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Biodiesel: A New Oildorado?

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Manuel Frondel and Jörg Peters

Biodiesel: A New Oildorado?

No. 36



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Manuel Frondel and Jörg Peters*

Biodiesel: A New Oildorado?

Abstract

Guaranteeing tax reductions and exemptions, the European governments intend to increase the share of biofuels in total EU fuel consumption to 5.75% by 2010. The financial support of this EU objective is frequently justified by expected positive environmental impacts, most notably the mitigation of climate change, and by favorable employment effects in the agricultural sector. This paper investigates the environmental and economic implications of the support of rapeseed-based biodiesel as a substitute for fossil diesel. Based on a survey of recent empirical studies, we find that the energy and greenhouse gas balances of this environmental strategy are clearly positive. Yet, its overall environmental balance is currently far from being unequivocally positive. Most importantly, biodiesel is not a cost-efficient emission abatement strategy. Thus, for the abatement of greenhouse gases, we recommend more efficient alternatives based on both renewable and conventional technologies.

JEL classification: Q28, Q42, Q58

Keywords: Renewable Energy, Environmental Policy, Greenhouse Gas Emissions

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1. Introduction

Tax exemptions of biofuels triggered a dramatic increase in the demand for biodiesel in Germany. Within two years, the production of biodiesel doubled and exceeded the threshold of one million tons in 2004 (EBB 2005). In several other European countries, most notably France and Italy, the production of biodiesel has also been boosted 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). A key objective of this set of policies is promoting renewable energy technologies. The corresponding national fiscal measures intend to support the achievement of the *indicative* targets for biofuels set by Directive 2003/30/EC. This directive demands that the shares of biofuels – measured on an energy content basis – should reach 2% by 2005 and, by 2010, 5.75% of the overall amount of gasoline and fossil diesel used in the EU25 transport sector.

The Directive 2003/30/EC justifies these targets on the basis of potentially positive environmental impacts, most notably the mitigation of climate change through greenhouse gas (GHG) abatement, of an increase of energy supply security, conservation of fossil fuels (Faaij 2006), as well as through expected positive employment effects in the agricultural sector. Given several biofuel alternatives, bioethanol produced out of sugar beet and wheat and biodiesel based on rapeseed are currently 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 et al. 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 consequence of the increased use of land for biofuel production might be 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. Therefore, the expected positive environmental benefits from the use of biofuels could be accompanied by substantial economic 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 et al. 2005: 2621). 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 GHG, we argue 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 GHG balances of the substitution of biodiesel for conventional diesel. We then discuss the overall environmental impact 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 GHG emissions. These estimates cast doubt on the cost efficiency of this climate protection strategy. The paper closes by suggesting more efficient biofuel alternatives and recommending several much more efficient GHG abatement options, based on both renewable and conventional technologies.

2. Economic Impacts of the Promotion of Biodiesel

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

In our forecast of the acreage demand for the amount of 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. Our calculations are documented in Table 2.

Diesel consumption is estimated by JRC (2004) to amount to 159.9 and 177.8 Mill. t in 2005 and 2010, respectively. Given that the EU targets are formulated in terms of the energy content of the fuels, we must take account of

Table 1

Recent Biodiesel Production in the EU25

2002 to 2004; 1000 t

Country	2002	2003	2004
Germany	450	715	1 035
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	1 065	1 434	1 933

Source: EBB 2005

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/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. The 2% target requires a biodiesel production of about 136.2 Mill. GJ in 2005, or equivalently, around 3.7 Mill. t. The 5.75% target implies a production of 11.7 Mill. t 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. ha of acreage. Note that the assumed figure for the biodiesel yield per acreage represents the EU15 average, which is certainly not standard in the new accession countries. This suggests that our acreage estimate for the necessary biodiesel production represents a lower bound. Likewise, our conservative acreage estimate for biodiesel target compliance in 2010 amounts to about 9 Mill. ha. This figure is

Table 2

Acreage Requirements for Biodiesel Target Compliance in the EU25

2005 and 2010

	2005	2010
JRC (2004) Forecasts		
Diesel Consumption Forecasts, Mill. t	159.9	177.8
Diesel Energy Equivalents, Mill. GJ	6,812	7,574
Requirements:		
EU Targets, %	2.00	5.75
Biodiesel Target Equivalents, Mill. GJ	136.2	435.5
Biodiesel Target Production, Mill. t	3.7	11.7
Acreage Requirement, Mill. ha	3.0	9.0
JRC 2004 and own calculations.		

Table 3

Acreage Requirements for Bioethanol Target Compliance in the EU25
2005 and 2010

	2005	2010
JRC (2004) Forecasts:		
Consumption of gasoline, Mill. t	133.0	139.1
Gasoline Energy Equivalents, Mill. GJ	5,573	5,828
Requirements:		
EU Targets, %	2.00	5.75
Bioethanol Target Equivalents, Mill. GJ	111.5	335.1
Bioethanol Target Production, Mill. t	4.2	12.6
Acreage Requirements, Mill. ha	0.8	2.2
JRC 2004 and own calculations.		

based on an increased biodiesel yield, for which JRC (2004: 24) forecasts 48.3 GJ/ha by 2010.

Similarly, Table 3 displays the corresponding acreage requirements for bioethanol, which is currently the only serious alternative to gasoline. The acreage figures are calculated on the basis of the energy contents of bioethanol, 26.6 GJ/t, and gasoline, 41.9 GJ/t, respectively, and the JRC assumptions on the bioethanol yields generated from wheat and sugar beet, 46.0 and 139.9 GJ/ha, respectively. These yields are expected to increase up to 47.5 and 150.5 GJ/ha in 2010. For simplicity, we further assume that bioethanol production is solely based on sugar beet and thus obtain the lower bounds of acreage requirements for bioethanol target compliance production.

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 11.2 Mill. ha are required for target compliance production in 2010. Given that the total arable land in the EU25 is gauged by the JRC (2004: 24) to amount to 82.4 Mill. ha, 11.2 Mill. ha represent 13.6% of the total arable land in the EU25. This estimate appears to be rather low: A recent IEA (2004: 132) study assumes a scenario in which both biodiesel and bioethanol displace 10% of their fossil counterparts in 2020 and estimates a land requirement of 38% of total acreage in the EU15.

It is often argued that the land currently set aside would be sufficient for the production of energy crops, such as rapeseed for biodiesel. Actually, the European Commission requests a compulsory set-aside land share of 10%, which must either remain fallow or be used for non-food production (JRC 2003: 45). Yet, given our prudent estimate of 13.6% of arable land required for the biofuel target compliance production in 2010, it is evident that the entire biofuel production simply cannot exclusively take place on set-aside land.

In Germany, for instance, some 317,000 ha of set-aside land are used for rapeseed cultivation in 2005. Yet, the production of biodiesel requires 680,000 ha (UFOP 2005b: 4). Consequently, roughly half of the rapeseed employed for biodiesel production in Germany is “crowding out” 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. Even more disconcertingly, the quality of set-aside land is not always appropriate for the cultivation of biofuel crops such as rapeseed.

Furthermore, the problem of land scarcity is intensified by the crop rotation periods of 3 to 7 years for rapeseed (IPTS 2003). Hence, even if 100% of total acreage were available for rapeseed production, a very optimistic average crop rotation period of four years 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. Using the JRC (2004: 23) forecast for fossil diesel consumption with an energy equivalent of 7 574 Mill. GJ in 2010 (Table 2), the energy equivalent of 995 Mill. GJ would mean an upper limit of about 13% for the biodiesel share. With ultimate shares clearly below 15%, biodiesel alone will certainly not be a successful strategy to combat resource scarcities and potential price peaks of fossil diesel, that is, price shocks in mineral-oil markets.

We now gauge the overall tax losses due to the EU countries’ current mineral oil tax exemptions for biodiesel, assuming that the EU target share of 5.75% for biofuels will be achieved by 2010. Tax exemptions and reductions are indispensable for achieving this objective, since the production of biodiesel is not an economically viable option. With 0.61 € per fossil diesel equivalent of one liter of biodiesel, production costs for biodiesel are substantially higher than those of conventional diesel (UFOP 2005a: 1).

Table 4 reports our estimates of the tax losses for the most significant biodiesel producing EU countries. In 2004, this promotion policy caused tax losses in the amount of roughly 737 Mill. € – an amount that is far from being negligible. With 508 Mill. €, Germany was the most ambitious biodiesel supporter. These figures are expected to rise dramatically until 2010 if the EU target of 5.75% biofuels is going to be met indeed. Using a weighted average of 0.41 €/l, which is based on the 2004 biodiesel production shares displayed in Table 1, we reckon that reaching the target compliance amount of 11.7 Mill. t, or equivalently 13.3 Bn l¹, of biodiesel may result in tax losses for EU25 countries that may add up to more than 5 Bn € in 2010. This outcome is obtained by multiply-

¹ The density of biodiesel amounts to 0,88 kg/l.

Table 4

Tax Losses due to Tax Reductions for the Biodiesel Promotion
2004

	Tax Reductions, €/l	Biodiesel, Mill. l	Replaced Diesel, Mill. l	Tax Losses, Mill. €
Germany	0.47	1 176	1 080	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
Total	–	2 028	1 862	737.1

Sources: EC 2004, EBB 2005, Economist 2005.

ing the weighted average for the tax reductions of 0.41 €/l with the fossil diesel equivalent of 13.3 Bn l of biodiesel, which amounts to 12.2 Bn l 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 of 37.5 Bn l (MWV 2005: 6). The 5.75% target implies that 2.2 Bn l of fossil diesel must be replaced by biodiesel. The volume of 2.2 Bn l of fossil diesel multiplied by the German tax on diesel of about 0.47 €/l 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.

Furthermore, as a result of 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 is apparently politically desired by some EU governments –, 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 to a smaller consumer surplus. A soaring biodiesel production also increases the supply 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, it is shown 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 this section that this scenario is not realistic if the 2010 EU targets are to be realized.

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, that is, the conservation of fossil fuels (Henke et al. 2005: 2 618). By employing biodiesel rather than conventional diesel, one might hope to save scarce and valuable fossil fuels. This assessment 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 Net Energy Balance

It would be naïve, however, to expect that the entire fossil energy contained in conventional diesel could be saved by replacing it liter by liter with biodiesel. In fact, the net energy balances presented in this section indicate that the usage of biodiesel rather than conventional diesel saves less than 100% of the fossil energy contained in conventional diesel. There are three 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/l, the heating value of conventional diesel is as high as 35.7 MJ/l (IEA 1999: 20).

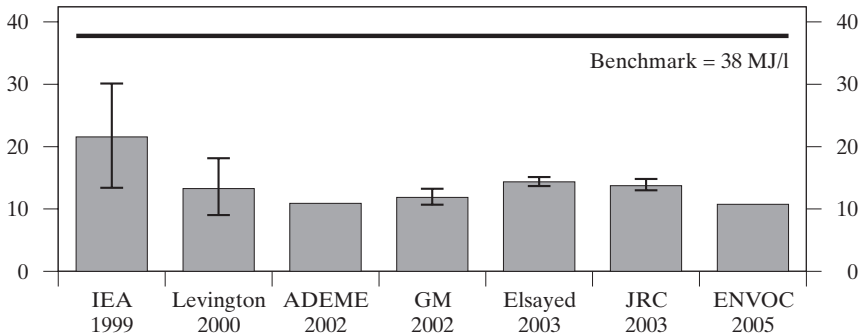
As a consequence, only about 0.92 l of conventional diesel is needed for the same performance provided by one liter of biodiesel. In other words, as a rule of thumb, cars need roughly 10% more biodiesel than fossil diesel to run the same distance. For what follows, we define the fossil diesel equivalent of one liter of biodiesel to amount to 0.92 l of fossil diesel, with the energy content of 32.8 MJ. Second, the production of rapeseed requires agricultural machinery that is typically run by fossil fuels, as well as fertilizers and pesticides, whose manufacturing energy needs to be included in any serious net energy balance. Third, the refinement of diesel originating from crude oil requires less energy than the conversion of rapeseed into biodiesel. Actually, this process, including the extraction of the rape oil from the seeds as well as the esterification of the oil to Rapeseed Methyl Ester (RME) is quite energy intensive (IEA 1999; Levington 2000; ENVOC 2005).

Figure 1 summarizes the results of our survey, which is based on a set of empirical 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 input required for the production of one liter of biodiesel is due to varying assumptions concerning rapeseed yields per hectare (ha), for example. In addi-

Figure 1

Fossil Energy Input for the Production of 1 Liter of Biodiesel

MJ/l Biodiesel



Sources see References.

tion, the concrete value of these estimates heavily depends on whether or not by-products such as rapeseed cake and glycerin are included in a study's energy balance – and if yes, to what degree. Rapeseed cake originating from the oil extraction process can be used as animal feed, for instance. In addition, an energy bonus is frequently granted in these studies for glycerin, an esterification by-product that is a perfect substitute for petro-chemically produced glycerin. Point estimates are indicated in Figure 1 by solid bars, while the range between the respective minimum and maximum assessments of the amounts of fossil energy required for the production of biodiesel is represented by thin lines. All these estimates are either directly provided by these empirical studies or are our own calculations based on their data material.

The benchmark of 38 MJ/l includes the energy content of the fossil diesel equivalent of one liter of biodiesel, 32.8 MJ/l, and the fossil energy input required for transport, refinement, etc. of the amount of fossil diesel that is replaced by biodiesel. According to JRC (2003), the fossil energy needed for these tasks amounts to roughly 16% of the energy content of fossil diesel. Thus, the benchmark of 38 MJ/l is the result of the multiplication of 1.16 with the energy content of 32.8 MJ/l per liter of fossil diesel equivalent of one liter of biodiesel. Recall that by referring to the fossil diesel equivalent of one liter of biodiesel, we take into account that the heating value of fossil diesel is higher than that of biodiesel.

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 two-thirds, more or less, of the fossil fuel in

form of diesel can be saved by substituting biodiesel for conventional diesel². This result can be recognized in Figure 1 by taking the difference of the displayed benchmark for conventional diesel and the estimates of the fossil energy input required for the production of one liter of biodiesel. While the IEA (1999) estimates suggest that only about half the fossil energy can be saved (if not less), more recent studies indicate that actual savings are in the realm of two-thirds.

3.2 Net Greenhouse Gas Balances

Potentially positive environmental benefits are arguably the most important argument for the promotion of biodiesel. First of all, the substitution of biodiesel for conventional fuel contributes to the reduction of GHG 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 bound during crop growth. More comprehensively, the 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 emission estimates for the production of one liter of biodiesel implied by a variety of empirical studies. Of course, GHG balances are intimately 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. Credits for these by-products, specifically, play a major role in many studies. Take, for instance, the GHG balance presented by Reinhardt/Jungk (2001: 3). Without these credits, their GHG balance would not be substantially positive for biodiesel.

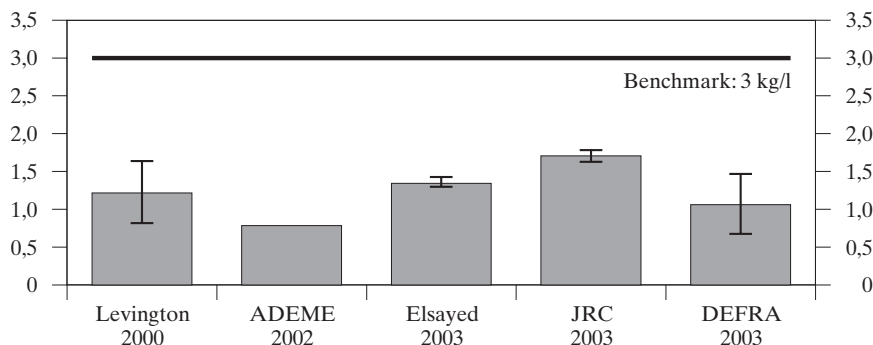
Even granting these credits, though, the substitution of biodiesel for diesel cannot avoid 100% of the GHG that would otherwise be emitted if fossil diesel were to be used. Actually, the different GHG emission estimates for one liter of biodiesel are between 22% and 59% of the emission benchmark for fossil diesel (Figure 2). Hence, the GHG saving estimates lie between 41% and 78%. The benchmark of around 3 kg per fossil diesel equivalent of one liter of

² Pimentel/Patzek (2005: 65) even find that biodiesel production using soybean, for example, requires 27% more fossil energy than the produced biodiesel contains. According to Pimentel/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 Emissions of Biodiesel and Fossil Diesel

kg GHG/l Biodiesel



Sources see References.

biodiesel results from multiplying the heating value of biodiesel, 32.8 MJ/l, with the specific emissions caused by fossil diesel, which amounts to 0.091 kg CO₂ equivalents per MJ and includes emissions originating from transport, refinement, etc. of fossil diesel (DLR 2000: 41).

3.3 Overall Environmental Impact

This section provides a concise qualitative comparison of the environmental impacts that the usage of biodiesel instead of conventional diesel may have. 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, comprising the impact of fertilizers and pesticides, for instance. 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 (S₂O) and nitrogen oxide (NO_x) emissions (IFEU 2003: 5). Furthermore, fertilizers induce entries into surface water that may cause eutrophication in the form of algal bloom, for instance. The most serious issue, however, seems to be the emission of nitrous oxides (N₂O) originating from fertilizers (Reinhardt, 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).

One might argue that the alternative production of wheat or other agricultural products on the same acreage needs pesticides and fertilizers as well (EC

Table 5

Stylized Facts on the Environmental Impacts

Environmental Impact	Advantages of Biodiesel	Disadvantages of Biodiesel
Resource Demand	Savings of finite fossil energy	Needs mineral resources
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

Source: Reinhardt, Jungk 2001.

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 does not hold. Furthermore, if rapeseed cultivation for biodiesel occurs on fallow set-aside land, this argument is even less valid.

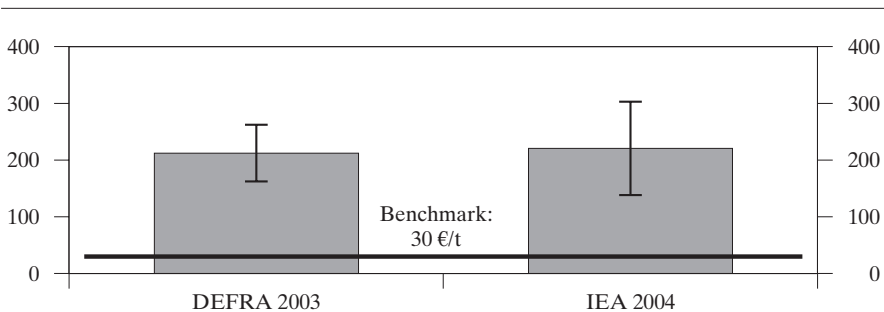
Table 5 summarizes all those environmental impacts of the usage of biodiesel that can be quantified – the greenhouse effect via calculating CO₂ equivalents, acidification effects via NO_x equivalents, and ozone depletion due to laughing gas (N₂O) emissions. Whether or not biodiesel induces more photo smog due to ozone production than fossil diesel remains unclear (IFEU 2004) and is therefore left out in Table 5. 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, the usage of biodiesel is not a vital alternative to the diesel particle filter. The reason is that the use of biodiesel does not drastically reduce the particle emissions, as is required. It is interesting in this context that diesel particle filters, which are currently the preferred method, are incompatible with the use of pure biodiesel (Köpke 2005: 4).

All in all, there are two major environmental aspects – resource conservation and GHG savings – that are clearly in favour of biodiesel, but not as strongly as one might expect. In fact, policy makers' frequently 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, Jungk 2001: 9). Above all, this is due to the emissions of laughing gas (N₂O), which causes stratospheric ozone depletion.

Figure 3

Greenhouse Gas Abatement Costs of Biodiesel

€/t



Sources see References.

4. 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, 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/Löschel (2002) and Klepper/Peterson (2004) predict a medium-term price of 30 €/t. We use this price as a benchmark for evaluating the abatement alternative presented in this section.

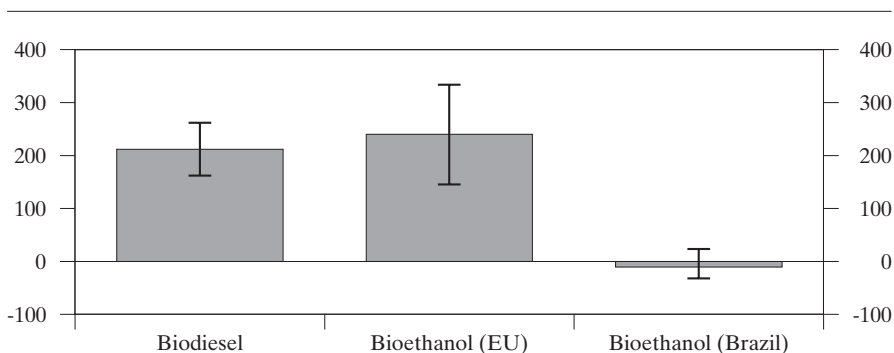
Figure 3 indicates that the costs for CO₂ abatement via biodiesel³ clearly exceed this benchmark. Even the most optimistic assessment given by the lower cost bound provided by the IEA (2004) is about 100 €/t higher than the medium-term benchmark of 30 €/t. In short, GHG emission abatement via

³ 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).

Figure 4

Abatement Costs of alternative Biofuels

€/t



Source: Biodiesel, DEFRA 2003; Bioethanol EU, Schmitz 2005; Bioethanol Brazil, IEA 2004: 93 and own calculations.

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, is an exception in that this EU country does not follow the EC (2001) 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” (EC 2004b: 3).

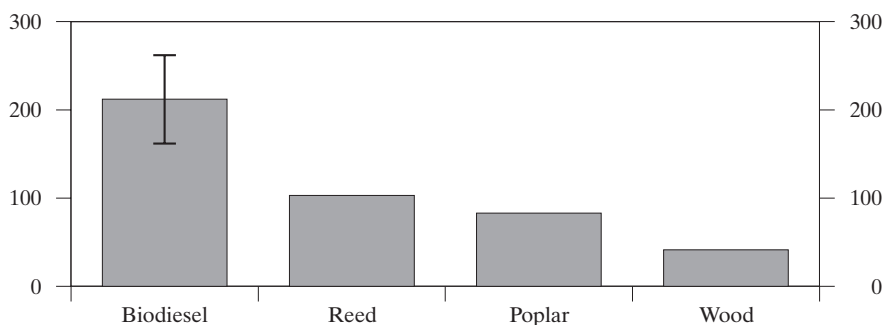
There are a number of more economic GHG abatement alternatives to biodiesel, comprising renewable energy technologies, the efficiency enhancement of conventional power plants, as well as other biofuels. For instance, bioethanol that is produced in Brazil out of sugar cane may even be cheaper than gasoline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

Yet, these outcomes heavily depend on world sugar demand: In times of high sugar demand, production costs for Brazilian bioethanol rise up and prices may exceed those of taxed gasoline, whereas Brazilian bioethanol prices can be lower than gasoline prices without tax in times when sugar prices slump. Thus, bioethanol prices may fluctuate dramatically, which might be the reason for certain tax incentives, including lower taxes on alcohol fuel than on gasoline, lower taxes on the purchase of dedicated ethanol vehicles, etc. (IEA 2004: 76). The 1980s direct subsidization of bioethanol, however, now no longer exists in Brazil.

Figure 5

Abatement Costs of Biodiesel versus Alternative Biomass Options for Power Generation

€/t



Source: Biodiesel, DEFRA 2003; Reed, poplar, wood, Hartmann, Kaltschmitt 2002.

In Europe, by contrast, bioethanol is mainly made out of sugar beet and wheat and needs subsidies. 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/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 (Figure 5). Reed grass and poplar, however, have not yet been cultivated 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 triggered by the ETS, either, and, hence, also need support that is provided by feed-in tariffs, for example.

Enhancing the efficiency of conventional power plants, though, is 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 modernization of existing plants appear to be an indication of this widely rumored expectation.

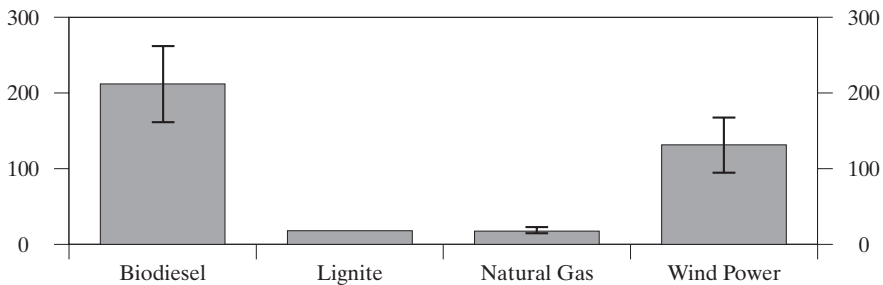
Figure 6 shows that it is actually tremendously cheaper to reduce GHG emissions by improving the efficiency of a lignite or natural gas power station than by substituting biodiesel for fossil diesel (Markewitz, Vögele 2004: 601). Even the GHG abatement costs of wind energy technologies (dena 2005), which will not be supported 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 ligno-cellulosic biomass and biodiesel from biomass gasi-

Figure 6

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

€/t



Source: Dena 2005; Makewitz, Vögele 2004; DEFRA 2003.

fication, relying on the Fischer-Tropsch synthesis and commonly referred to as Biomass-to-Liquids (BtL; IEA 2004: 94). Due to higher rates of yield, biomass-based technologies may 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.

Nevertheless, this section has provided a number of practicable alternatives to the substitution of biodiesel for fossil diesel that are more efficient in terms of GHG abatement costs. 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 ct/l (Henke et al. 2005: 2620).

5. Summary and Conclusion

In addition to the substitution of bioethanol for gasoline, replacing fossil diesel with biodiesel is currently 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 GHG abatement, conservation of fossil fuels and, hence, aspects of energy supply security, as well as positive employment effects in the agricultural sector. 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 and economic aspects of rapeseed-based biodiesel as a substitute for fossil diesel. First, a thorough energy balance based on 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 two-thirds, not 100%. Second, our net 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, the primary and widely accepted instrument for providing cost-efficient climate protection. Therefore, biodiesel needs promotion measures such as tax exemptions, which are perfectly in accord with Directive 2003/96/EC. In 2004, total tax losses due to tax exemptions for biodiesel in the 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 the 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 rape 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 GHG 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 endeavors 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).

References

- ADEME – 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) (eds.) (2002), *Energy and Greenhouse Gas Balances of Biofuels Production Chains in France*. Paris. Internet: 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 – Department for Environment, Food and Rural Affairs (ed.) (2003), *Liquid Biofuels – Industry Support, Cost of Carbon Savings and Agricultural Implications*. Prepared for the Department for Environment, Food and Rural Affairs (defra). Internet: www.defra.gov.uk/farm/acu/research/reports/biofuels_industry.pdf.
- dena – Deutsche Energie Agentur (Hrsg.) (2005), *Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020*. Berlin.
- DLR – German Aerospace Center (ed.) (2000), *Globale Umweltvorteile bei Nutzung von Elektroantrieben mit Brennstoffzellen und/oder Batterien im Vergleich zu Antrieben mit Verbrennungsmotor*. Stuttgart.
- DfT – UK Department for Transport (ed.) (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 by E4Tech UK Ltd, December 2003. London.
- EBB – European Biodiesel Board (ed.) (2005), *Statistics*. Internet: www.ebb-eu.org/stats.php.
- Economist (2005), Stirrings in the Corn Fields – Special Report Biofuels. *Economist* May 14th 2005, 67–69.
- EC – European Commission (ed.) (2001), 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. Brussels.
- EC – European Commission (ed.) (2004a), *Member States Reports in the frame of Directive 2003/30EC*. Brussels. Internet: http://europa.eu.int/comm/energy/res/legislation/biofuels_members_states_en.htm.
- EC – European Commission (ed.) (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. Brussels. Internet: http://europa.eu.int/comm/energy/res/legislation/doc/biofuels/member_states/2003_30_da_report_en.pdf.
- Elsayed, M.A., R. Matthews, and N.D. Mortimer (2003), *Carbon and Energy Balances for a Range of Biofuels Options*. Internet: www.dti.gov.uk/renewables/publications/pdfs/bb600784.pdf.
- ENVOC (2005), Energy-Based Efficiency and Renewability Assessment of Biofuel Production. *Environmental Science & Technology* 39 (10): 3878–3882.
- Faaij, A.P.C. (2006) Bio-energy in Europe: Changing Technology Choices. *Energy Policy*, forthcoming.
- Hartmann, H. and M. Kaltschmitt (2002), *Biomasse als Erneuerbarer Energieträger*. Münster: Landwirtschaftsverlag.
- 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 – International Energy Agency (ed.) (1999), *Automotive Fuels for the Future – The Search for Alternatives*. Paris.
- IEA – International Energy Agency (ed.) (2001), *CO₂-Emissions from Fuel Combustion, 1971–1999*. Paris.
- IEA – International Energy Agency (ed.) (2004), *Biofuels for Transport*. Paris.
- IFEU – Institut für Energie und Umweltforschung (ed.) (2003), *Erweiterung der Ökobilanz für RME*. Heidelberg. Internet: www.ifeu.org/landwirtschaft/pdf/rme-2003.pdf.
- IFEU – Institut für Energie und Umweltforschung (ed.) (2004), *CO₂ Mitigation through Biofuels in the Transport Sector – Status and Perspectives*. Heidelberg. Internet: www.biodiesel.org/resources/reportsdatabase/reports/gen/20040801_gen-351.pdf.
- IPTS – Institute for Prospective Technological Studies (ed.) (2003), Unmodified Vegetable Oil as an Automotive Fuel. IPTS Report 74. Sevilla. Internet: www.jrc.es/home/report/english/articles/vol74/TRA1E746.htm.

- IVA – Industrieverband Agrar (ed.) (2004), *Wichtige Zahlen – Düngemittel – Produktion, Markt, Landwirtschaft, 2003–2004*. Frankfurt a.M. Internet: www.iva.de/pdf/wiza0304.pdf.
- JRC – EUCAR, CONCAWE, Joint Research Centre (eds.) (2003), *Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*. Well-to-Tank Report, Version 1. Internet: <http://ies.jrc.cec.eu.int/Download/eh>.
- JRC – Institute for Prospective Technological Studies, Joint Research Center (ed.) (2004), *Biofuel Potentials in the EU*. Internet: [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 1195. Kiel. Internet: www.uni-kiel.de/ifw/pub/kap/2004/kap1195.htm.
- Köpke, R. (2005), Mehr Flower-Power im Tank. *Energie & Management* 11: 4.
- Levington (ed.) (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. Internet: www.senternovem.nl/mmfiles/27781_tcm24-124189.pdf.
- Markewitz, P. and S. Vögele (2004), *Technikspezifische CO₂-Vermeidungskosten*. Eine geeignete Bewertungsgröße für Treibhausgas-minderungs-Maßnahmen. *Energie-wirtschaftliche Tagesfragen* 54 (9): 601–605.
- MWV – Mineralölwirtschaftsverband (Hrsg.) (2005), *MWV Prognose 2020 für die Bundesrepublik Deutschland*. Hamburg. Internet: 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*. Institut für Energie und Umweltforschung, Heidelberg. Internet: http://biodiesel.pl/uploads/media/Pros_and_cons_of_RME_compared_to_conventional_diesel_fuel.pdf.
- Schmitz, N. (2005), Innovationen bei der Bioethanolerzeugung. Schriftenreihe *Nachwachsende Rohstoffe* 26. Münster: Landwirtschaftsverlag.
- UFOP – Union zur Förderung von Öl- und Proteinpflanzen (Hrsg.) (2005a), *Ölsaaten und Biokraftstoffe*. UFOP Marktinformation Mai 2005. Berlin. Internet: www.ufop.de/download/MI_05_05.pdf.
- UFOP – Union zur Förderung von Öl- und Proteinpflanzen (Hrsg.) (2005b), *Ölsaaten und Biokraftstoffe*. UFOP Marktinformation November 2005. Berlin. Internet: [www.ufop.de/downloads/RZ_MI_11_05\(1\).pdf](http://www.ufop.de/downloads/RZ_MI_11_05(1).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). Internet: www.nobio.no/fileupl/VIEWLS%20WP5%20final%20report%2020053107.doc.