

Frondel, Manuel; Peters, Jörg

Research Report

Questioning the sustainability of Biodiesel: Final report - October 2005

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Rheinisch-Westfälisches Institut
für Wirtschaftsforschung

Questioning the Sustainability of Biodiesel

Final report



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Phone +49 (0) 201/81 49-0, Fax +49 (0)201/81 49-200, e-mail: rwi@rwi-essen.de
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Questioning the Sustainability of Biodiesel

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Project-Team: Dr. Manuel Frondel (Project leader) and Jörg Peters

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Questioning the Sustainability of Biodiesel

Manuel Frondel and Jörg Peters, RWI, Essen

October 2005

Abstract. Biofuels contribute to the mitigation of climate change. Directive 2003/30/EC thus aims at increasing the share of biofuels in total EU fuel consumption by up to 5.75 % by 2010. The rationale behind this directive can be found in potentially positive environmental impacts, most notably the reduction of greenhouse gas emissions, and by positive employment effects in the agricultural sector. This paper investigates the environmental, economic, and social implications of the support of rapeseed-based biodiesel as a substitute for fossil diesel. Based on a meta-analysis of recent empirical studies, we find clearly positive energy and greenhouse gas balances of this environmental strategy. Yet, the overall environmental balance of the substitution of rapeseed-based biodiesel for fossil diesel is currently far from being unequivocally positive. Our major finding is, however, that biodiesel is *not* a cost-efficient emission abatement strategy. When taking all economic, ecological, and social aspects into account, we conclude that Biodiesel is not a sustainable solution. We therefore suggest more efficient climate gas abatement strategies. Among these alternatives are synthetically generated biofuels that can substitute for fossil fuels in the future.

Keywords: Renewable Energy, Environmental Policy, Greenhouse Gas Emissions.

JEL-Classification: Q28, Q42, Q58.

Corresponding Author: Dr. Manuel Frondel, Division Chief “Environment and Resources”, Rheinisch-Westfaelisches Institut fuer Wirtschaftsforschung (RWI), Hohenzollenstr. 1-3, 45128 Essen, Germany, email: frondel@rwi-essen.de.

Table of Contents

1. Introduction	5
2. Land Use and Current and Future Biodiesel Production in the EU25.7	
3. Environmental Impacts of Biodiesel.....	10
3.1 The Net Energy Balance.....	10
3.2 Net Greenhouse Gas Balances.....	12
3.3 Overall Environmental Impact	13
4. Economic Impacts of the Promotion of Biodiesel	15
5. Alternative Options	17
6. Summary and Conclusion	21
References	23

1. Introduction

The tax exemption of biofuels triggered a dramatic increase in the demand for biodiesel in Germany. Within two years, the production of biodiesel doubled and exceeded the limit of one million tonnes in 2004 (EBB 2005). In several other European countries, most notably France and Italy, the production of biodiesel has also been pushed through tax reductions and exemptions. Currently, these three countries dominate the European biodiesel market, with Germany contributing more than half to the overall production (EBB 2005).

Tax exemptions and reductions for biofuels are just one facet of a kaleidoscope of activities and directives within the general environmental policy framework of the European Commission (EC) that aim specifically at promoting renewable energy technologies. The goal of such national fiscal measures, which are in line with the EU Council Directive 2003/96/EC, is to support the achievement of the indicative targets for biofuels that are set by Directive 2003/30/EC. This directive's target shares for biofuels - measured on an energy content basis - are 2 % by 2005 and, by 2010, 5.75 % of the overall amount of gasoline and fossil diesel used in the EU25 transport sector. A further, much more ambitious objective is to substitute alternative fuels for 20 % of conventional fuels by 2020 (EC 2001a: 43).

The indicative targets of 2 % and 5.75 % are justified by Directive 2003/30/EC on the basis of (see Faaij 2005):

- Mitigation of climate change through greenhouse gas (GHG) abatement.
- Increase of energy supply security.
- Diversification of energy sources.
- Conservation of fossil fuels.
- Potentially positive employment effects in the agricultural sector.

Among the various biofuel alternatives, bioethanol produced out of sugar beet and wheat and biodiesel originating from rapeseed are currently seen as the two most important options to reach the EU targets (JRC 2004: 1). At present, bioethanol is the only substitute for gasoline, while rapeseed-based biodiesel, or in technical terms, rape methyl ester (RME), is a major biofuel alternative to fossil diesel (Henke, Klepper, Schmitz 2005: 2618).

If the indicative - yet not mandatory - EU targets are adopted in each EU Member State much more acreage will be required for the production of rapeseed and crops such as wheat and sugar beet. The increased use of land for biofuel production is likely to result in a growing competition for acreage, because agricultural feedstock production for biofuel purposes competes with other major applications such as crop production for food – and, more recently, electricity generation. In fact, the availability of land is considered a core limitation of biofuel production (JRC 2004: 1). As a result of potential land limitation and increased competition for acreage, prices for food based on agricultural feedstock may rise. In this case, the expected positive environmental benefits from the use of biofuels will create substantial economic and social effects.

This paper investigates both the environmental and economic aspects of rapeseed-based biodiesel as a substitute for fossil diesel. Rather than providing an exhaustive cost-benefit analysis, we focus particularly on the issue of climate change mitigation, which is one of the most-cited justifications for the promotion of biodiesel (Henke, Klepper, Schmitz 2005: 621). Our major finding, based on a meta-analysis of a variety of empirical studies, is that biodiesel is far from being a cost-efficient emission abatement strategy. Thus, for the abatement of greenhouse gases, we recommend that other, more efficient alternatives based on both renewable and conventional technologies need to be considered.

In the subsequent section, we provide a detailed picture of the current biodiesel production situation within the EU25 and the future amounts of biodiesel, rapeseed, and acreage required to meet the 5.75 % target by 2010. On the basis of the results of a series of empirical studies, we thoroughly investigate in Section 3 both the energy and greenhouse gas balances of the substitution of biodiesel for conventional diesel. We then discuss the overall environmental impacts of the use of biodiesel, including climate aspects, soil contamination, and depletion of the ozone layer.

In Section 4, we sketch the economic consequences of the growing demand for rapeseed that may arise when complying with the EU targets. Section 5 provides cost estimates of the biodiesel option for the abatement of greenhouse gas emissions. These estimates cast doubt on the cost efficiency of this climate protection strategy. Thus, the paper closes by suggesting more efficient biofuel alternatives and recommending several much more efficient greenhouse gas abatement options that are based on both renewable and conventional technologies.

2. Land Use and Current and Future Biodiesel Production in the EU25

Boosted by the tax credits for biofuels that are currently granted by most of the EU Member States (see EC (2004a)), biodiesel production has increased substantially and almost doubled between 2002 and 2004 (see Table 1). In 2004, European biodiesel production nearly reached the level of 2 Mill. tonnes. With a share of 53.5 %, Germany was, by far, the most important supplier of biodiesel in 2004.

Table 1
Recent Biodiesel Production in the EU25 in 1000 t (Source: EBB 2005)

Country	2002	2003	2004
Germany	450	715	1035
France	366	357	348
Italy	210	273	320
Austria	25	32	57
Denmark	10	41	70
United Kingdom	3	9	9
Czech Republic	-	-	60
Others	1	7	29
Total	1065	1434	1933

In order to forecast the acreage demand for future biodiesel and bioethanol production that will comply with the EU targets, we take account of the projections on the future fossil diesel and gasoline demands established by JRC (2004). We assume that the EU targets are fulfilled for both biodiesel as a substitute for conventional diesel and bioethanol as a substitute for gasoline. Diesel consumption is estimated by JRC (2004) to amount to 159.9 and 177.8 Mill. tonnes in 2005 and 2010, respectively (see Table 2).

Given that the EU targets are formulated in terms of the energy content of the fuels, we take account of the different heating values of fossil diesel and biodiesel (JRC 2004: 23), which amount to 42.6 GJ/t and 37.3 GJ/t, respectively. Using the heating value of 42.6 GJ per t, the energy content of the JRC (2004: 23) fossil diesel consumption estimates equals roughly 6,812 Mill GJ in 2005 and 7,574 Mill. GJ in 2010 (see Table 2). The 2 % target requires a biodiesel production of about 136.2 Mill. GJ in 2005, or equivalently, around 3.7 Mill. tonnes, and the 5.75 % target implies a production of 11.7 Mill. tonnes by 2010.

Assuming biodiesel yields of 45.6 GJ/ha (JRC (2004: 24)), the required biodiesel production of 136.2 Mill. GJ in 2005 would occupy about 3 Mill. hectares (ha) of acreage (see Table 2). This amount of acreage was required in 2004 for rapeseed production for food purposes alone. Likewise, our conservative acreage estimate for biodiesel target compliance in 2010 amounts to about 9 Mill. ha. It is obvious, therefore, that the rapeseed production for non-food purposes will exceed that for food purposes by far.

Table 2
Acreage Requirements for Biodiesel Target Compliance in EU25

	2005	2010
EU Targets	2 %	5.75 %
Diesel Consumption Forecasts	159.9 Mill. t	177.8 Mill. t
Diesel Energy Equivalentents	6,812 Mill. GJ	7,574 Mill. GJ
Biodiesel Target Equivalentents	136.2 Mill. GJ	435.5 Mill. GJ
Biodiesel Target Production	3.7 Mill. t	11.7 Mill. t
Acreage Requirement	3.0 Mill. ha	9.0 Mill. ha

The figure of 9 Mill. ha is based on an increased biodiesel yield, for which JRC (2004: 24) forecasts 48.3 GJ/ha by 2010. Note that the assumed figure for the biodiesel yields per acreage represents the EU15 average, which is certainly not standard in the new accession countries. Thus, our acreage estimates for the necessary biodiesel production represent lower bounds.

Table 3 displays the acreage requirements for bioethanol, which is currently the only serious alternative to gasoline. The acreage figures are calculated on the basis of the assumptions that half of the bioethanol production results from wheat and half from sugar beet. The energy contents of bioethanol, 26.6 GJ/t, and gasoline, 41.9 GJ/t, respectively, and the JRC (2004: 24) assumptions on the bioethanol yields generated from wheat and sugar beet, 46.0 GJ/ha and 139.9 GJ/ha, respectively. These yields are expected to increase up to 47.5 GJ/ha and 150.5 GJ/ha in 2010. Obviously, acreage requirements decline, if bioethanol production is solely based on sugar beet: 0.8 Mill. ha and 2.2 Mill. ha would be needed in 2005 and 2010 respectively.

Table 3
Acreage Requirements for Bioethanol Target Compliance in the EU25

	2005	2010
Targets	2 %	5.75 %
Consumption of gasoline	133.0 Mill. t	139.1 Mill. t
Gasoline Energy Equivalentents	5,573 Mill. GJ	5,828 Mill. GJ
Bioethanol Target Equivalentents	111.5 Mill. GJ	335.1 Mill. GJ
Bioethanol Target Production	4.2 Mill. t	12.6 Mill. t
Acreage Requirements	1.6 Mill. ha	4.6 Mill. ha

In sum, it becomes obvious that the promotion of biofuels requires huge amounts of arable land that is also needed for traditional purposes such as food production. By adding our figures for biodiesel and bioethanol, we estimate that 13.6 Mill. ha are required for target compliance production in 2010. Given that the total arable land in EU25 is gauged by the JRC (2004: 24) to amount to 82.4 Mill. ha, 13.6 Mill. ha represent 16.5 % of the total arable land in EU25. This share appears to be at the lower end of an IEA (2004: 132) study that assumes a scenario in which both biodiesel and bioethanol displace 10 % of their fossil counterparts in 2020. The IEA study estimates a land requirement of 38 % of total acreage in EU15.

It is often argued that there would be sufficiently enough set-aside land for the production of energy crops, such as rapeseed for biodiesel. Actually, the European Commission prescribes a compulsory set-aside land share of 10 %, which must either remain fallow or be used for non-food production (JRC 2003: 45). Yet, the estimate of 16.5 % of arable land, required for the biofuel target compliance production in 2010, is substantially higher – in fact, by 65 % – than the compulsory set-aside land share of 10 %. It is evident, therefore, that the entire biofuel production cannot solely take place on set-aside land – not to mention the fact that the quality of set-aside land is not always appropriate for the cultivation of biofuel crops such as rapeseed.

For instance, although 317,000 ha of set-aside land are currently being used for rapeseed cultivation in Germany, biodiesel production requires 680,000 ha in 2005 (UFOP 2005b: 4). Less than half of the rapeseed employed for biodiesel production in Germany is thus grown on set-aside land. As a consequence, rapeseed cultivation for biodiesel in fact competes with

crop cultivation for other purposes. This conclusion is in accord with the JRC (2003: 49) study, which claims that biodiesel manufacturers are forced to buy rapeseed grown on non-fallow land.

Furthermore, the problem of land scarcity is intensified by the crop rotation periods of 3 to 7 years for rapeseed (IPTS 2003). Even if 100 % of total acreage were available for rapeseed production, a crop rotation period of four years, which is rather optimistic, would mean that, in effect, only one fourth of total arable land would be available for rapeseed cultivation. On 20.6 Mill. ha, which is one fourth of total arable acreage of 82.4 Mill. ha, biodiesel with an energy equivalent of about 995 Mill. GJ can be produced if acreage yield is assumed to be 48.3 GJ/ha in 2010. Taking the JRC (2004: 23) forecast for fossil diesel consumption with an energy equivalent of 7 574 Mill. GJ in 2010 (see Table 2), the energy equivalent of 995 Mill. GJ would mean an upper limit of about 13 % for the biodiesel share.

3. Environmental Impacts of Biodiesel

In addition to energy supply security, another major argument for the promotion of biodiesel is the protection of natural resources, i.e., the conservation of fossil fuels (Henke, Klepper, Schmitz 2005: 2618). By employing biodiesel rather than conventional diesel, it is frequently assumed that scarce and valuable fossil fuels can be saved. This assumption is based on the fact that biodiesel is ultimately generated by the natural conversion of sunlight into the required crop - rapeseed, mainly, and occasionally, sunflower (IFEU 2004: 15). This mechanism of the conversion of energy in the form of ubiquitous sunlight into other forms of energy, such as fuel and electricity, is the common feature of all renewable energy technologies, be it photovoltaic or wind energy technologies.

3.1 The Net Energy Balance

One litre of biodiesel does, however, not replace exactly one litre of conventional diesel. The net energy balances presented in this section indicate that one litre of biodiesel does not save the entire fossil energy of the equivalent it replaces. There are several reasons for this outcome: First of all, the heating values of biodiesel and conventional diesel are different.

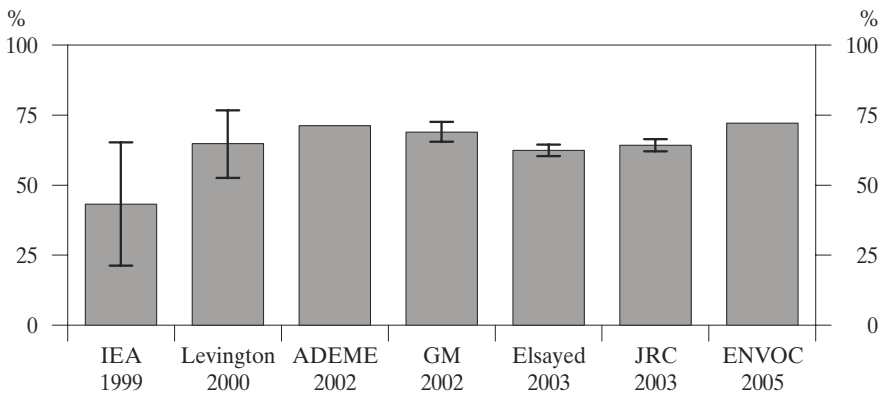
While the heating value of biodiesel roughly amounts to 32.8 MJ per litre, the heating value of conventional diesel is as high as 35.7 MJ per litre (IEA 1999: 20). Therefore, only about 0.92 litre of conventional diesel is needed for the same performance provided by 1 litre of biodiesel. In other words, as a rule of thumb, cars need roughly 10 % more biodiesel than fossil diesel to run the same distance. For what follows, we define the *fossil diesel equiva-*

lent of one litre of biodiesel to amount to 0.92 litre of fossil diesel, with the energy content of 32.8 MJ.

Secondly, the production of rapeseed requires agricultural machinery that is typically run by fossil fuels, as well as fertilizers and pesticides, whose manufacturing energy must be included in any net energy balance. Thirdly, the refinement of diesel originating from crude oil requires less energy than the conversion of rapeseed into biodiesel. This process, including the extraction of the oil from the seeds as well as the esterification of the oil to Rapeseed Methyl Ester (RME) is actually very energy intensive (IEA 1999, Levington 2000, ENVOC 2005).

Figure 1 summarizes the results of our meta-analysis, which is based on a set of empirical life-cycle analyses recently performed by institutions such as the Joint Research Centre of the European Commission (JRC 2003) and the International Energy Agency (IEA 1999). The wide range of estimates of the fossil energy savings that accrue when biodiesel is substituted for fossil diesel is due to the varying sets of distinct assumptions invoked by these studies. Point estimates are indicated in Figure 1 by solid bars, while the range between minimum and maximum amounts of fossil energy required for the production of one litre of biodiesel is represented by thin lines. These estimates are either directly provided by these empirical studies or are our own calculations based on their data material.

Figure 1
Fossil Energy Savings from Biodiesel



The concrete value of these estimates heavily depends on whether or not by-products such as rapeseed cake and glycerine are included in a study's energy balance - and if yes, to what degree. For instance, rapeseed cake

originating from the oil extraction process can be used as animal feed. In addition, an energy bonus is frequently granted in these studies for glycerine, an esterification by-product that is a perfect substitute for petrochemically produced glycerine. Finally, the large variety of point estimates is due to varying assumptions concerning rapeseed yields per hectare, the impact of fertilizers and pesticides, etc.

In sum, irrespective of the concrete estimate and empirical study, a thorough energy balance shows that biodiesel is far from being a perfect substitute of conventional diesel. In fact, only about 60 % of the fossil fuel can be saved by substituting biodiesel for conventional diesel¹. For the calculation of the fossil energy savings, the difference in the heating values of biodiesel and fossil diesel are taken into account, as well as the fossil energy input required for diesel transport, refinement, etc.

3.2 Net Greenhouse Gas Balances

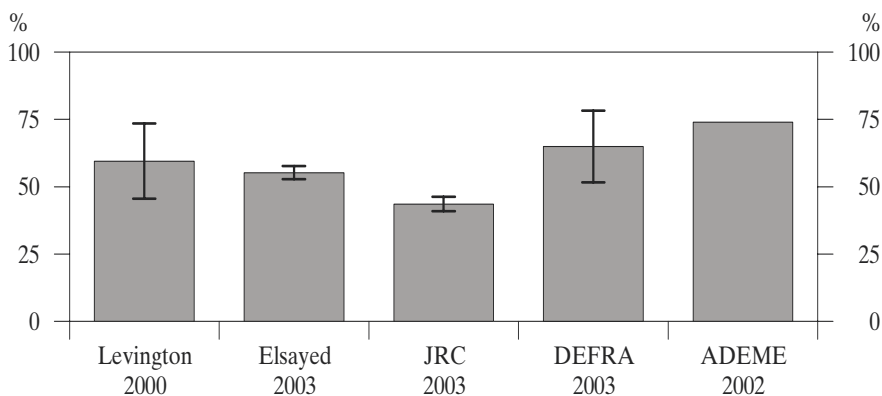
Potentially positive environmental benefits are considered to be the most important argument for the promotion of biodiesel. First of all, the substitution of biodiesel for conventional fuel contributes to the reduction of greenhouse gas emissions, such as carbon dioxide (CO₂), and thus helps to achieve international climate commitments. This positive effect is based on the assumption that the combustion of biofuels is CO₂ neutral, because the amount of CO₂ accruing during their combustion equals the amount that is absorbed during crop growth.

The greenhouse gas (GHG) balances presented in this section take into account the emissions of the six climate gases defined in the Kyoto Protocol. Each kind of gas enters the balance according to its global warming potential. Laughing gas (N₂O, nitrous oxide), for instance, is a highly potent greenhouse gas whose CO₂ equivalent amounts to 310 (IEA 2001: III.3). This figure indicates that the climate impact of N₂O is 310 times higher than that of CO₂. Figure 2 presents several GHG saving estimates for the substitution of biodiesel for fossil diesel.

Of course, GHG balances are closely correlated with the energy balances presented in the previous section. Therefore, the considerable variation among GHG emission estimates again reflects the studies' different assumptions regarding rapeseed yields per hectare, by-products, etc. In particular,

¹ Pimentel and Patzek (2005: 65) find that biodiesel production using soybean, for example, requires 27 % more fossil energy than the produced biodiesel contains. According to Pimentel and Patzek (2005: 73), it is particularly problematic, however, that the oil extraction processes are highly energy intensive for all oil crops.

Figure 2
Greenhouse Gas Savings from Biodiesel



credits for these by-products play a major role in many studies. Yet, even when these credits are taken into account, the substitution of biodiesel for diesel does not mean a 100 % reduction of greenhouse gases that would be emitted if fossil diesel were to be used. In fact, the different GHG saving estimates for biodiesel are between 41 % and 78 % (Figure 2) with an average of about 60 %.

3.3 Overall Environmental Impact

This section provides a concise qualitative comparison between the environmental impacts of the usage of biodiesel and, alternatively, conventional diesel. In addition to greenhouse gas emissions, there are further environmental aspects that are relevant for the overall environmental balance of the substitution of biodiesel for its fossil counterpart, such as the impact of fertilizers and pesticides. Fertilizers and pesticides are indispensable for the cultivation of rape, because rape is a particularly sensitive plant.

The input of fertilizers disturbs the acid equilibrium in soils. This is called acidification and is mainly due to sulphur dioxide (S_2O) and nitrogen oxide (NO_x) emissions (IFEU 2003: 5). Furthermore, fertilizers induce entries into surface water that may cause, e.g., eutrophication in the form of algal bloom. The most serious issue, however, is considered to be the emission of nitrous oxides (N_2O) originating from fertilizers (Reinhardt and Jungk 2001: 4). Nitrous oxides not only contribute to global warming, but also cause ozone depletion. In addition to fertilizers, the cultivation of rapeseed also requires pesticides, which causes toxic pollution of surface water (IFEU 2003: 5).

It might be argued that the alternative production of wheat or other agricultural products on the same acreage needs pesticides and fertilizers as well (EC 2004b), albeit less than the sensitive cultivation of rape (IVA 2004). Yet, if crop cultivation for alternative purposes must take place elsewhere in order to meet demand, this argument is no longer valid. Indeed, it is even less valid if rapeseed cultivation for biodiesel occurs on fallow set-aside land.

Table 4 summarizes all those environmental impacts of the usage of biodiesel that can be quantified – the greenhouse effect via calculating CO₂ equivalents, acidification effects via NO_x equivalents, and ozone depletion due to laughing gas (N₂O) emissions. Whether or not biodiesel induces more photo smog due to ozone production than fossil diesel remains unclear (IFEU 2004) and is therefore left out in Table 4. (If at all, the effect appears to be negligible, with a slight advantage for biodiesel (IFEU 2003).) Finally, although the combustion of biodiesel causes less sulphur dioxide and diesel particle emissions than fossil diesel does, this reduction is not sufficient to be a vital alternative to the diesel particle filter. In this context, it should be noted that diesel particle filters, which are currently the preferred method, are incompatible with the use of pure biodiesel (Köpke 2005: 4).

Table 4
Stylized Facts on the Environmental Impacts (Reinhardt and Jungk 2001)

Environmental Impact	Advantages of Biodiesel	Disadvantages of Biodiesel
Resource Demand	Savings of finite fossil energy	Needs mineral resources due to synthetic fertilizers
Greenhouse Effect	Lower GHG emissions	
Acidification		Higher acidification
Stratospheric Ozone Depletion		More N ₂ O emissions
Eutrophication		Higher NO _x emissions
Human and Eco-toxicity	Lower diesel particle emissions, lower SO ₂ emissions	Pollution of surface waters by pesticides

All in all, there are two major environmental aspects - resource conservation and greenhouse gas savings - that are clearly in favour of biodiesel, but not as positive as one might expect. In fact, policy makers' frequent positive assessment of biodiesel appears to be mainly the result of the strong emphasis on climate protection in today's environmental policy. However, the overall balance of the substitution of biodiesel (RME) for fossil diesel is far

from being unequivocally positive: “[a]n overall final assessment in favour of RME [...] is not inescapable” (Reinhardt and Jungk 2001: 9). This is most of all due to the emissions of laughing gas (N_2O), which causes stratospheric ozone depletion.

4. Economic Impacts of the Promotion of Biodiesel

In this section, we discuss the economic consequences of enhanced biodiesel production, such as potentially increasing food prices. In particular, we gauge the overall tax losses due to the EU countries’ current mineral oil tax exemptions for biodiesel, assuming that the EU target share for biofuels will be achieved by 2010. Tax exemptions and reductions are indispensable, since the production of biodiesel is not an economically viable option: Production costs for biodiesel are 0.61 € per fossil diesel equivalent of one litre of biodiesel, while the costs per litre of conventional diesel are 0.24 € (UFOP 2005a: 1).

Table 5 reports our estimates of the tax losses for the most significant biodiesel producing EU countries. In 2004, this promotion policy caused considerable tax losses in the amount of roughly 737 Mill. €. With 508 Mill. €, Germany was the greatest biodiesel supporter. These figures are expected to rise dramatically until 2010 if the EU target of 5.75 % biofuels is going to be met. Using the tax credits of 2005 and a weighted average for the tax credits of 0.41 € per litre of fossil diesel that is based on the 2004 production shares displayed in Table 1, we reckon that reaching the target compliance amount of 11.7 Mill. tonnes of biodiesel (see Section 2), or equivalently 13.3 Bn litres, may result in tax losses for EU25 countries in the order of more than 5 Bn € in 2010. This outcome is obtained by multiplying the weighted average for the tax credits of 0.41 € per litre of fossil diesel with the fossil diesel equivalent of 13.3 Bn litres of biodiesel, which amounts to 12.2 Bn litres of fossil diesel.

For Germany, in particular, we gauge that the biodiesel production must be subsidized in 2010 by more than 1 Bn €. This magnitude is based on the diesel consumption projection by MWV (2005: 6), which expects a diesel consumption of 37.5 Bn litres. The 5.75 % target implies that 2.2 Bn litres of fossil diesel must be replaced by biodiesel. The volume of 2.2 Bn litres of fossil diesel multiplied by the German tax credit of about 0.47 € per litre diesel yields roughly 1 Bn €. This amount would more than double if the bioethanol target is also achieved in 2010, because the mineral-tax on gasoline is substantially higher.

Table 5
Tax Losses due to Tax Credits for the Biodiesel Promotion in 2004

Country	Tax Credit, €/l	Biodiesel, Mill. l	Replaced Diesel, Mill. l	Tax Losses, Mill. €
Germany	0.47	1 176	1080	507.6
France	0.33	395	363	119.8
Italy	0.29	364	334	96.9
Czech Rep.	0.10	68	62	6.2
Spain	0.29	15	14	4.1
UK	0.28	10	9	2.5

Sources: European Commission, EC (2004), European Biodiesel Board, EBB (2005), Economist (2005).

Furthermore, as a result of a growing demand for rapeseed, European tax payers may face rising prices of goods based on rapeseed (IEA 2004: 94). While it can be expected that these price increases have positive implications for the agricultural sector - and thus are politically desired -, the net effect on society is much less clear (IEA 2004: 177). There may be a negative impact on consumers (IEA 2004: 21), because mounting crop and food prices will most likely trigger consumer surplus losses. A soaring biodiesel production also pushes the amount of co-products, such as rapeseed cake sold as livestock feed, causing their prices to decline (IEA 2004: 95).

Moreover, prices of other agricultural products, such as wheat, flowers, etc. may increase. For the US agricultural sector, for example, Walsh et al. (2002) show that not only can an increased demand for crops, such as rapeseed, lead to an increase in the price of these crops. It can also increase the price of other crops competing for the same agricultural land (IEA 2004: 95), since their supply may be reduced by the increased competition for acreage. Such price effects are likely to occur unless rapeseed is exclusively cultivated on fallow set-aside land and, hence, competition among alternative agricultural purposes for acreage is not increased. Yet, we have demonstrated in Section 2 that this scenario is not realistic if the 2010 EU targets are to be realized.

5. Alternative Options

Given the politicians' focus on climate change mitigation and GHG emission reduction, we demonstrate in this section that the biodiesel option is not a cost-efficient emission abatement strategy. Instead, we present a number of alternative options that allow for a much more efficient accomplishment of emission reduction targets. To trigger such low-cost abatement options is the major task of the European CO₂ Emissions Trading System (ETS). Launched in January 2005, the ETS is conceived to be the primary instrument to alleviate Europe's GHG abatement burden that is stipulated by the Kyoto protocol, because it is widely accepted among economists that this kind of climate policy instrument spurs emission abatement at low cost (Böhringer and Löschel 2002).

Prices of ETS certificates represent an upper limit for emission abatement cost and thus provide a clear signal for cost-effective climate protection. Only those abatement efforts will be spurred by the ETS whose costs are below this signalling price. Therefore, ETS certificate prices provide a perfect benchmark for the economic evaluation of biodiesel as a climate protection strategy. Studies by Böhringer and Löschel (2002) and Klepper and Peterson (2004) predict a medium-term price of 30 €/t. Therefore, we use the price of 30 €/t as a benchmark for evaluating the abatement alternative presented in this section.

Figure 3 indicates that the costs for CO₂ abatement via biodiesel² clearly exceed this benchmark. Even the most optimistic assessment given by the lower cost bound provided by the IEA (2004) is about 100 €/t higher than the medium-term benchmark of 30 €/t. In short, GHG emission abatement via biodiesel is far from being a cost-efficient climate protection strategy. That is, biodiesel will certainly not be fostered by the ETS, but needs additional promotion measures. In other words, the exemptions for biofuels from mineral-oil taxes that are currently in force in many European countries are still indispensable for the promotion of biodiesel, even in the new age marked by the take-off of the ETS.

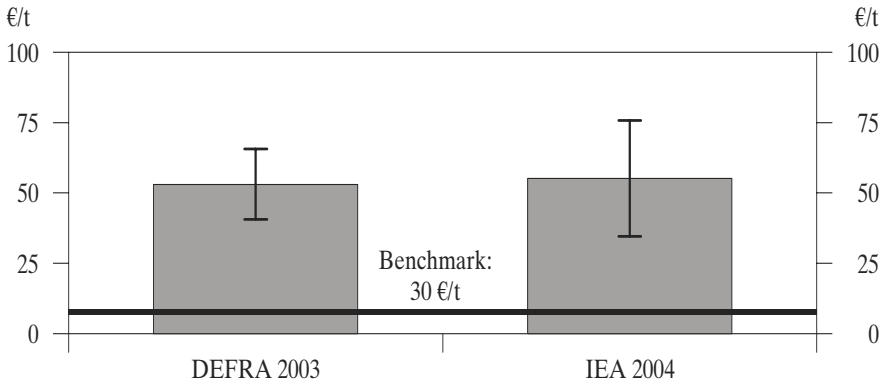
Denmark, however, does not follow the EC (2001b) suggestion regarding such fiscal measures and refuses to exempt biofuels from the mineral-oil tax, since "the promotion of biofuels is not a cost-effective environmental policy measure" (see EC 2004b: 3). Further reasons might be that "[t]heir costs will also increase as growing production volumes eventually lead to saturation of

² The use of rapeseed oil rather than biodiesel (RME) would be cheaper because of lower production cost, but this is not practicable without any technical adjustments of the motor engines. Yet, backfitting costs of engines and infrastructure are prohibitive (IPTS 2003).

by-product markets (e.g., glycerol and animal feed) and consequently less by-product credits” (VIEWLS 2005: 2).

Figure 3

Greenhouse Gas Abatement Costs of Biodiesel in € per t GHG

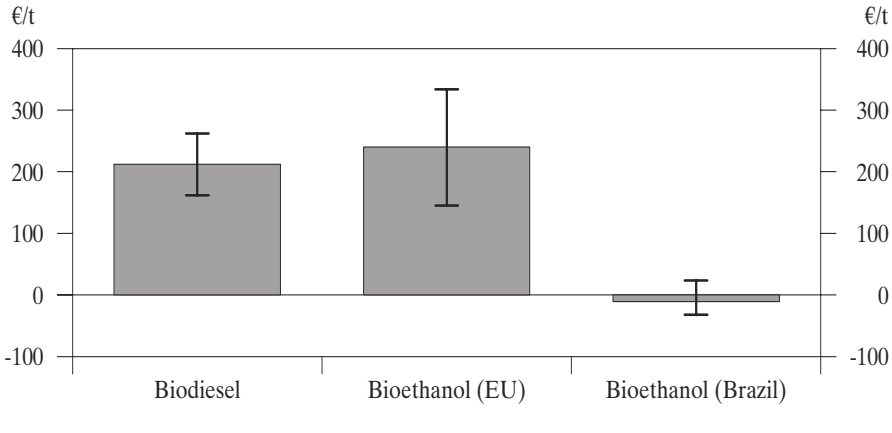


There are a number of more economic GHG abatement alternatives to biodiesel, comprising renewable energy technologies, the efficiency enhancement of conventional power plants, as well as other biofuels. For instance, bioethanol that is produced in Brazil out of sugar cane may even be cheaper than gasoline (IEA 2004: 77). Therefore, the GHG abatement costs of this biofuel alternative may even turn out to be negative, as depicted in Figure 4 (Sources: Biodiesel, Defra 2003; Bioethanol EU, Schmitz 2005; Bioethanol Brazil, IEA 2004: 93).

In Europe, by contrast, bioethanol is mainly made out of sugar beet and wheat. Figure 4 reveals that – in terms of GHG abatement cost – European bioethanol is not a significantly better alternative to biodiesel. Beyond biofuel options, such as Brazilian bioethanol, there are further alternatives based on renewable energy technologies that are superior to biodiesel. According to the data provided by Hartmann and Kaltschmitt (2002), the input of biomass for power generation, be it reed grass, poplar, or other wood as a forestry waste product, would be much a cheaper alternative than the biodiesel option (see Figure 5). The cultivation of reed grass and poplar, however, has not yet been practised in Europe on a large scale, although it could be a more viable alternative than the cultivation of rapeseed as biodiesel input. Nevertheless, these alternatives would not be pushed by the ETS, either, and, hence, also need support that is provided by feed-in tariffs, for example.

Figure 4

Abatement Costs of alternative Biofuels in € per t GHG



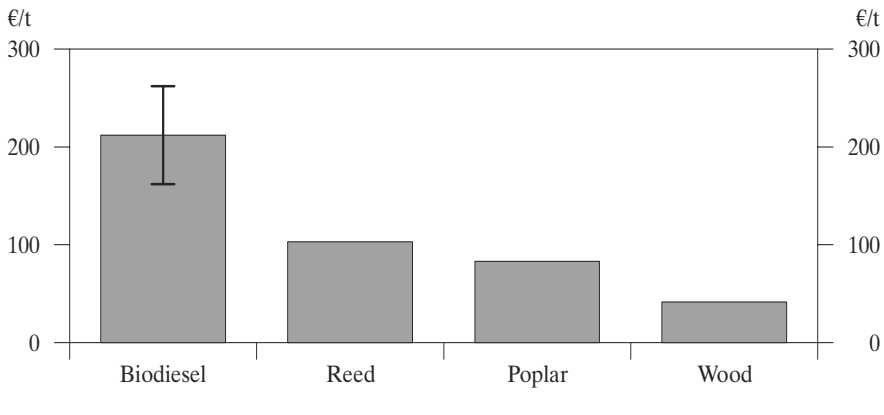
Enhancing the efficiency of conventional power plants is, however, an inexpensive GHG abatement option that is very likely to be triggered by the ETS. The recent announcements of German power producers on the construction of new power plants as well as the modernisation of existing plants appear to be an indication of this widely rumoured expectation.

Figure 6 shows that it is actually tremendously cheaper to reduce GHG emissions by improving the efficiency of a lignite or natural gas power station than by substituting biodiesel for fossil diesel (Markewitz and Vögele 2004: 601). Even the GHG abatement costs of wind energy technologies (dena 2005), which will not be pushed by the ETS but require substantial financial support, are significantly lower than those of the biodiesel abatement option.

Finally, the hope of many people is based on synthetically generated biofuels, e.g., bioethanol from cellulosic biomass and biodiesel from biomass gasification, relying on the Fischer-Tropsch synthesis and commonly referred to as Biomass-to-Liquids (BtL), see IEA (2004: 94). Due to higher rates of yield, there is the hope that biomass-based technologies alleviate the problem of land scarcity (DfT 2003: 60). The reason is that these procedures make use of the entire plant, which, in principle, is advantageous compared to the biodiesel production using only the oil-rich parts of sunflowers or rapeseed. Yet, these methods have not yet been widely applied, and reliable GHG abatement cost estimates are not available.

Figure 5

Abatement Costs of Biodiesel (RME) versus alternative Biomass Options for Power Generation



This section has shown that a number of practicable alternatives to the substitution of biodiesel for fossil diesel are available that are more efficient in terms of GHG abatement costs (see Figure 7). Enhancing the efficiency of conventional power plants is one of the most inexpensive abatement options that will certainly be triggered by the ETS. Brazilian bioethanol would also be a viable option in Europe if it were not burdened by an import tariff of 19.2 cent a litre (Henke, Klepper, Schmitz 2005: 2620).

Figure 6

GHG Abatement Costs of Biodiesel versus Wind Power and Efficiency Enhancement of Conventional Power Plants

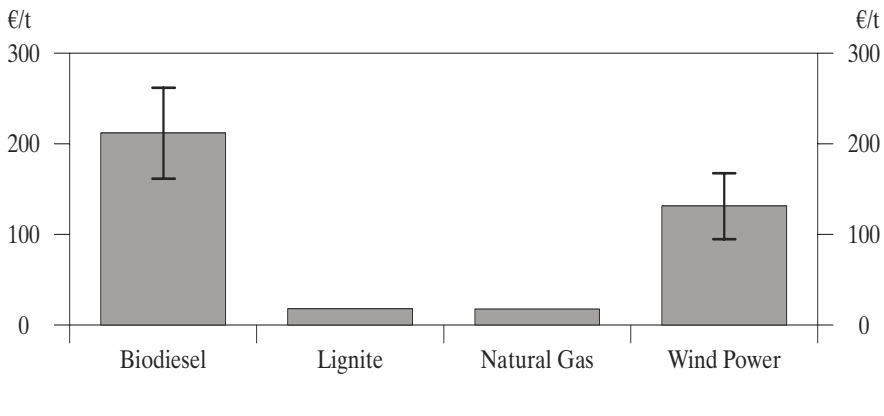
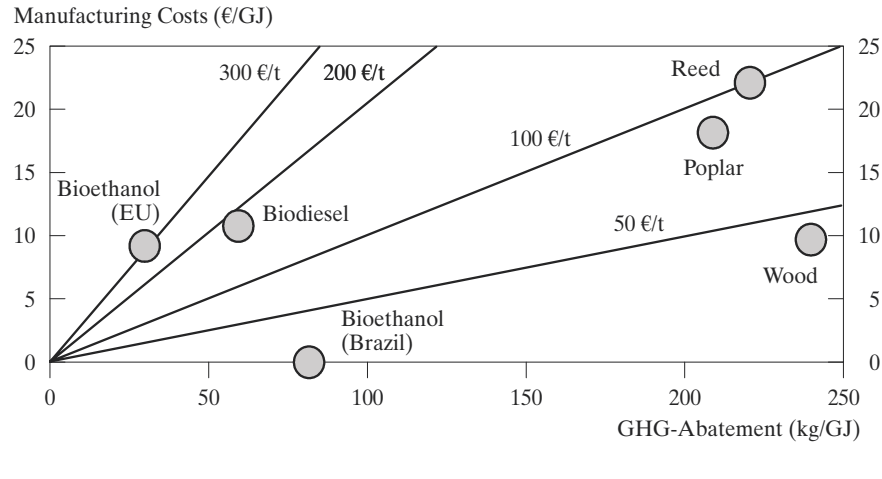


Figure 7
Relationship between Manufacturing Costs and GHG-Abatement



6. Summary and Conclusion

In addition to the substitution of bioethanol for gasoline, replacing fossil diesel with biodiesel is currently considered to be the major avenue for complying with the indicative EU targets that demand biofuel shares of 2 % in 2005 and 5.75 % by 2010. The rationale for these targets are potentially positive environmental impacts, most notably the mitigation of climate change through greenhouse gas (GHG) abatement, conservation of fossil fuels and, hence, aspects of energy supply security, as well as positive employment effects in the agricultural sector (see 2003/30/EC). At present, however, neither bioethanol nor biodiesel are competitive to conventional fuels in Europe. In many Member States, therefore, tax exemptions and reductions are granted for these biofuels in order to reach the indicative, yet not mandatory, EU targets.

In this paper, we have analysed the environmental, economic, and social aspects of rapeseed-based biodiesel as a substitute for fossil diesel. First, a thorough energy balance based on a meta-analysis of a variety of recent empirical studies indicates that biodiesel *does* conserve part of the energy contained in the replaced fossil diesel – but only by about 60 %, not 100 %. Second, our net greenhouse gas (GHG) balances demonstrate that GHG savings from using biodiesel instead of fossil diesel are around 60 %. In fact, policy makers' frequent positive assessment of biodiesel appears to be mainly the result of the strong emphasis on climate protection in today's environmental policy.

The overall environmental balance of the substitution of biodiesel for fossil diesel, however, is far from being unequivocally positive, most notably due to laughing gas emissions contributing to ozone depletion. In line with politicians' most important concern, we have focused on the issue of climate change mitigation, rather than providing an exhaustive cost-benefit analysis, which is an important challenge for future research given the difficulty in quantifying all environmental and economic impacts.

Our major finding is that biodiesel is far from being a cost-efficient emission abatement strategy. In fact, with current GHG abatement cost of about 200 €/t, biodiesel will not be fostered by the recently launched European emission trading system (ETS), the primary and widely accepted instrument for providing cost-efficient climate protection. Therefore, biodiesel needs promotion measures such as tax exemptions, which are in accord with Directive 2003/96/EC. In 2004, total tax losses due to tax exemptions for biodiesel in EU25 were as high as 736 Mill. €, with Germany contributing about 500 Mill. €. We have gauged that the EU25 tax losses may easily increase up to 5 Bn € by 2010.

Furthermore, it has been demonstrated that acreage requirements for biodiesel and bioethanol production clearly exceed the available amount of set-aside land in EU25. The scarcity of arable land will inevitably lead to increased competition for acreage. It appears to be obvious that biofuel production will thus compete with agricultural feedstock cultivation for food purposes. As a consequence, prices of both rapeseed oil and derived food products may rise if rapeseed supply does not accelerate accordingly.

Therefore, we have suggested a variety of more efficient alternatives for the abatement of greenhouse gases based on both renewable and conventional technologies. Electricity generation on the basis of fast-growing plants, such as poplar and reed grass, for example, might be both a relatively cheaper alternative in terms of abatement cost and an alternative income source and employment support measure for the agricultural sector. Limiting this kind of agricultural cultivation precisely to the mandatory share of EU set-aside land of 10 % would help to, first, avoid competition for acreage and, second, contribute to the 22 % share of renewable energy technologies in electricity generation that is demanded by the European Commission by 2020. However, supporting both biomass-based electricity generation via feed-in tariffs and biofuels via tax exemptions at the same time, as it is currently the case in Germany, could lead to unnecessary competition for acreage because of the fact that biomass-based electricity and biofuel generation are competing for the same biomass resources (VIEWLS 2005: 1).

Rather than incurring substantial further increases in tax losses up to 5 Bn € due to the promotion of biofuels in 2010, any government would be well

advised to spend only part of that amount of money in the research and development (R&D) of future technologies, such as the Fischer-Tropsch synthesis, which would open the scope of raw materials. Eventually, successful R&D endeavours and high crude oil prices may render advanced biofuels (BtL) a serious and competitive option for Europe, whose CO₂ emission reduction potential is also much higher than that of conventional biofuels, amounting to 90 % compared to replaced fossil fuels (VIEWLS 2005: 3). In any case, a comprehensive, supra-national policy approach would be desirable for the future, integrating bioenergy, agricultural, forestry, waste, R&D, and industrial policies and incorporating demonstration and deployment trajectories for key options such as advanced biofuel concepts (Faaij 2005: 1).

References

2003/30/EC Directive of the European Parliament and of the Council on the Promotion of the Use of Biofuels or other Renewable Fuels for Transport. European Commission, Brussels.

europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_123/l_12320030517en00420046.pdf

2003/96/EC Council Directive restructuring the Community framework for the taxation of energy products and electricity. European Commission, Brussels.

europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&type_doc=Directive&an_doc=2003&nu_doc=0096&lg=EN

ADEME (2002), Energy and Greenhouse Gas Balances of Biofuels Production Chains in France. Direction of Agriculture and Bioenergies of the French Environment and Energy Management Agency (ADEME) and the French Direction of the Energy and Mineral Resources (DIREM), Paris. www.ademe.fr/partenaires/agrice/publications/documents_anglais/synthesis_energy_and_greenhouse_english.pdf

Böhringer, C. and A. Löschel (2002), Assessing the Costs of Compliance: The Kyoto Protocol. *European Environment* **12**, 1-16.

Defra (2003), Liquid Biofuels – Industry Support, Cost of Carbon Savings and Agricultural Implications. Prepared for the Department for Environment, Food and Rural Affairs (defra).

www.defra.gov.uk/farm/acu/research/reports/biofuels_industry.pdf

dena (2005), Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020. (Strategy for the Integration of On- and Offshore Wind Energy into the

German Electricity Supply System by 2020.) German Energy Agency (dena), Berlin.

DLR (2000), Globale Umweltvorteile bei Nutzung von Elektroantrieben mit Brennstoffzellen und/oder Batterien im Vergleich zu Antrieben mit Verbrennungsmotor. (On the Global Environmental Benefits by Using Electric Drive with Fuel Cells, Battery Storage or Hybrid Systems as Compared to Advanced Conventional Vehicle Systems with IC Engine Drive.) German Aerospace Center (DLR), Stuttgart.

DfT (2003), Liquid Biofuels and Hydrogen from Renewable Resources in the UK to 2050: A Technical Analysis. An Assessment of the Implications of Achieving Ultra-low Carbon Road Transport. Carried out for the UK Department for Transport (DfT) by E4Tech UK Ltd, December 2003.

EBB (2005) European Biodiesel Board – Statistics.

www.ebb-eu.org/stats.php

Economist (2005), Stirrings in the Corn Fields – Special Report Biofuels. *The Economist*, May 14th 2005, 67 – 69.

EC (2001a), Green Paper – Towards a European Strategy for the Security of Energy Supply. European Commission, Brussels.

europa.eu.int/comm/energy_transport/doc-principal/pubfinal_en.pdf

EC (2001b), Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions on Alternative Fuels for Road Transportation and on a Set of Measures to Promote the Use of Biofuels. COM/2001/547. European Commission, Brussels.

EC (2004a), Member States Reports in the frame of Directive 2003/30EC. European Commission, Brussels.

europa.eu.int/comm/energy/res/legislation/biofuels_members_states_en.htm

EC (2004b), Statement on the implementation of the EU Biofuels Directive. Denmark report for the European Commission on the implementation of European Parliament and Council Directive 2003/30/EC. European Commission, Brussels. europa.eu.int/comm/energy/res/legislation/doc/biofuels/member_states/2003_30da_report_en.pdf

Elsayed, M.A., R. Matthews, N.D. Mortimer (2003), Carbon and Energy Balances for a Range of Biofuels Options. Resources Research Unit, Sheffield Hallam University.

www.dti.gov.uk/renewables/publications/pdfs/bb600784.pdf

ENVOG (2005), Energy-Based Efficiency and Renewability Assessment of Biofuel Production. *Environmental Science & Technology* **39** (10), 3878-3882.

Faaij, A.P.C. (2005), Bio-energy in Europe: Changing Technology Choices. *Energy Policy*, forthcoming.

GM (2002), GM Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study, General Motors, Ottobrunn. www.lbst.de/gm-wtw

Hartmann, H. and M. Kaltschmitt (2002), *Biomasse als Erneuerbarer Energieträger (Biomass as a Renewable Energy Carrier)*. Landwirtschaftsverlag, Münster.

Henke, J.M., G. Klepper, and N. Schmitz (2005), Tax Exemption for Biofuels in Germany: Is bio-ethanol Really an Option for Climate Policy. *Energy* **30**, 2617-2635.

IEA (1999), *Automotive Fuels for the Future – The Search for Alternatives*. International Energy Agency, Paris.

IEA (2001), CO₂-Emissions from Fuel Combustion, 1971 - 1999. International Energy Agency, OECD, Paris.

IEA (2004), *Biofuels for Transport*. International Energy Agency, Paris.

IFEU (2003) Erweiterung der Ökobilanz für RME. (Expansion of the Life Cycle Analysis on RME). Institute for Energy and Environmental Research Heidelberg (IFEU), Heidelberg. www.ifeu.de/englisch/agri/download/rme-2003.pdf

IFEU (2004) CO₂ Mitigation through Biofuels in the Transport Sector – Status and Perspectives. Institute for Energy and Environmental Research (IFEU), Heidelberg. www.biodiesel.org/resources/reportsdatabase/reports/gen/20040801_gen-351.pdf

IPTS (2003), Unmodified Vegetable Oil as an Automotive Fuel. IPTS Report, Volume 74, May 2003. Institute for Prospective Technological Studies, Sevilla. www.jrc.es/home/report/english/articles/vol74/TRA1E746.htm

IVA (2004), Wichtige Zahlen – Düngemittel – Produktion, Markt, Landwirtschaft, 2003 - 2004. (Important Numbers – Fertilizers – Production, Market, Agricultural Sector, 2003 - 2004). Industrieverband Agrar (Agro-Industrial Association), Frankfurt. www.iva.de/pdf/wiza0304.pdf

JRC (2003), Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context. Well-to-Tank Report, Version 1. EUCAR, CONCAWE, Joint Research Centre.
ies.jrc.cec.eu.int/Download/eh

JRC (2004), Biofuel Potentials in the EU. Institute for Prospective Technological Studies, Joint Research Center.
[www.europarl.eu.int/stoa/ta/renewable_energies/biomass/biofuel2\(ipts\).pdf](http://www.europarl.eu.int/stoa/ta/renewable_energies/biomass/biofuel2(ipts).pdf)

Klepper, G., and S. Peterson (2004), The EU Emission Trading Scheme: Allowance Prices, Trade Flows, Competitiveness Effects. Kiel Working Paper No. 1195. www.uni-kiel.de/ifw/pub/kap/2004/kap1195.htm

Köpke, R. (2005), Mehr Flower-Power im Tank (More Flower Power in the Tank). *Energie & Management*, Vol. 11, 2005, Page 4, Herrsching.

Levington (2000), Energy Balances in the Growth of Oilseed Rape for Biodiesel and of Wheat for Bioethanol. Levington Agriculture Report for the British Association for Bio Fuels and Oils.
www.senternovem.nl/mmfiles/27781_tcm24-124189.pdf

Markewitz, P. and S. Vögele (2004), Technikspezifische CO₂ – Vermeidungskosten. Eine geeignete Bewertungsgröße für Treibhausgasminderungs-Maßnahmen (Technology-Specific CO₂-Abatement Costs – An Appropriate Evaluation Parameter for Greenhouse Gas Mitigation Strategies). *Energiewirtschaftliche Tagesfragen* **54 (9)**, 601 – 605.

MWV (2005), MWV Prognose 2020 für die Bundesrepublik Deutschland. (MWV forecast 2020 for the Federal Republic of Germany.) Association of the Petroleum Industry, Hamburg.
www.mwv.de/Download%5CPrognose.pdf

Pimentel, D., and T.W. Patzek (2005), Ethanol Production Using Corn, Switchgrass and Wood; Biodiesel Production Using Soybean and Sunflower. *Natural Resources Research*, **14** (1), 65-75.

Reinhardt, G., and N. Jungk (2001), Pros and Cons of RME compared to conventional Diesel Fuel. Institute for Energy and Environmental Research (IFEU), Heidelberg. biodiesel.pl/uploads/media/Pros_and_cons_of_RME_compared_to_conventionaldiesel_fuel.pdf

Schmitz, N. (2005) Innovationen bei der Bioethanolerzeugung, (Innovations in the Generation of Bioethanol) Schriftenreihe Series „Nachwachsende Rohstoffe“ (Renewable Resources), Volume 26, Landwirtschaftsverlag, Münster.

UFOP (2005a), Marktinformation Ölsaaten und Biokraftstoffe – April. (Market Information Oil Seeds and Biofuels – April.) Union for the Promotion of Oil and Protein Plants, Berlin. www.ufop.de/download/MI_04_05.pdf

UFOP (2005b), Marktinformation Ölsaaten und Biokraftstoffe. (Market Information Oil Seeds and Biofuels – April.). Union for the Promotion of Oil and Protein Plants, Berlin. www.ufop.de/download/MI_05_05.pdf

VIEWLS (2005), Biofuel and Bio-energy implementation scenarios. Final report of VIEWLS WP5, modelling studies. Published within the framework of the European Commission-supported project “Clear Views on Clean Fuels” (NNE-2001-00619).
www.nobio.no/fileupl/VIEWLS%20WP5%20final%20report%2020053107.doc

Walsh, M.E. et al. (2002), The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture. Report prepared for the U.S. Department of Energy and the U.S. Department of Agriculture.
bioenergy.ornl.gov/papers/misc/eco_impacts.html