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Tax exemption for biofuels in Germany: Is bio-ethanol really an option for climate policy?

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Abstract

In 2002 the German Parliament decided to exempt biofuels from the gasoline tax to increase their competitiveness compared to conventional gasoline. The policy to promote biofuels is being justified by their allegedly positive effects on climate, energy, and agricultural policy goals. An increased use of biofuels would contribute to sustainable development by reducing greenhouse-gas emissions and the use of non-renewable resources. The paper takes a closer look at bio-ethanol as a substitute for gasoline. It analyzes the underlying basic German, European, and worldwide conditions that provide the setting for the production and promotion of biofuels. It is shown that the production of bio-ethanol in Germany is not competitive and that imports are likely to increase. Using energy and greenhouse-gas balances we then demonstrate that the promotion and a possible increased use of bio-ethanol to reduce greenhouse-gas emissions are economically inefficient and that there are preferred alternative strategies. In addition, scenarios of the future development of the bio-ethanol market are derived from a model that allows for variations in all decisive variables and reflects the entire production and trade chain of bio-ethanol, from the agricultural production of wheat and sugar beet to the consumption of bio-ethanol in the fuel sector.

1. Introduction

In 2002 the German Parliament decided to exempt all biofuels from the gasoline tax. The exemption is in force only until the end of 2009, and a report by the government on progress in the market introduction of biofuels and on the price development of biomass, crude oil, and fuels is required every other year to allow for adaptations if necessary [1]. The coalition parties, as well

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as the opposition party Christlich Demokratische Union Deutschlands/Christlich Soziale Union (CDU/CSU) consider the exemption as a decisive contribution to the goals of reducing greenhouse-gas (GHG) emissions in the transport sector, of protecting natural resources, becoming less oil-dependent, and of securing incomes and jobs in the agricultural sector. Overall they believe that an increased use of biofuels can contribute to sustainability. Only the liberal party, the Freie Demokratische Partei (FDP), rejects the law, arguing that the promotion of biofuels is controversial from an environmental point of view, causes tax losses, and leads to new long-lasting subsidies because biofuels are not likely to be competitive [2].

The European Commission has also declared its intention to promote biofuels. The objective is to substitute renewable fuels for 20% of traditional fuels by 2020 [3]. To attain this long-term goal the Commission makes two proposals. First, a minimum biofuel content of at least 2% will be required which would be technologically feasible and would create a stable market for biofuels. Second, a European framework is planned that would allow member states to implement tax breaks for biofuels [4].

The political rationale behind the increased promotion of biofuels is their alleged positive contribution to climate policy and also to agriculture and the security of energy supplies. Today climate policy consists of a large number of policies that are intended to increase the efficiency of energy use, i.e. through reducing the energy intensity of economies, by reducing energy-intensive activities, and finally by substituting renewable energy sources for fossil energy. In addition to renewable energy from wind, water, or sun, biomass also provides a possible substitute for fossil energy sources.

Biomass can be produced either directly from the cultivation of agricultural resources or from waste material accumulated during agricultural production and processing. There are different options for using this biomass for energy purposes. The strategic aim of the tax exemption for biofuels is to produce agricultural products that can be converted to non-fossil fuels as a substitute for fossil fuels. Today, rape oil produced from rape (or after another level of conversion rape methyl ester (RME)) can be substituted for diesel fuels whereas bio-ethanol is the only substitute for gasoline. With present automobile technology, this can be done today up to a volume share of 10% of fossil gasoline. Bio-ethanol can be made from different agricultural products of which sugar beet and wheat are of special importance in Germany.

Whereas the use of rape oil and RME has been tested in detail for its impacts on energy and climate policy [5,6] there are many studies on bio-ethanol with widely differing results. Some use relatively old data; others refer to different countries or analyze the production of bio-ethanol from crops such as sugar cane or corn which, because of climatic conditions, are not relevant for Germany [7–10]. In this study, we will address only the use of bio-ethanol as a substitute for gasoline. The central question will be whether the strategy to use farmland to grow the basic raw materials for bio-ethanol production is a reasonable option for climate policy. Instead of creating a completely new data set for the construction of energy and GHG balances—an expensive and time consuming exercise beyond the scope of this study—we have carried out a meta-analysis of existing studies [11–17] relevant to the German situation in terms of climatic conditions and the political environment as far as agriculture, the fuel sector, and the alcohol sector are concerned. This meta-analysis first sought to identify the causes of the divergence in results. We then used additional up-to-date, bottom-up information from the agricultural sector, ethanol sector, and mineral oil industry to derive an estimate of the energy and GHG balances for Germany. We also used a linear programming model for bio-ethanol production developed for the German government.[1] In this paper, we do not intend to present a full cost-benefit analysis of the use of bio-ethanol. Such approaches can be found in Refs. [8,18–22].

Whereas our primary focus is on the climate-policy aspect of the German bio-ethanol policy we cannot ignore some of the other policy areas influencing the bio-ethanol markets. These include not only energy and agricultural policy but also trade policy, bio-ethanol being a tradable product in which Germany does not have a competitive advantage.

First therefore, we briefly analyze the goals and basic conditions that provide the setting for the promotion of biofuels. An economic evaluation on the basis of energy balances for bio-ethanol and alternative energy sources made from biomass follows. Finally, we assess the promotion of biofuels from an overall economic aspect and take a closer look at some scenarios for the future development of the German market for bio-ethanol.

2. Objectives of and basic conditions for the promotion of biofuels

2.1. Climate, energy, agricultural, and trade policy issues

The production and promotion of biofuels takes place within a framework shaped by the German and European climate, energy, agricultural, and trade policy; and the tax exemption for biofuels is often justified by an alleged positive effect on these policy areas.

The basic goal of climate policy is to reduce the use of fossil energies and thus CO_2 emissions. Within this objective the transport sector is still one of the biggest challenges [23], and the promotion of biofuels is one strategy that would contribute to the reduction of CO_2 emissions within this sector and to the overall climate policy commitments of Germany [24]. The extent to which bio-ethanol would be part of an efficient climate policy will be analyzed in detail in Section 3. Climate policy is directly linked to energy policy with its three objectives of security of supply, cost-effectiveness, and sustainability [3,24,25]. The contribution of biofuels to the security of fuel can be modest at best as the availability of agricultural land is a limiting factor [4]. Biofuels cannot contribute to cost-effectiveness as production costs are much higher than for traditional gasoline, and in the case of bio-ethanol, imports would also be cheaper than bio-ethanol produced in Germany [32]. The contribution of biofuels to sustainability is linked to their contribution to climate policy and is analyzed in Section 3. The different objectives of energy and climate policy, however, are often contradictory and hard to solve simultaneously [20,26].

Reforms of the Common Agricultural Policy (CAP) will also have an influence on the production of biofuels. The possible abolition of the common market organization for sugar will reduce incentives to produce agricultural feedstocks for biofuels. Liberalizing the sugar market would reduce prices for the energy feedstock sugar beet and therefore domestic supplies. Prices for wheat as a feedstock have already reached world-market levels but reforms could lead to decreased direct payments—e.g. the abolition of the premium for set-aside land [28]—and thus reduce domestic production of wheat as an energy feedstock. Effective support of agriculture through the production of biofuels is therefore unlikely. Moreover, increased protection of the domestic bio-ethanol market from international

[1] The model and its results are described in Ref. [32].

Table 1
European Union tariffs on imports from Brazil, USA, and Poland[a]

Traded good	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Methanol (TARIC: 2905110000): In Ecu/hl resp. €/hl as of 1999	12.3	10.8	10.8	10.0	9.3	8.5	7.8	7.0	6.3	5.5
Undenatured ethyl alcohol of an alcoholic strength by volume of 80% vol. or higher (TARIC 2207100000): In Ecu/hl resp. €/hl as of 1999	30.0	28.2	26.4	24.6	22.8	21.0	19.2	19.2	19.2	19.2
Ethyl alcohol and other spirits, denatured, of any strength (TARIC 2207200000): In Ecu/hl resp. €/hl as of 1999	16.0	15.0	14.1	13.1	12.1	11.2	10.2	10.2	10.2	10.2
Undenatured ethyl alcohol of an alcoholic strength by volume of less than 80% vol., in containers holding more than 2 l (TARIC: 2208909900): In Ecu/%vol./hl resp. €/%vol./hl as of 1999	1.6	1.5	1.4	1.3	1.2	1.1	1.0	1.0	1.0	1.0

[a] Tariff rates are always given for 1st January.

competition does not seem possible because of the pressure from the increasing liberalization of international trade. As Table 1 shows, import tariffs on ethanol have already been reduced, and further tariff reductions for developing countries were introduced in 2002 [28]. In spite of these liberalization pressures, however, the Council of the European Union laid down specific measures concerning the market in ethyl alcohol of agricultural origin [29]. Although this regulation must be consistent with the WTO agreement it is clearly an attempt to protect the European market for bio-ethanol from more competitive foreign suppliers.

2.2. The German market organization for ethanol

In Germany the *Bundesmonopolverwaltung für Branntwein* (Federal Monopoly Administration for Spirits), a national market organization responsible for buying and marketing ethanol produced in the agricultural sector has a strong influence on the market for bio-ethanol. Originally, it was designed as a means of creating income for the state. Today it subsidizes and protects mainly small and medium-sized German producers of bio-ethanol against foreign competitors and helps to preserve ecologically valuable landscapes. Prices paid to the producers by the *Bundesmonopolverwaltung* exceed market prices and most producers would not survive without this support. The resulting deficits are covered by the federal budget. However, this form of government aid contradicts to the rules for government aid in the European Single Market, and the German market organization is violating the rules of free movement of agricultural goods and application of uniform instruments in the member states.

The reforms in the *Haushaltssanierungsgesetz* (budget consolidation law) of 1999 [30] have already determined that the deficits covered by the federal budget will be reduced, with industrial producers being excluded from price supports. There is additional pressure from the proposal of the European Commission for a Regulation on the common organization of the market in ethyl alcohol of agricultural origin [31]. This regulation calls the whole German market organization for ethanol into question. The German government, however, has insisted on a Regulation that still allows for government aid and, indeed, a new Council Regulation was introduced laying down specific measures concerning the market in ethyl alcohol of agricultural origin, and, for a limited period of time, allows for the continuation of this support [29].

3. Can increased use of bio-ethanol contribute to energy and climate policy goals?

To assess the possible contribution of bio-ethanol to climate and energy policy goals, we construct energy balances for the production of bio-ethanol from German raw materials, derive GHG balances, and compute CO_2 abatement costs for different bio-ethanol strategies. As mentioned in Section 1, this is done by combining a meta-analysis of existing studies with new data assembled from partners from industry and agriculture during a project on bio-ethanol for the German government.

3.1. Why energy and greenhouse gas balances?

Substituting bio-ethanol for traditional gasoline will not take place without economic and fiscal policy support. Production costs for bio-ethanol in Germany amount to 0.45–0.55 per liter of gasoline-equivalent even in the best-case scenario. More likely is a range of 0.80–0.90 per liter of gasoline-equivalent[2] [32]. In contrast, tax-free prices for gasoline amount to only 0.20€ per liter. Thus, bio-ethanol is not competitive at all without the tax exemption. The tax exemption would, however, need some economic justification, of which its supposed contribution to climate protection is one of the most-cited arguments. Energy and GHG balances can be used to analyze the contribution of bio-ethanol to this objective. The energy balance compares the input of fossil energy necessary for the production of bio-ethanol to the energy content of the gasoline for which bio-ethanol is substituted. This comparison computes the net savings of fossil fuels. GHG balances compare GHG emissions during the production of biofuels with emissions from the use of traditional fossil gasoline. As GHG emissions can be reduced by a variety of different strategies, the abatement costs of alternative strategies can be compared to the bio-ethanol strategy. Different studies on the costs of reducing GHG emissions in the most efficient way show that the objectives of the Kyoto Protocol can be reached with abatement costs of around

[2] These numbers are based on a study on the evaluation of bio-ethanol production in Germany prepared for the Federal Ministry of Consumer Protection, Food and Agriculture [32]. The broadly based study was prepared by a consortium of representatives from producers of feedstock, ethanol producers, other industries, and academics. Technological and economic aspects were taken into consideration on every stage of production and legal and political conditions were accounted for (also see Section 4 for a more detailed description).

30€ per ton of CO_2 [33,34]. Assuming the implementation of emissions trading in the European Union the European Commission also estimates abatement costs of a maximum of 30€ per ton [35].

If substituting bio-ethanol for traditional gasoline and the strategy of promoting bio-ethanol are to be justified, two premises must be fulfilled. First, the use of bio-ethanol must result in significant savings of fossil-energy sources and a reduction in GHG emissions. Second, the costs of making GHG reductions as a result of using bio-ethanol must not be much larger than those of alternative climate-policy measures. This means that the cost of substituting bio-ethanol, with production costs of between 0.45 and 0.90€ per liter, for traditional gasoline, with tax-free prices of only 0.20€ per liter, in amounts necessary to avoid one ton of CO_2 must not be more than 30€. Certainly, results strongly depend on the price of crude oil, which directly affects the price of gasoline. Rising oil prices would increase the price of gasoline, and thus reduce the price differential of bio-ethanol and gasoline, which again would reduce abatement costs.

To analyze whether these two premises are fulfilled we compute energy and GHG balances and we evaluate whether the strategy to promote bio-ethanol is efficient from an economic point of view.

3.2. Energy balances for bio-ethanol

3.2.1. Problems in the generation of energy balances for bio-ethanol

To generate energy balances for bio-ethanol, the entire input of energy during the complete production chain needs to be estimated. The production process can be separated into two stages: the production of the agricultural energy feedstock and the conversion of these feedstock into bio-ethanol. In Germany sugar beet, grain and potatoes are the main feedstocks. Fossil energy input during the production of the feedstock results mainly from the energy content of fertilizer and pesticides, the use of agricultural machinery and the energy input for transporting the feedstock. The energy input necessary for both agricultural production and conversion varies between different feedstocks.

The detailed studies of feedstock production [11–17] show varying results for the energy inputs[3]. In general, grain production needs less energy input per hectare compared to sugar beet. Nevertheless this is compensated for by a greater yield of sugar beet per hectare. Therefore, the decisive figure is the energy input in the agricultural production of the feedstock necessary for producing 1 l of bio-ethanol. For both wheat and sugar beet the fossil energy input during agricultural production varies between 4 and 8 MJ per liter of ethanol. The fluctuation is due to different assumptions on fertilizer input and on outputs per hectare.

The second stage of production, the conversion of the feedstock to ethanol, demands the largest part of the entire fossil energy input (numbers vary between 10 and 27 MJ per liter of ethanol). The size, technological standard, type of energy input, and the efficiency of energy use of the facility used for conversion are the decisive factors for the amount of overall energy input at this stage of production. Altogether, fossil energy input for the production of 1 l of ethanol roughly varies between 14 and 35 MJ, compared to a heating value of 21.2 MJ per liter of ethanol.

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[3] As described in section 1, we have analyzed all available studies, which offered adequate data and consistency concerning our objectives. In addition, we communicated with experts from the Suedzucker AG and with Klaus Buercky from the Bodengesundheitsdienst GmbH to analyze the production of bio-ethanol based on wheat and sugar beet. Studies on sugar-cane- and corn-based production are not important for Germany because of unfavorable climatic conditions. For the potato-based production there is no adequate study and this option is not taken into account. Rough calculations indicate that potatoes have no chance of competing with wheat or sugar beet as a feedstock.

To determine the net savings of fossil energy when bio-ethanol is substituted for traditional gasoline we compare the entire energy input of traditional gasoline with fossil energy input in the production of bio-ethanol. The different combustion characteristics of the fuels must also be taken into account. In the end, the fossil energy input of bio-ethanol is compared to the fossil energy input for which it has been substituted, i.e. to the calorific value equivalent of bio-ethanol as a substitute for traditional gasoline.

Studies that have generated energy balances for bio-ethanol show strongly varying results from three critical variables that have a decisive impact on the energy balance. First, energy input during production of agricultural feedstock depends on the amount of fertilizer and pesticides used and on the energy needed for transport and farm machinery. Second, the conversion of feedstock to bio-ethanol is very energy-intensive. During conversion, different by-products, with a relevant energy content themselves, accumulate. To some extent they can be sold or used again during the production process itself. An assessment of the use of by-products in terms of energy savings and profitability is only possible to a limited extent. Third, the types of agricultural feedstock used for the production of bio-ethanol and their yields per hectare also influence the energy balance. Worldwide, most production of bio-ethanol is based on sugar cane and corn whereas in Germany bio-ethanol is produced from wheat and sugar beet. Therefore, energy balances for bio-ethanol from different countries are not transferable to Germany. Obviously, different assumptions regarding these three critical variables can easily change energy balances and are the major reason for the variation among different studies.

3.2.2. Energy balances for the production of bio-ethanol based on wheat and sugar beet

Fig. 1 gives an overview of different studies on the input of fossil energies necessary for the production of ethanol based on wheat. The studies are sorted according to the year to which they refer. The lower segment of the different bars reflects the fossil energy input for the production of feedstock wheat. This amounts to between 6 and 8 MJ per liter of ethanol for fertilizers and pesticides. The forecast for future technologies by the International Energy Agency (IEA) [15] assumes that this input can be cut by one half. Adding the energy input for farm machinery and transport (middle segment of the bars) increases the overall input to around 10 MJ. The primary energy necessary to convert wheat into ethanol (upper segment of the bars) represents the largest part of the overall energy input although studies vary considerably. Austmeyer, Röver [11] estimate fossil energy demands of 16 MJ whereas the study by the CCPCS [12] estimates 26 MJ and the IEA [15] predicts less than 10 MJ per liter of bio-ethanol. This range is due to the varying output and energy efficiency of different facilities.

Fig. 2 gives an overview of different studies on the input of fossil energies needed for the production of bio-ethanol based on sugar beet. The variation between the different studies is larger than that for bio-ethanol produced from wheat. The agricultural production of sugar beet needs less fossil energy input per liter of bio-ethanol produced, mainly because of lower fertilizer requirements, whereas energy input for the conversion is about the same.

The energy input for the production of traditional gasoline, including the calorific value and the energy needed for refining is shown as a reference in both figures. Engine performance using bio-ethanol compared to traditional gasoline is also taken into account. The petroleum industry assumes that 1 l of ethanol produces the same performance as 0.65 l of traditional gasoline [36,37]. This number is calculated based on the ratio of the different calorific values of bio-ethanol (21.2 MJ per liter) and traditional gasoline (32.4 MJ per liter). The gross energy content of gasoline (35.6 MJ per liter) is

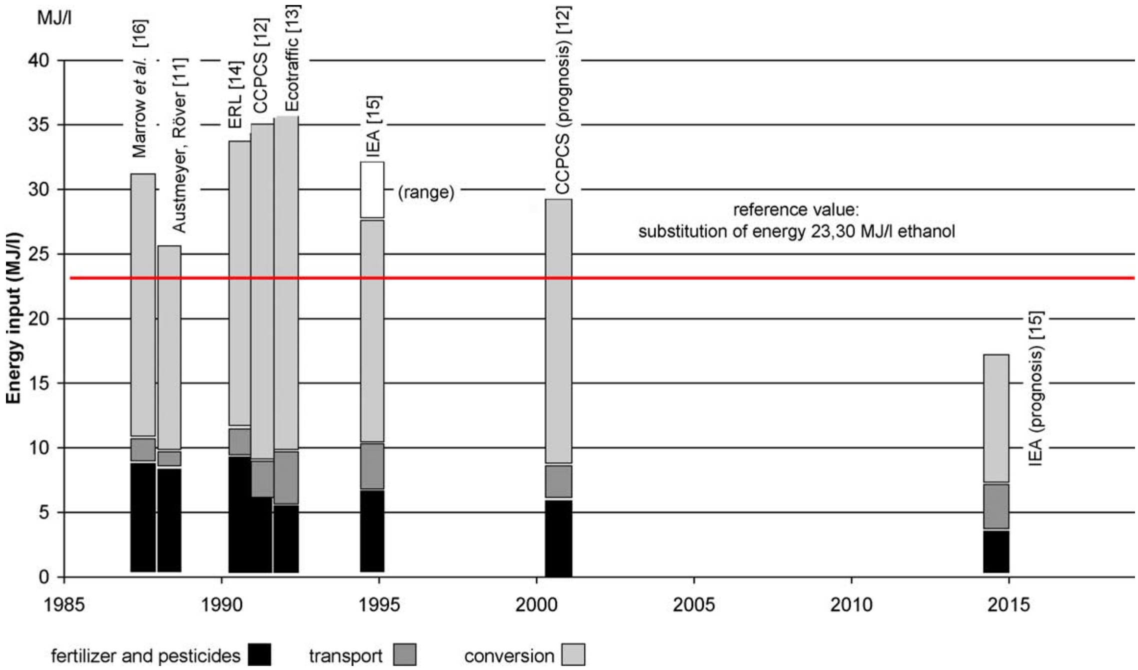


Fig. 1. Fossil energy input in the production of bio-ethanol based on wheat. (The reference value is the energy input for the production of gasoline from crude oil adjusted to the calorific value of ethanol, taking account of the gross energy content of gasoline and of the lower engine performance of ethanol. See Section 3.2.2.)

the calorific value of gasoline (32.4 MJ per liter) plus a 10% surcharge for the production process ($32.4\times1.1=35.6$). This number multiplied by the ratio of the different calorific values of ethanol and gasoline ($21.2/32.4=0.65$) gives us the reference value of 23.3 MJ per liter which is used in the figures. However, a consensus on these numbers has not yet been reached. Studies on energy balances use values between 0.65 and 1 for the ratio of substitution between ethanol and gasoline. Currently, further studies are being performed, and we expect that they will end up with a ratio that is closer to 0.65 than to 1.

3.2.3. Net energy balances

To receive the net energy surplus or loss resulting from the production of bio-ethanol we compare fossil energy input during the production process of bio-ethanol as shown in Figs. 1 and 2 with the input of fossil energy that is avoided (the reference value of 23.3 MJ/l described above) because of the substitution of bio-ethanol for traditional gasoline. The resulting net energy balances are shown in Figs. 3 and 4.[4]

Overall, the results of the net energy balance are better for sugar beet as a feedstock for the production of bio-ethanol than for wheat. In some, mainly older studies the net energy balance for wheat even turns out to be negative. This implies that more fossil energy is needed to produce bio-ethanol than is saved by substituting bio-ethanol for traditional gasoline. The IEA predicts that productivity gains in agricultural

[4] To guarantee comparability of the different studies we use a consistent reference value for the energy content of gasoline that is substituted. This has not been done in the original studies.

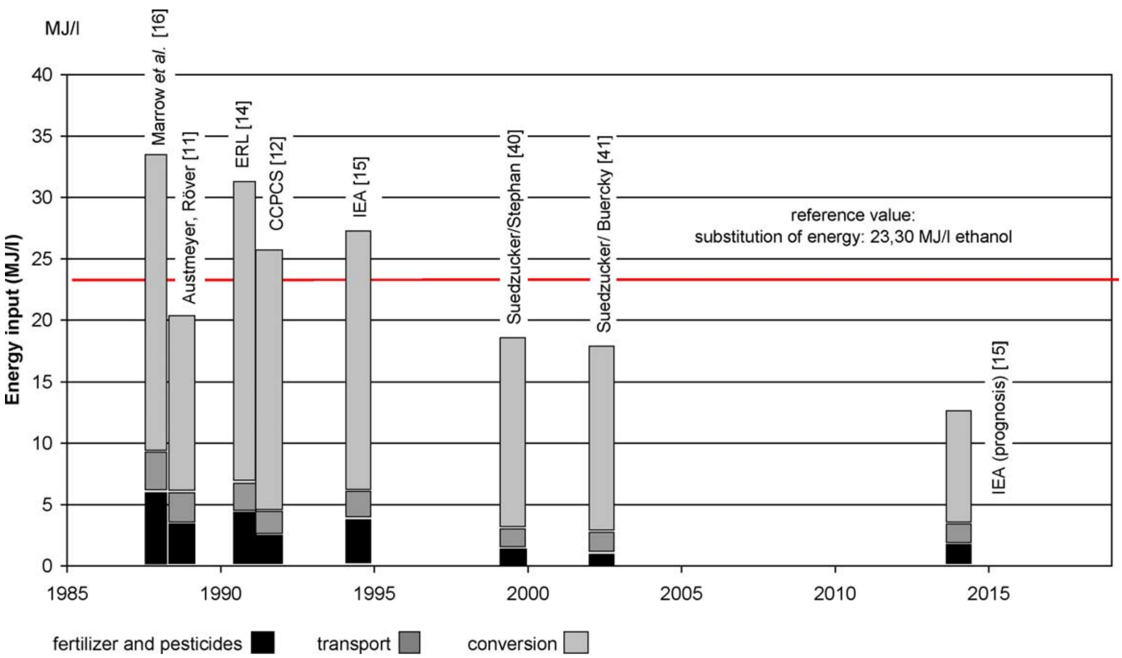


Fig. 2. Fossil energy input in the production of bio-ethanol based on sugar beet. (The reference value is the energy input for the production of gasoline from crude oil adjusted to the calorific value of ethanol, taking account of the gross energy content of gasoline and of the lower engine performance of ethanol. See Section 3.2.2.)

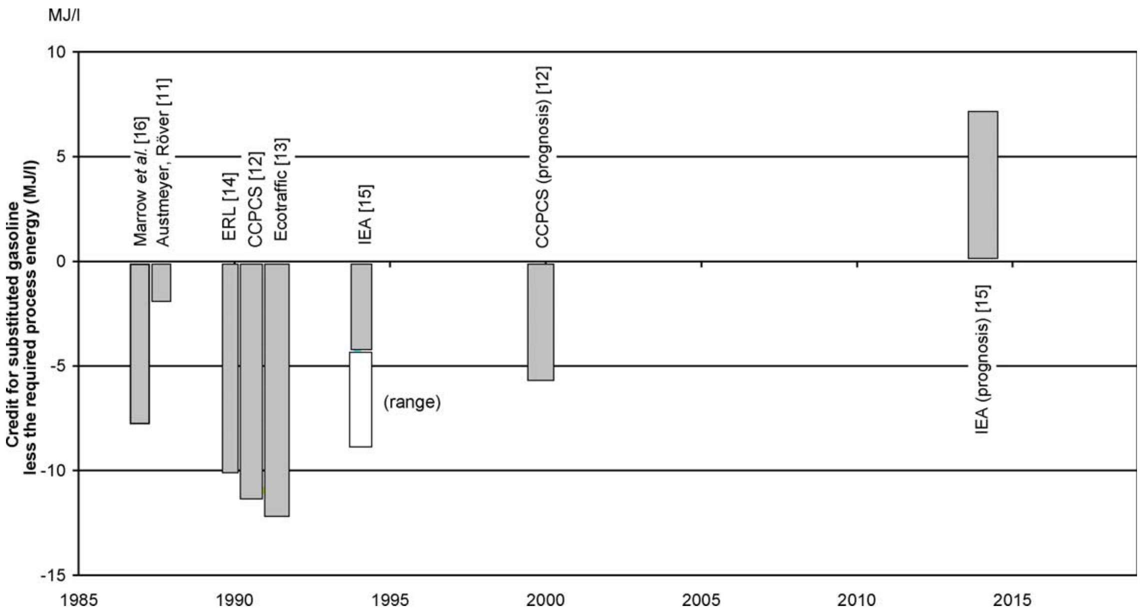


Fig. 3. Net energy balance for the substitution of gasoline by bio-ethanol based on wheat.

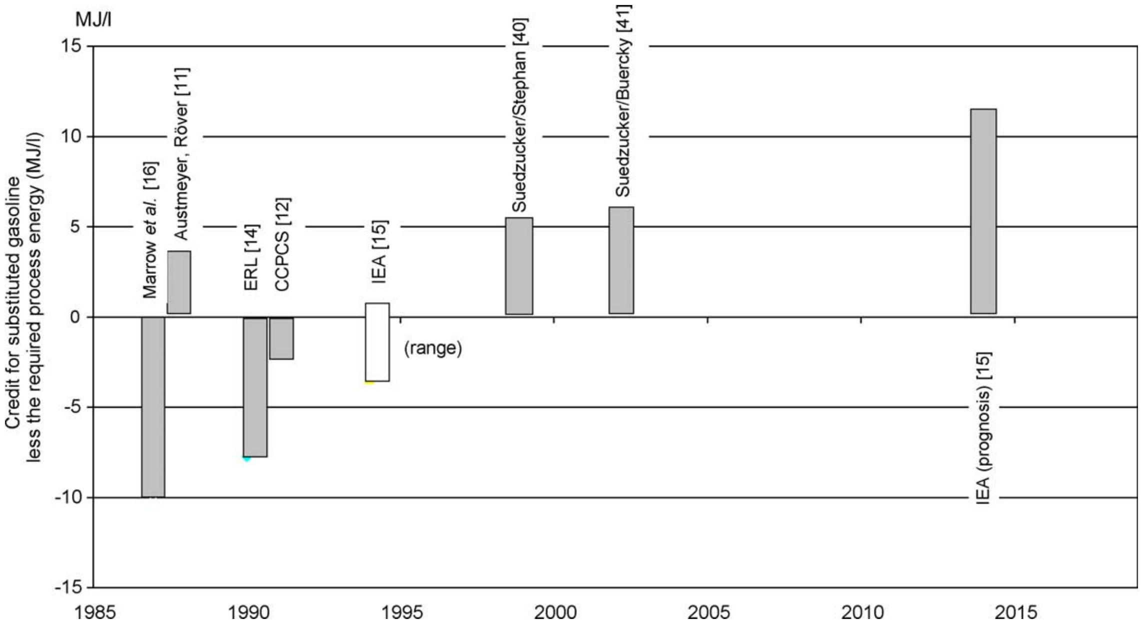


Fig. 4. Net energy balance for the substitution of bio-ethanol for gasoline based on sugar beet.

production as well as energy savings during the conversion will make the net energy balances more positive in the future. Nevertheless net energy savings are currently rather low.

Assuming a more favorable ratio of the performance between gasoline and bio-ethanol than 0.65, the net energy balances would improve. Balances for wheat would become slightly positive. The balances for sugar beet would even double under the unrealistic assumption of a one-to-one substitution of bio-ethanol for traditional gasoline.

3.3. The economic perspective: There are better strategies for using agricultural land

The assessment of the energy balances in the previous section shows that bio-ethanol production using current technological options can indeed save fossil energy. For the large-scale introduction of biofuels, significant areas of agricultural land would need to be devoted to the production of the feedstock. As fertile land is in limited supply the question arises as to whether other forms of producing renewable energy could be even more successful in replacing fossil fuels.

In fact, from an overall economic perspective there are better strategies. The crucial question is how much fossil energy can be saved on a given amount of agricultural land using a particular strategy. As well as the production of biofuels such as bio-ethanol or diesel made from rape crops there are options for substituting biomass for other fossil energy sources, e.g. gas, oil, or coal for the production of electricity or heat, thus leaving more fossil fuels available to the transport sector. Fig. 5 compares different options for replacing fossil energy with agricultural feedstock. The bars for sugar beet, wheat, and corn refer to the cultivation of these feedstocks for the production of bio-ethanol; the bar for rapeseed refers to the production of RME; and the bar for wood to the production of electricity by burning wood. To reach the objective of maximum savings of fossil energy on a certain area of

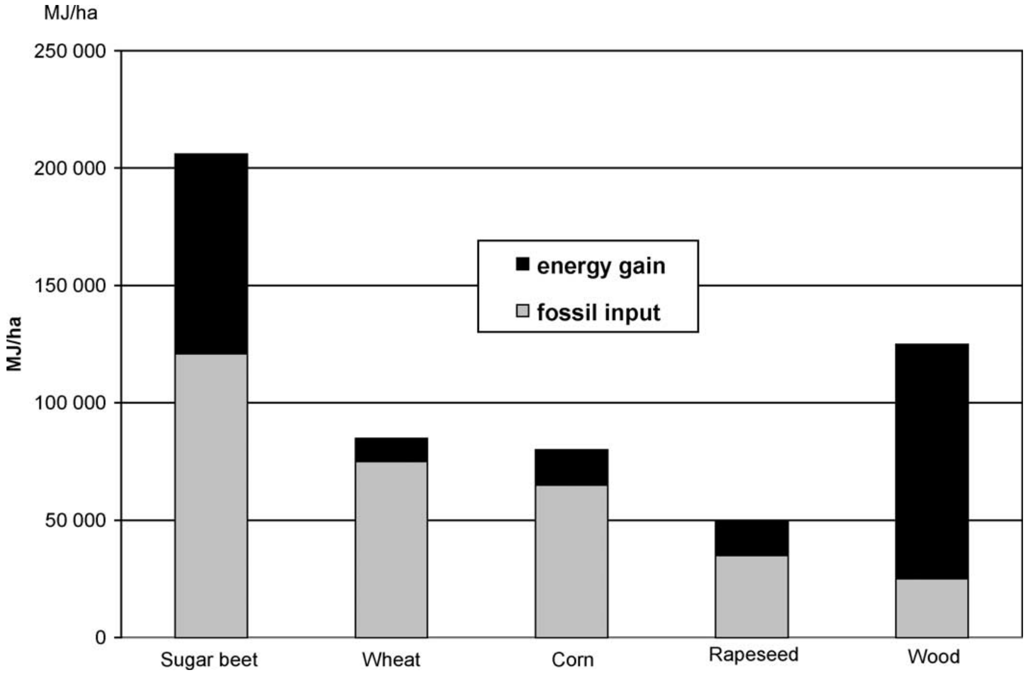


Fig. 5. Fossil energy savings per hectare for different agricultural feedstock and the substitution of different energy sources.

agricultural land (the energy gain in Fig. 5), the best option would be to use the agricultural land for the cultivation of fast-growing woods to produce electricity and not for the cultivation of feedstock to produce bio-ethanol as a substitute for traditional gasoline[5].

3.4. Is the bio-ethanol strategy an alternative for climate policy?

3.4.1. Net greenhouse-gas balances for bio-ethanol

To analyze an increased use of bio-ethanol from a climate policy point of view we need to determine GHG emissions during the production process of bio-ethanol, i.e. during the cultivation of agricultural feedstock and the process of conversion. Emission figures for the six GHGs defined in the Kyoto Protocol are weighted according to their global warming potential and summed to give a single figure for emissions which is expressed in CO_2 equivalents. Then the effect on GHG emissions of the substitution of bio-ethanol for traditional gasoline is evaluated and presented in net GHG balances. They can show whether the substitution of bio-ethanol for traditional gasoline really does reduce GHG emissions.

Fig. 6 presents the net GHG balance for the production of bio-ethanol based on wheat. The considerable variation is due mainly to different assumptions about GHG emissions during

[5] The results of Fig. 5 are based on more favorable ratios of substitution between bio-ethanol and traditional gasoline (greater than 0.65) and a higher gross energy content of gasoline (greater than 35.6 MJ per liter) than used in the studies mentioned above. Therefore, net energy savings for the production of bio-ethanol based on wheat are positive and for sugar beet greater than shown above. If we were to use the data explained earlier (0.65 as the ratio of substitution and 35.6 MJ per liter as the gross energy content of gasoline) the advantage of growing wood for energy production would be even greater.

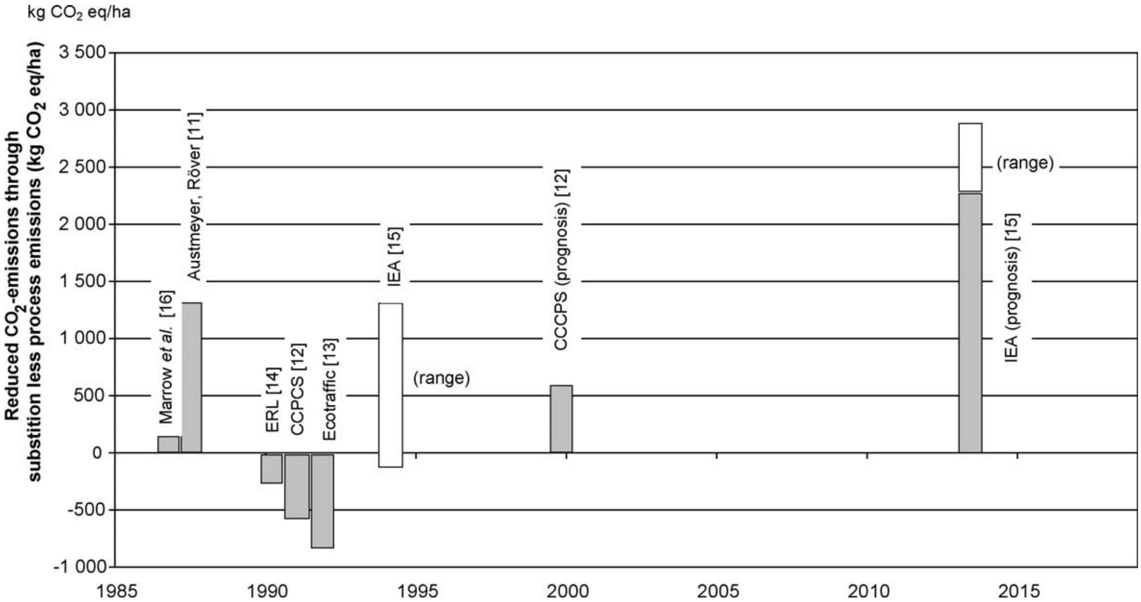


Fig. 6. Net greenhouse gas balance in the production of bio-ethanol based on wheat.

the conversion process. The IEA [15] for example considers two different technologies, the use of coal and gas as fuels for the conversion process, and the use of gas, electricity, and combined-heat-and-power generation. In the first case the net GHG balance turns out to be negative; in the second case GHG emissions can be reduced by approximately 1.3 tons of CO_2 equivalent per hectare. Altogether, some studies show little reduction in GHG emissions, others even an increase. Only the IEA [15] predicts a significant reduction of emissions in the future because of a strongly reduced energy input during conversion.

The net GHG balance for bio-ethanol based on sugar beet is more favorable (Fig. 7). Compared to the amount of bio-ethanol produced on one hectare of agricultural land, the use of traditional gasoline causes 14 tons of CO_2-equivalent emissions per hectare while the production of bio-ethanol only causes around 10 tons of CO_2-equivalent emissions. This results in net savings of around 4 tons in most of the studies. Again, the IEA prediction assumes a reduction in fossil energy inputs during conversion which improves net GHG balances considerably.

3.4.2. CO_2-abatement costs of the bio-ethanol strategy

The energy and GHG balances show that under today's conditions for producing raw materials and conversion, small savings of fossil energy sources and GHG emissions are possible if bio-ethanol is substituted for traditional gasoline.

GHG emissions have the same environmental impact no matter where and during what kind of process they are emitted. An efficient climate policy therefore requires a reduction of GHG emissions at those sources where a reduction can be carried out at the lowest cost. The abatement costs of one ton of CO_2 in the European Union amount to a maximum of 30€, if the European commitment in the Kyoto Protocol were to be fulfilled. Variations depend on the different climate policy instruments used [33–35]. This figure should be used as the benchmark for evaluating the bio-ethanol strategy.

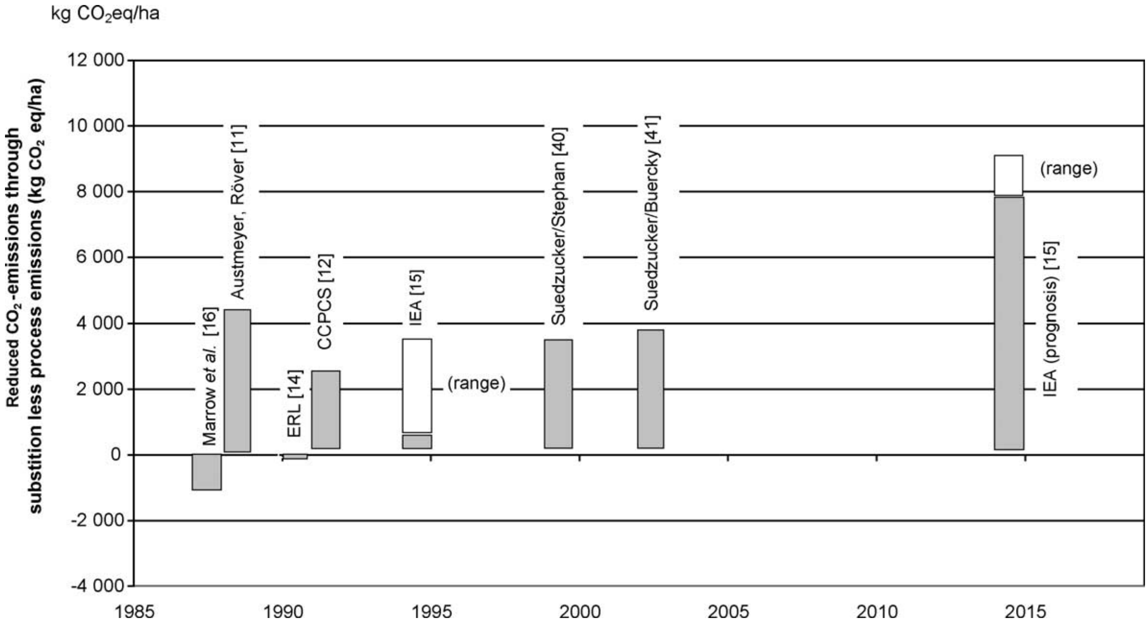
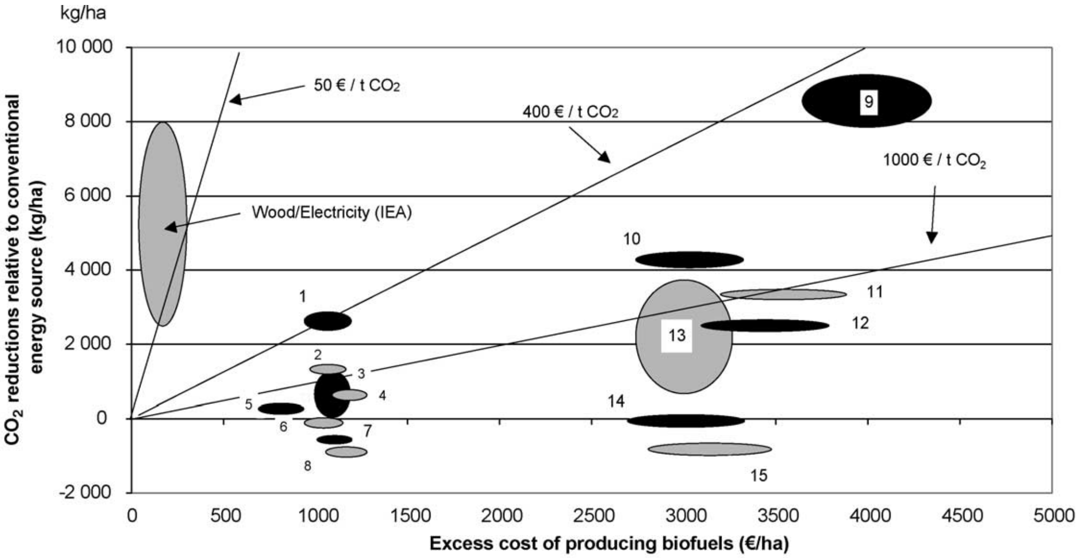


Fig. 7. Net greenhouse-gas balance in the production of bio-ethanol based on sugar beet.

Fig. 8 shows the relationship between the CO_2 reductions per hectare, the cost of bio-ethanol, and the cost of reducing CO_2 emissions, as they are derived in the different studies. The *y*-axis shows possible CO_2 reductions in kilograms per hectare of cultivated land and the *x*-axis shows additional costs resulting from a substitution of bio-ethanol for traditional gasoline. Finally the straight lines show the combinations of CO_2 reductions from the *y*-axis and additional production costs from the *x*-axis that result in a certain price for the reduction per t CO_2. The left line, for example, illustrates the combination where the reduction of one ton of CO_2 costs around 50€. To derive these lines the excess costs are divided by the CO_2 reduction per ha., e.g. the 1000€/t CO_2 line intersects excess costs of 4000€/ha from the *x*-axis and CO_2-reduction of 4000 kg/ha from the *y*-axis. This gives us abatement costs of 1000€ per ton of CO_2. As some results from older studies show a negative GHG balance they fall below the *x*-axis (studies 6–8 for wheat and studies 14 and 15 for sugar beet). For the production of bio-ethanol based on wheat, abatement costs amount to a minimum of 1000€ per ton of CO_2 (studies 2–5 in Fig. 8). Only the IEA (study 1 in Fig. 8) predicts that with future technologies, abatement costs come down to about 400€ per ton of CO_2. Abatement costs for bio-ethanol based on sugar beet (studies 9–15) vary around 1000€ per ton of CO_2 and the IEA prediction falls around 500€ (study 9). Fig. 8 also shows that the additional costs of production per hectare are greater for sugar beet (around 1000€/ha) than for wheat (around 3000€/ha). At the same time net GHG balances for sugar beet are more positive so that abatement costs turn out to be about the same. To illustrate an alternative use of agricultural land, power generation based on fast-growing woods is also included. This alternative can save up to 5 tons of GHG emissions per hectare, mainly because the GHG emissions from conversion processes can be avoided. Therefore, the CO_2-abatement costs for this land-use option amount to less than 50€ per ton [38].

The cost of GHG abatement using the bio-ethanol strategy could be reduced: if by-products resulting from the production process were sold at sufficiently high prices; if the production processes were



Wheat	1 IEA (prognosis) [15]	2 Austmeyer, Röver [11]	3 IEA [15]	4 CCPCS (prognosis) [12]
	5 Marrow *et al.*[16]	6 ERL [14]	7 CCPCS [12]	8 Ecotraffic [13]
Sugar beet	9 IEA (prognosis) [15]	10 Austmeyer, Röver [11]	11 Suedzucker (Buercky & Stephan) [39,40]	
	12 CCPCS [12]	13 IEA [15]	14 ERL [14]	15 Marrow *et al.* [16]

Fig. 8. Relationship between process costs and CO_2 abatement for producing biofuels.

optimized; and if economies of scale were realized by building large-scale production facilities. But even in such a best-case scenario abatement costs could only be lowered to about 300€ per ton of CO_2 for wheat and sugar beet [32]. This would still be ten times the estimated abatement costs of emissions trading as an alternative climate strategy and six times the estimated abatement costs of the cultivation of wood to produce electricity as an alternative land-use strategy. Therefore, the bio-ethanol strategy is an expensive policy option and not a first best alternative for climate policy. With the same economic effort a larger amount of GHG emissions could be avoided elsewhere.

4. Scenarios for the German bio-ethanol market

4.1. The model

It is clear from Section 2 that the production of bio-ethanol will take place in a policy environment that is heavily regulated. Agricultural policies, energy and climate policy, and trade policy have an important impact on the profitability of biofuels. At the same time these policies, and also the technologies, are likely to change in the coming years. It is therefore helpful to have at hand a simulation tool with which alternative scenarios can be assessed. For this purpose a simulation model covering the bio-ethanol process from cradle to grave was developed. The model is the synthesis of a study on the evaluation of bio-ethanol production in Germany prepared for the Federal Ministry of Consumer Protection, Food, and Agriculture [32]. It consists of a bottom-up linear programming approach. Recent input coefficients of agricultural production in Germany and the trade in agricultural products are included. Different conversion technologies and economies of scale in the plant size are accounted for. Detailed cost structures, prices, and data to produce energy balances and evaluate environmental effects throughout the entire life cycle of bio-ethanol have been added.

With this linear programming model specific strategies for introducing bio-ethanol into the German market can be simulated. This allows the identification of the macroeconomic impacts of particular political objectives such as substituting bio-ethanol for 10% of fossil fuels. The programming can also be used to assess the sensitivity of crucial but uncertain parameters to the expected results. Finally, measurements of importance to political decision makers can be easily computed, such as the subsidies necessary to achieve a particular bio-ethanol strategy. In the following, results from a few scenarios for the production of bio-ethanol based on sugar beet and wheat are presented to illustrate the feedback mechanisms between the economic and ecological aspects of the strategy.

4.2. Some scenarios

Bio-ethanol made from sugar beet using new conversion technology: In this simulation we analyze the production of bio-ethanol based solely on sugar beet as a feedstock. We use the following assumptions: the substitution of bio-ethanol for traditional gasoline begins at 2% in 2005 and rises to 15% in 2020. Bio-ethanol is produced in newly built, modern, large-scale plants; by-products from agricultural production create 10% additional revenues, and byproducts from the conversion process 20%. Prices for the feedstock are exogenous, and we use the actual ratio of substitution between bio-ethanol and gasoline of 0.65 as described in Section 3.2.2. For this scenario the simulation can show us the development between 2005 and 2020 of the agricultural area needed for the production of bio-ethanol in relation to the total agricultural area used for the production of sugar beet; the amount of bio-ethanol produced in Germany that is necessary to reach the assumed contents of biofuels; the CO_2 abatement costs; and finally the amount of subsidization in terms of the tax exemption necessary for this strategy. In 2000, without any bio-ethanol production the total area used for the production of sugar beet in Germany amounted to 451,000 ha. In 2005 the agricultural area needed for the cultivation of sugar beet which will then be used to produce bio-ethanol will be 74,000 ha which is 16% of the total area used for the cultivation of sugar beet in 2000. By the year 2020 when bio-ethanol will be substituted for traditional gasoline at a rate of 15%, the area needed to produce bio-ethanol will rise to 3,57,000 ha. This is 80% of the total area used for the cultivation of sugar beet in 2000. The amount of bio-ethanol produced will rise from 0.59 million m^3 in 2005 to 3.23 million m^3 in 2020. Because of cost reductions in the production of bio-ethanol, CO_2-abatement costs will decrease from 402 to 279€/tCO_2. The amount of subsidization necessary for this scenario in the form of lower gasoline tax revenues will amount to 254million€ in 2005 and will increase to 1146million€ in 2020.

Bio-ethanol made from sugar beet using current conversion technology: In this scenario, we use the same simulation as above except that we assume the use of currently available small-scale conversion technologies with higher conversion costs. This shows the extent to which the technologies and plant size in the conversion process determine CO_2-abatement costs. Abatement costs will amount to

540€/tCO_2 in 2005 (compared to 402€/tCO_2 using new technologies) and decrease to 367€/tCO_2 in 2020 (compared to 279€/t CO_2 using new technologies).

Bio-ethanol made from sugar beet versus bio-ethanol made from wheat: Using the above scenario with newly built, large-scale plants we compare the production of bio-ethanol based on sugar beet with the production of bio-ethanol based on wheat. The domestic production of bio-ethanol is the same in both cases. The amount of agricultural land used for the production of bio-ethanol is about twice as high for wheat as for sugar beet. This is because of lower yields of bio-ethanol based on wheat per ha of cultivated land than for bio-ethanol based on sugar beet per ha of cultivated land. However, the amount of agricultural land used for wheat as a feedstock for bio-ethanol as a percentage of the 2000 total crop area in wheat is lower than for sugar beet, using the same parameters (6.0% in 2005 and 24.1% in 2020 for wheat and 16.4% in 2005 and 79.2% in 2020 for sugar beet). Prices, based on production costs of bio-ethanol, are lower for the production from wheat compared to sugar beet. However, the energy balance in MJ/l is more favorable for sugar beet and CO_2-abatement costs turn out to be about the same.

The influence of crude oil prices: Crude oil prices directly affect prices for gasoline. The model can show how much oil prices would have to rise to balance the higher costs for bio-ethanol. Crude oil prices of 20 US$ per barrel result in a price differential of 0.34€ per liter of bio-ethanol compared to gasoline (without taxes). If crude oil prices rose to 50 US$ per barrel the price difference would almost disappear. Hence CO_2-abatement costs would be reduced significantly. Because of this correlation oil prices have a decisive impact on abatement costs of the bio-ethanol strategy. With rising oil prices, subsidies necessary to make ethanol competitive would fall. However, the relative advantage of using biomass directly would still remain valid if heat and electricity were produced from fossil fuels.

5. Conclusions

The promotion of bio-ethanol as a gasoline substitute in Germany is in line with the recommendations by the EU to increase the share of renewable energy sources in all energy sectors. In order to make bio-fuels competitive against fossil fuels, the former are completely exempted from the gasoline tax. However, this is not the only state intervention. Bio-ethanol production is subject to many additional regulations and support programs such as the set-aside premium, the partial state monopoly for ethanol, and price controls for agricultural products.

The support for bio-ethanol production is justified by the German government with objectives such as support of the farm sector, energy security, and climate protection. In this paper the main focus is on the climate-policy aspects of the bio-ethanol policies. For this purpose a review of all the available evidence for Germany was done by looking at the energy balances of different strategies, at the GHG balances, and at the GHG-abatement costs.

The energy balance for the production of bio-ethanol has in the past been found to be negative or only slightly positive, i.e. almost the same quantity of fossil fuel was necessary to produce bio-ethanol as the gasoline being replaced. This situation has improved through increased yields of the main feedstocks, wheat and sugar beet, through reduced use of fertilizer, and by improvements in the conversion technologies. The evidence would suggest that sugar beet has a slightly better energy balance than wheat.

The net-energy and net GHG balances are to a large degree determined by the ratio of substitution between bio-ethanol and fossil gasoline that yields the same engine performance as using pure gasoline.

Since this issue has not been resolved, the net energy savings from bio-ethanol cannot be predicted with accuracy.

Bio-ethanol is one strategy for producing renewable energy on agricultural soils. A comparison of different land-use options shows that the yield of fossil energy saved from producing bio-ethanol on a hectare of land is lower than some alternatives, e.g. a direct use of the energy in biomass would create larger savings of GHGs than the production of biofuels.

An efficient climate-policy scenario would consist of all measures that reach a specific GHG reduction goal at lowest cost. Estimates of the cost of achieving the commitments of the EU as stated in the Kyoto Protocol amount to at most 30€/t CO_2 equivalents. Assessments of the likely GHG-abatement costs for the bio-ethanol strategy vary strongly as they depend on many assumptions. However, the variation of 200–1000€/t CO_2 equivalents avoided is still far above the many other policy instruments that can be used to reduce GHG emissions. Therefore, the promotion of bio-ethanol is not an economically viable option for climate policy.

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