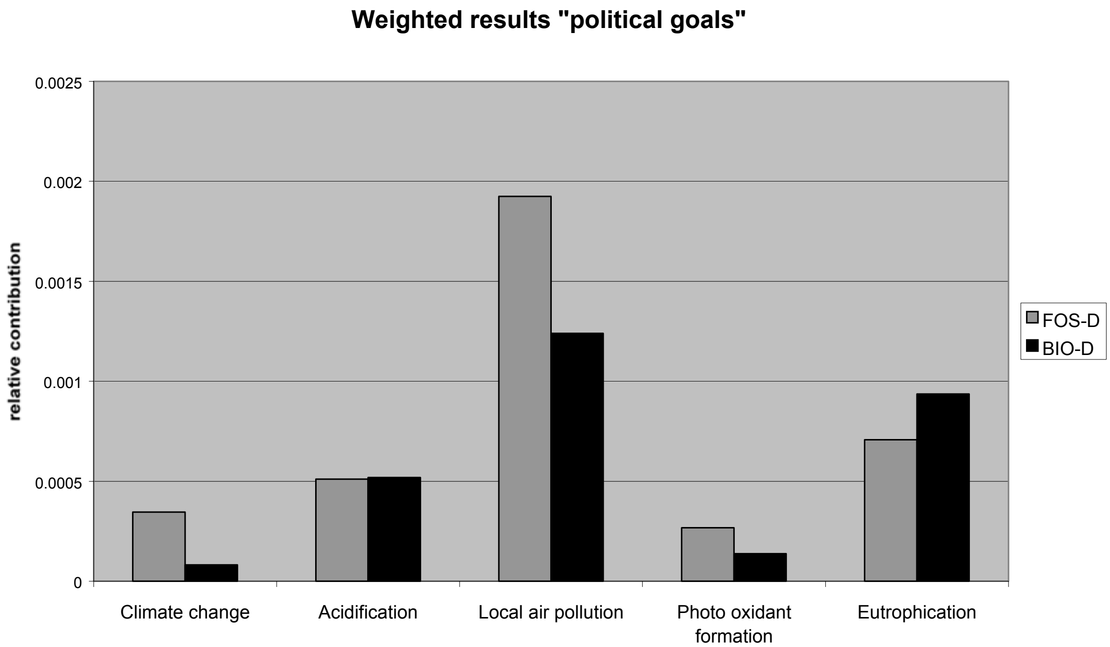

Figure 3:Weighted results based on political targets

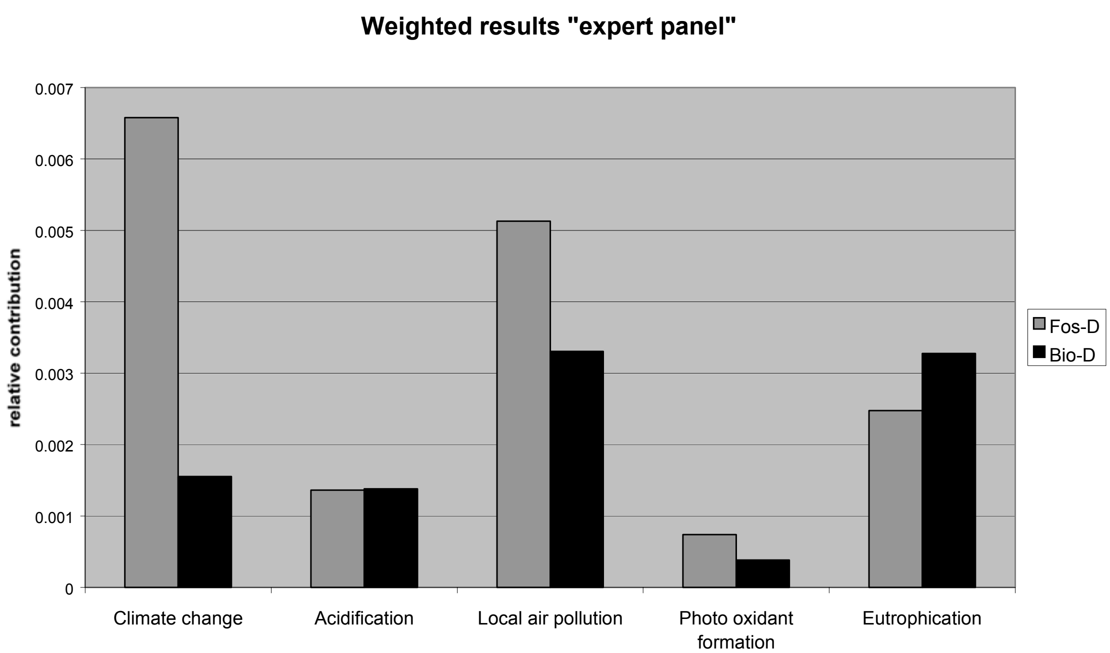

Figure 4: Weighted results based on expert panel procedures

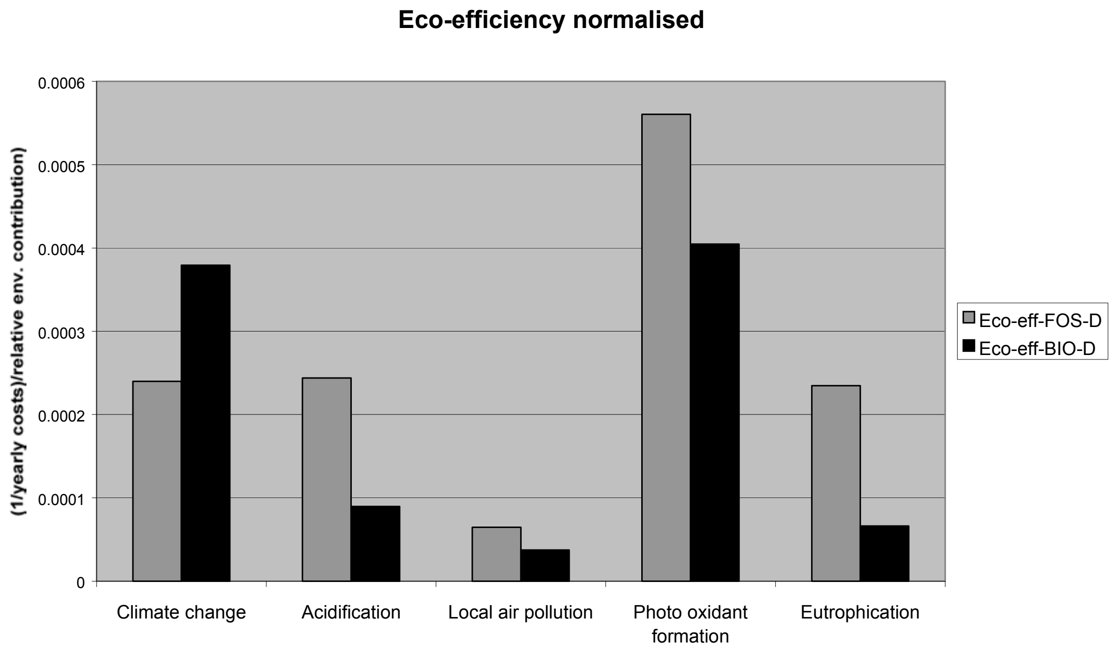

Figure 5: Eco-efficiency for normalised values

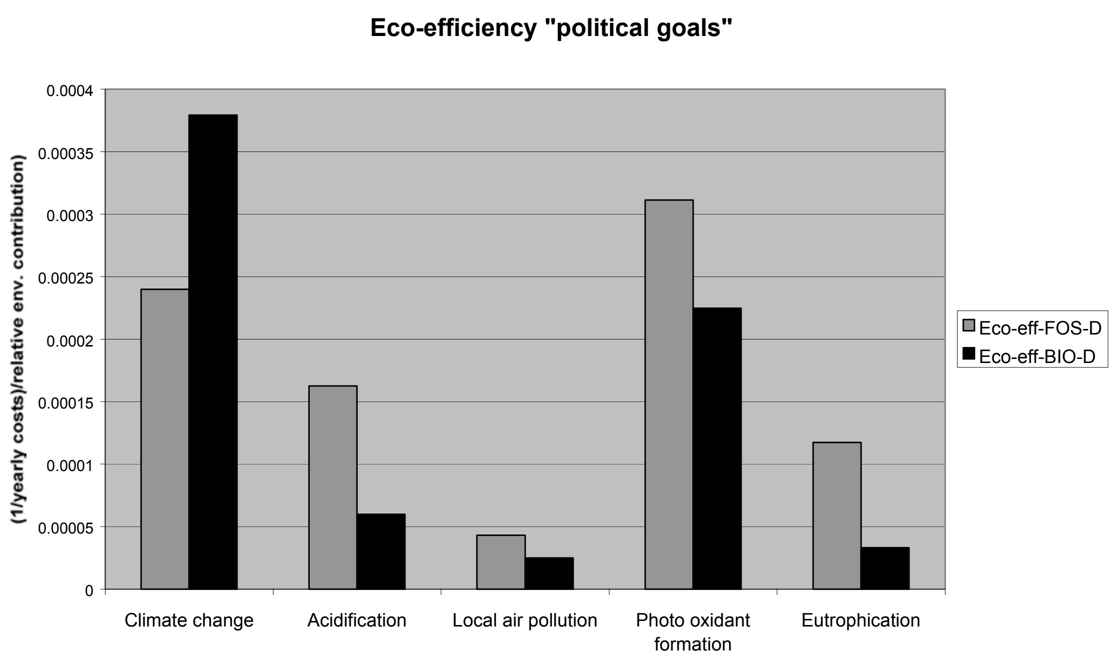

Figure 6: Eco-efficiency based on political targets

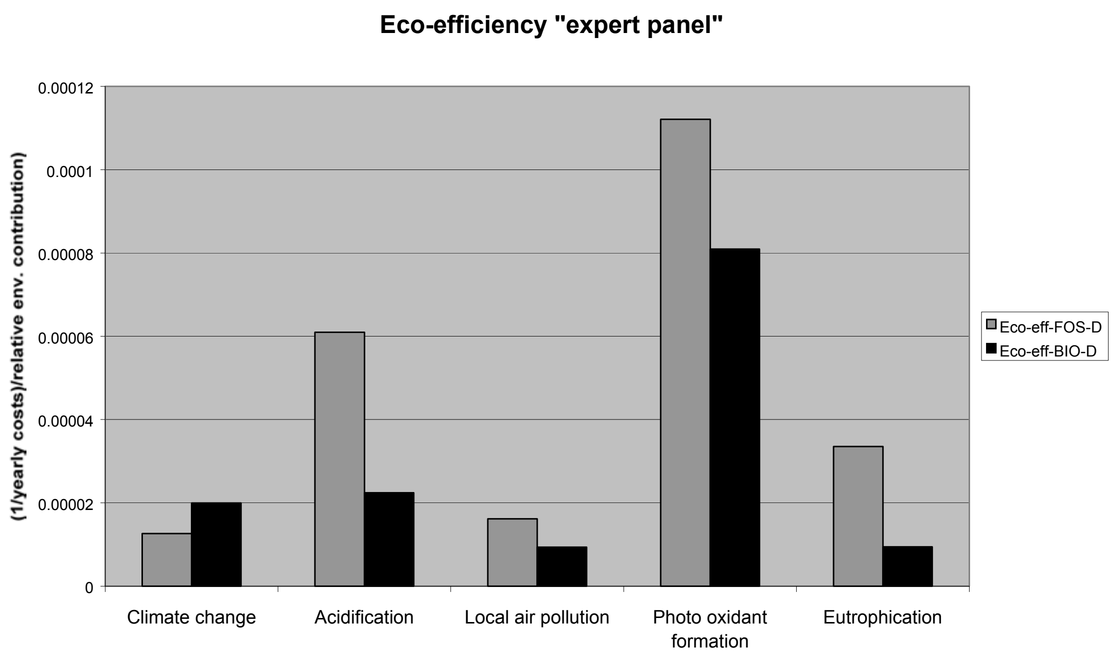

Figure 7: Eco-efficiency based on expert panel procedures