Article

The Long-Term Prospects of Biofuels in the EU-15 Countries

Amela Ajanovic [1,]*, **Gerfried Jungmeier** [2], **Martin Beermann** [2] **and Reinhard Haas** [1]

[1] Energy Economics Group, Vienna University of Technology, Gusshausstrasse 25-29/370-3, Vienna 1040, Austria; E-Mail: haas@eeg.tuwien.ac.at

[2] Joanneum Research, Elisabethstrasse 5, Graz 8010, Austria;
E-Mails: gerfried.jungmeier@joanneum.at (G.J.); martin.beermann@joanneum.at (M.B.)

* Author to whom correspondence should be addressed; E-Mail: ajanovic@eeg.tuwien.ac.at;
Tel./Fax: +43-1-588-013-7364.

Abstract: The core objective of this paper is to analyze the energy and CO_2 reduction potentials as well as the market prospects of biofuels in EU-15 in a dynamic framework till 2050. The most important result of this analysis is that 2nd generation biofuels might become economically competitive between 2020 and 2030, yet this can only be achieved if the following preconditions are fulfilled: (1) achievement of significant learning effects leading to considerably lower plant costs; (2) significant improvement of conversion efficiency from feedstock to fuel leading to lower feedstock costs and better ecological performance; (3) increases in conventional diesel and gasoline prices, e.g., due to CO_2 based taxes.

Nomenclature

BD-1	biodiesel from rape seed and other oil seeds
BD-2	biodiesel with Fischer-Tropsch (FT) process
BE-1	bioethanol from wheat and maize
BE-2	bioethanol from lignocellulose
BF-1	1st generation biofuels
BF-2	2nd generation biofuels
BM	biomethane from manure, grass and green maize
CNG	compressed natural gas

SNG   synthetic natural gas from biomass
TTW   Tank-to-Wheel
WTW   Well-to-Wheel
WTT   Well-to-Tank

1. Introduction

In many policy directives and scientific papers biofuels are expected to contribute significantly to the reduction of fossil fuel consumption and corresponding CO_2 emissions. Yet, currently used 1st generation biofuels (BF-1)—e.g., biodiesel from rapeseed, bioethanol from wheat and maize—are associated with ecological problems, high costs, low net energy yields, limited potential, land-use changes and competition with food production. 2nd generation biofuels (BF-2)—FT-Diesel, ethanol from lignocellulose, synthetic natural gas from wood—are considered to be future alternatives to currently used biofuels. Major advantages expected from BF-2 are:

- Better ecological performance because of lower life-cycle carbon emissions;
- No associated land-use changes;
- Due to the fact that they are produced from lignocellulose, considerable potentials for the required feedstocks are expected. These primary lignocellulose resources encompass: straw, corn stover, forest wood residues, wood industry residues, waste wood and short rotation coppice;
- If produced on large scale also economic competiveness is expected.

The core objective of this paper is to investigate the energetic and CO_2 reduction potentials as well as the market prospects of biofuels for transport in EU-15 in a dynamic framework till 2050 (this work is based on the ALTETRÄ project which has been funded by the Austrian FFG, see [1]). Our approach is based on scenarios for the development of conversion efficiencies, corresponding life-cycle CO_{2_equ} balances, scenarios of oil price and CO_2-cost development and international learning rates for the corresponding conversions technologies. This work builds on the analyses conducted in Ajanovic *et al.* [2–4], Hamelinck and Faaij [5,6], Hamelinck *et al.* [7] and EEA [8].

We focus on the following categories of biofuels:

- BD-1: 1st generation biodiesel from rape seed and other oil seeds;
- BE-1: 1st generation bioethanol from wheat and maize;
- BG: biogas from manure, grass and green maize;
- BD-2: 2nd generation biodiesel with Fischer–Tropsch process;
- BE-2: 2nd generation bioethanol from lignocellulose;
- SNG: synthetic gas from biomass;
- Electricity based on biomass (here, electricity based on biomass, which could be used in transport applications, is also considered as "biofuel").
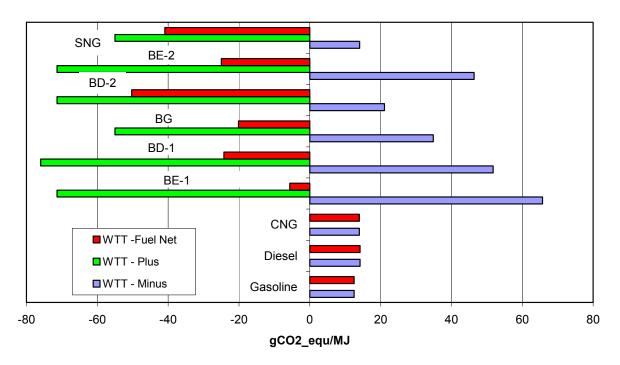
2. Dynamic Environmental and Energetic Performance

In the context of the current poor ecological and energetic performance of BF-1 it is very important to consider the whole fuel chain by means of so-called Life Cycle Assessment (LCA) or ecological Well-to-Wheel (WTW) assessment. The calculation of greenhouse gas emissions and primary energy demand is based on the method of LCA. According to EN ISO 14040:2006 "Environmental management—life cycle assessment—principles and framework" the environmental impacts are calculated along the supply chain of a product or service: from extraction of raw materials for its production through its use to its disposal. In LCA are included all relevant materials, energy inputs and emissions related to the environment and to the extraction of the primary resource, transportation of the resource to a conversion facility, conversion of the resource into a final energy carrier, distribution of the final energy carrier and their use to provide energy service—mobility, for more detail see [1]. The net WTT emissions, as depicted for the year 2010 in Figure 1, are calculated as follows:

$$WTT = WTT\text{-}minus + WTT\text{-}plus \tag{1}$$

where WTT-plus is CO_2 fixation due to biomass planting; WTT-minus is CO_2 emissions during fuel production.

Figure 1. Calculation of WTT-net CO_2 emission balances for 2010 (source: based on Joanneum Research calculations).

The WTW-emissions are the sum of Well-to-Tank (WTT)- and Tank-to-Wheel (TTW)-emissions, see Figure 2.

Figure 2. WTT-, TTW- and WTW net CO_2 net emissions of fossil fuels vs. biofuels in 2010 for the average of EU countries (source: based on own analyses by Joanneum Research).
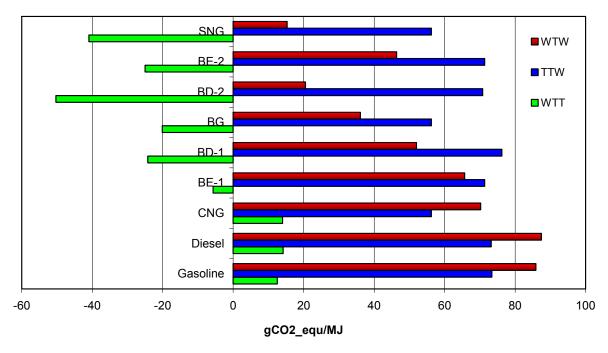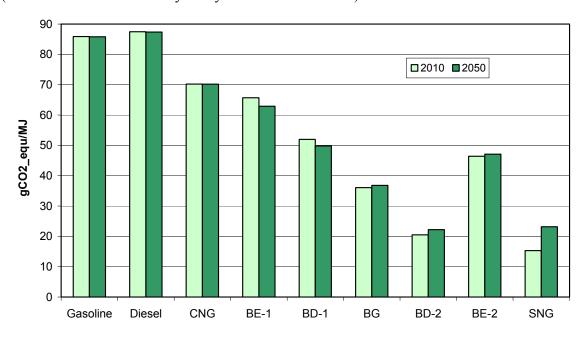

Figure 3 shows the expected development of CO_2 emissions of fossil fuels *versus* biofuels from 2010 to 2050 for the average of EU countries on a WTW basis.

Figure 3. CO_2 emissions of fossil fuels vs. biofuels in 2010 and 2050 on a WTW basis (source: based on own analyses by Joanneum Research).
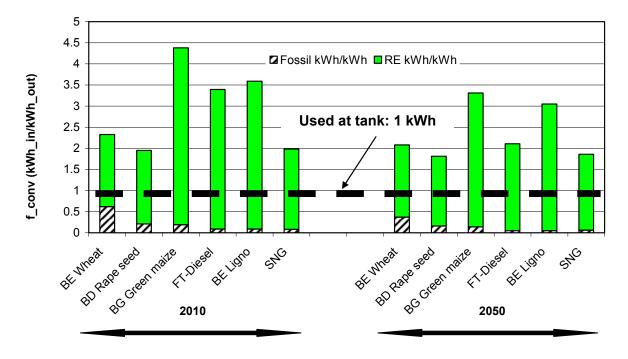

We can see from Figure 3 that in 2010 BF-1 had only about 40% lower CO_2 emissions than fossil fuels (for the ecological and economic analysis it is important to note that for all fuels by-products were considered in all cases as they may have a positive influence on costs and emissions performance). An important observation from Figure 3 is slight improvements of the ecological performance are

expected up to 2050 only for BD-1 and BE-1. For biogas and all BF-2 the CO_2 emissions will even increase slightly.

From an energetic point-of-view it is of interest to see what this performance looks like currently and what can be expected in the future. Figure 4 compares the energetic conversion factors (reverse of production efficiency) of the considered biofuels for 2010 and 2050. We can see in Figure 4 that the major problem for BF-1 is the relatively high share of fossil energy whereas for BF-2 it is the low conversion efficiency and the corresponding high input of renewable feedstocks. By 2050 it is expected that these problems will be only slightly relieved. The most important perception from Figure 4 is that FT-Diesel could significantly improve its energetic performance by reducing its energetic input/output ratio by about 35%.

Figure 4. Energetic conversion factors of the considered biofuels for 2010 and 2050 (source: based on own analyses by Joanneum Research).

3. Scenarios for Biofuels in EU-15 up to 2050

An important feature of our analysis is the dynamic economic assessment of the investigated categories of biofuels. Total biofuel production costs (C_{BF}) are calculated for every year as follows (see also [2] and Appendix):

$$C_{BF} = \frac{IC \cdot CRF}{T} + \frac{P_{FS} \cdot f_{TC}}{f_{conv}} + C_{TDM} - R_{By} \qquad [\text{€}/\,\text{kWh}_{BF}] \qquad (2)$$

where: *IC* is investment costs; *CRF* is capital recovery factor; T is operating hours per year; P_{FS} is feedstock price; f_{conv} is conversion factor; f_{TC} is factor for transaction costs; C_{TDM} is transport, distribution and marketing costs; R_{by} is revenues from by-products.

In the following we derive two scenarios up to 2050 for biofuels from "new" biomass (excl. pellets, wood chips, fuel wood):

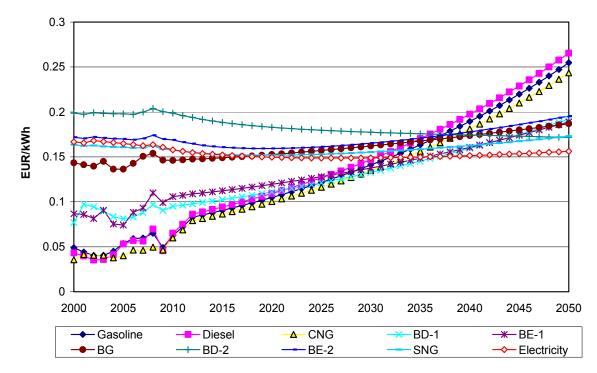*3.1. Business-as-Usual (BAU) Scenario*

In the BAU scenario it is assumed that: (1) the amount of arable land currently used for biofuels will not increase till 2050; (2) no additional policies will be applied and (3) there is no priority for any energy carrier.

3.2. Policy Scenario

In the Policy Scenario it is assumed that till 2050 additional arable land (max. 30% of total arable land in 2050) will be used for biofuels. The Policy Scenario corresponds to the assumptions of international deployments of biofuels according to IEA ([9–11]). In this scenario priority is given to the production of liquid biofuels over electricity. The major economic assumptions for the dynamic Policy Scenario analysis are the following:

- Increases in fossil fuel prices are based on expected price developments as documented by IEA [8,12] and in case of feedstock and wood prices on own analyses. For both scenarios we use price increases for fossil fuels of 3% per year till 2050, 2% per year for feedstocks (oil seeds, cereals) and 1% per year for wood-based resources (e.g., wood industry residues, waste wood);
- All monetary figures are of 2010; that is to say all costs and prices are converted to the values of the year 2010;
- The cost development of analysed biofuels without taxes is shown in Figure 5. In this case between 2035 and 2040 all biofuels will become cheaper than fossil fuels.

Figure 5. Development of costs of various biofuels in comparison to conventional fuels (without taxes) till 2050.
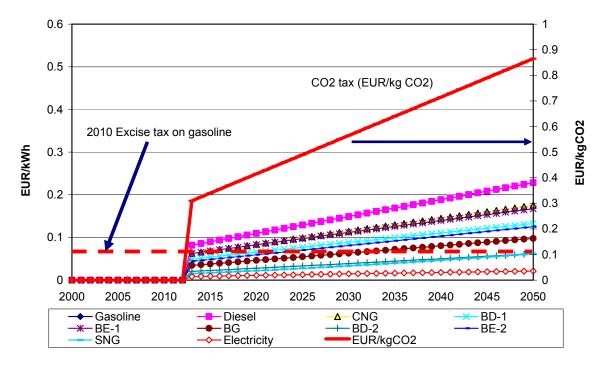

- Development of investment costs of biofuels is based on global developments, particularly regarding technological learning effects for the corresponding investments (for details see [1]);

- Taxes will have an important impact on the future economic competitiveness of biofuels. In the Policy Scenario the introduction of a CO_2 based tax is assumed.

All analyzed biofuels have different CO_2 emission balances and could, more or less, contribute to the reduction of GHG emissions. With an appropriate CO_2-based tax biofuels with the lowest CO_2 emissions (such as electricity from biomass, BD-2 and SNG) could become more competitive on the market. Such a policy is assumed in the Policy Scenario starting in 2013. Figure 6 shows development of CO_2 tax on biofuels. The major assumptions and ideas regarding CO_2 based tax are described in following:

The highest excise tax in 2010—which was on gasoline—is converted into a CO_2 tax of the same magnitude. For all other fuels, including diesel and CNG, this tax is set relative to their WTW—CO_2 emissions compared to gasoline. This tax starts in 2013 and is increased by 0.015 EUR/kgCO_2 per year till 2050. As a consequence biofuels with lowest CO_2 balances will have lowest tax levels in 2050.

Figure 6. CO_2 tax developments of various biofuels in comparison to conventional fuels up to 2050 and CO_2 tax per kg CO_2 (starting in 2013).

4. Resources for Biofuels in EU-15

In this section we document the major assumptions regarding the available resources in the scenarios described above. The types of resources are split into area-dependent (such as cereals, oil seeds, grass, short rotation coppice, forest wood residues) and area-independent ones (like waste fat, organic waste, wood industry residues, wood waste).

Next, we describe the maximum of land areas available for biofuels in EU-15 till 2050 and document the availability of non-area dependent resources. In our analyses no imports of biofuels or feedstocks are considered. Since our main focus in on resources available in EU-15, land use change is not considered. It is assumed that no significant land use changes will take place due to the production of biofuels.

4.1. Maximal Area-Based Resources

The conventional biofuels are based on the feedstocks grown on arable land, which is very limited in EU-15, about 71 Mill. hectares (app. 23% of the total land area in EU-15, which is in about 313 Mill. hectares). However, with the option of using second generation biofuels other land areas such as meadows, pastures and forest area could also be used for biofuels production, so that total land area potential for biofuels could become significantly higher.

Regarding the future land use we have assumed that maximal 30% of arable land in 2050, about 21 Mill. hectares, can be used for growing biofuels. About two thirds of this area (app. 14 Mill. hectares) can be used for oil seeds. In addition, 10% of pasture land and 10% of meadows could be used for feedstock production for biofuels by 2050. Figure 7 provides a comparison of total areas, the currently used areas for biofuels in 2010 and maximal available areas for biofuels in 2050 (the forest area equivalent describes how many hectares of forest area are required to produce equivalently the same amount of forest wood used for biofuels as the total production of wood on one hectare, see also [1]). In total (excl. forest area) about 27 Mill. hectares (app. 8% of total land area) would be used for the production of biofuels by 2050 in our Policy Scenario.
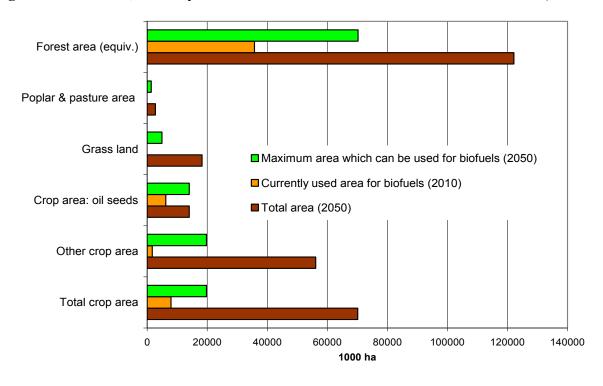
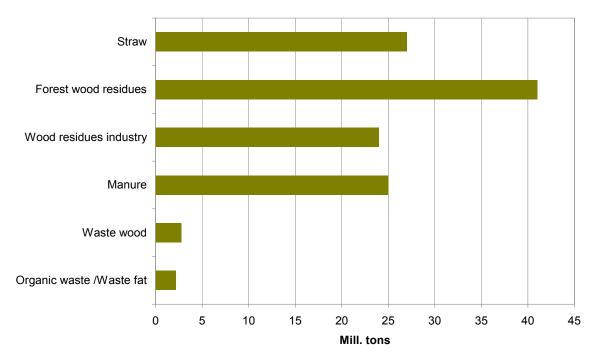**Figure 7.** Total areas, currently used areas and maximum available areas for biofuels (in EU-15)

4.2. Potentials of Non-Area-Based Resources

Aside from resources, which need land areas for their production (and which are in principle in competition with food or feed supply or deployment for wind turbines or photovoltaic systems), there are also resources based on residues and waste (e.g., organic waste, wood industry residues, waste wood).

Figure 8 shows their maximum potentials in 2050. The highest quantities can be expected from forest wood residues (about 40 Mill. tons). The quantities of straw, residues from the wood industry and manure which can be used for biofuels production are 27, 23 and 25 Mill. tons, respectively. For the

straw potential it is important to note that we consider only potential of about 0.9 tons/ha for energetic purposes. The rest is assumed to be needed for ground recovery and for other non-energetic purposes.
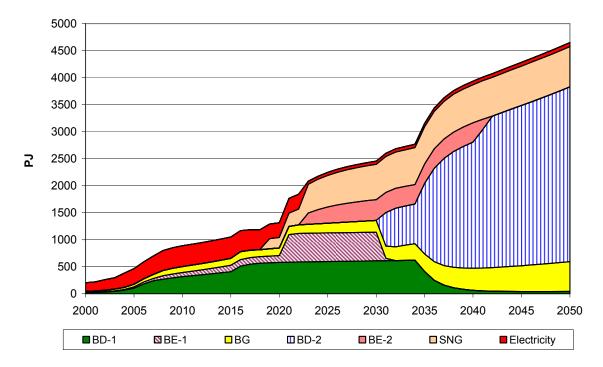
Figure 8. Maximal potentials for biofuel production from non-area-dependent resources in EU-15 in 2050 (Sources: [8,13–15]).

5. Potentials for Biofuels

Next we present two scenarios which depict the lower and the upper range of biofuels in EU-15 till 2050. These scenarios are based on a model using historical data from FAOSTAT and EUROSTAT [16,17] for feedstock yields, production, agricultural and forestry areas, as well as meadows/pastures and fallow land for the exploration of potentials. Potentials from areas are achieved in practice if the production costs are lower than the market prices of conventional diesel and gasoline prices, incl. taxes.

Figure 9 depicts the Policy Scenario. In this scenario by 2050 about 4600 PJ of biofuels will be produced. This is about five times more than in 2010 (incl. electricity). Due to technology maturity a significant and continuously increasing share of the 2nd generation bioethanol can be noticed after 2023 whereas the increasing share of 2nd generation biodiesel is starting from 2032. Most BD-2 are produced from corn stover (whole plant used) from arable land. In this scenario SNG provides significant contribution to energy production starting from 2018. Yet, this development takes place only if it can be managed that 2nd generation biofuels technologies become mature and if significant learning effects are achieved. Due to the better energetic and economic performance of BD-2 it also substitutes BE-2 production after 2030. A note on biogas: there is a temporarily slight decrease of biogas, because its production from maize silage will phase out. But on the other hand gradually more biogas will be produced from grass. Because of the priority for biofuels in the Policy Scenario electricity will be produced only from those feedstocks which are not usable for biofuels production such as waste wood.
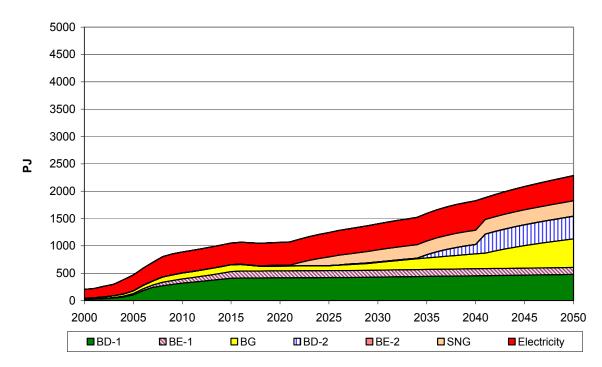
Figure 9. Energy production (final energy) in the Policy Scenario.

The major reasons why in Figure 9 BD-2 and SNG reach so high amounts are the following:

- They have highest energy efficiency and hence lowest feedstock costs;
- They have lowest CO_2-emissions and hence lowest CO_2-taxes.

Figure 10 shows the development of energy production in the BAU Scenario without any new policies and without use of additional arable land for biofuels. With no tax changes 1st generation biofuels remain in the market till 2050 and electricity retains a remarkable share.

Figure 10. Energy production (final energy) in the BAU Scenario.
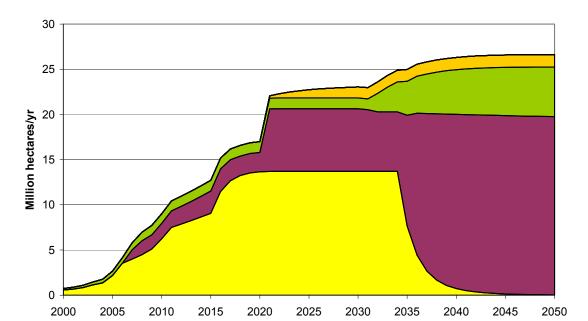
6. Land Areas and Resources Used in Scenarios

The following figures depict the effects of the Policy Scenario on use of land areas and resources. The increasing production of biofuels based on feedstocks produced in EU-15 will occupy additional land, although for 2nd generation biofuels mainly non- crop area dependent resources will be used.

With growing economic attractiveness of BF-2 the arable land area is more and more used for whole plants like corn stover, while BD-1 and BE-1 are phasing out. Moreover, increasing biogas production (which is produced mainly from grass) will also significantly increase the use of grass area after 2030 to about 5.5 Mill. Hectares, see Figure 11 (note, that there is no competition with BF-2 for grass area).

Due to the switch to the 2nd generation biofuels after 2020 poplar areas could also be used for biofuels production. Total land area (excl. forest area) for biofuels production will increase to 26 Mill. hectares by 2050. Figure 12 shows the corresponding tons of feedstock used for the production of biofuels by type of feedstock.

The type of areas used for biofuels in the BAU Scenario are depicted in Figure 13. In this scenario used area is about 9 Mill. hectares less than in the Policy Scenario. The corresponding feedstock-mix is shown in Figure 14. As opposite to the Policy Scenario in this case corn stover will not significantly contribute to biofuels production. However, rapeseed remains an important feedstock for biodiesel production over the whole analyzed period.

Figure 11. Areas for biofuels by area type, 2000–2050, in Policy Scenario (excl. forest area).

Figure 12. Tons of feedstock used for the production of biofuels by type, 2010–2050, Policy Scenario.
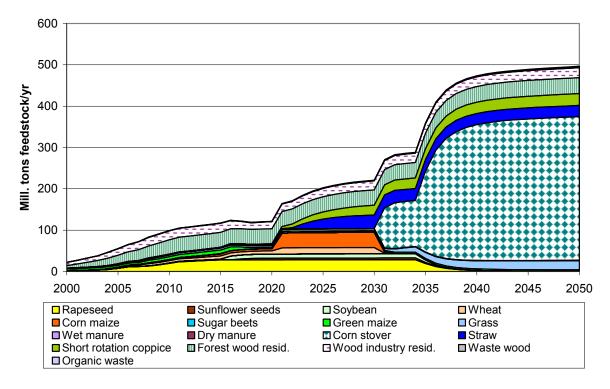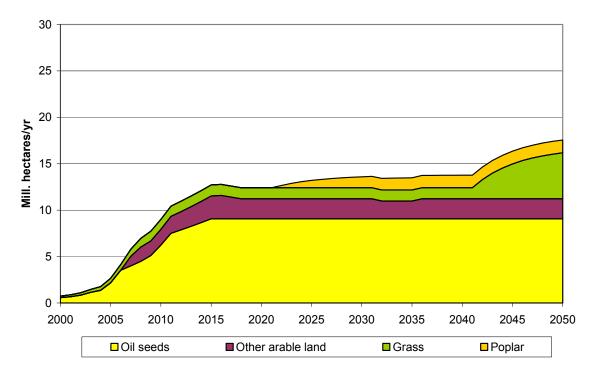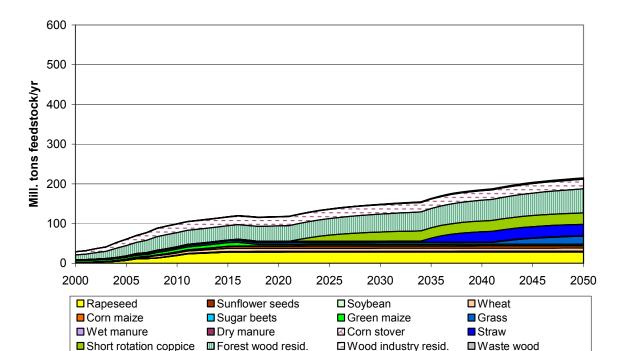

Figure 13. Areas for biofuels by area type, 2000–2050, in BAU Scenario (excl. forest area).

Figure 14. Tons of feedstock used for the production of biofuels by type, 2010–2050, BAU Scenario.

7. Effects on CO$_2$ Emissions

One of the major reasons for the forced introduction of biofuels is that they are expected to reduce GHG emissions significantly. The following figures depict the effects on CO$_2$ emissions in the analyzed scenarios.
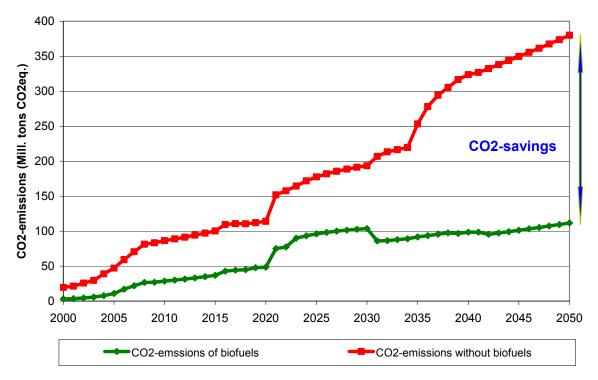
Figure 15 shows the total CO$_2$ emissions from biofuels in EU-15 from 2000 to 2050 in the Policy Scenario in comparison to total CO$_2$ emissions without the use of biofuels. The upper curve depicts the development of CO$_2$ emissions of the equivalent of substituted gasoline and diesel fuels. We can see that by 2050 the CO$_2$ emissions in the Policy Scenario could be reduced by about 70%.

The magnitude of this potential impact can be seen from the following comparison: In 2010 total consumption of fossil fuels in road passenger transport in EU-15 was about 6000 PJ. Total corresponding CO$_2$ emissions were about 520 Mill. tons CO$_2$-eq.
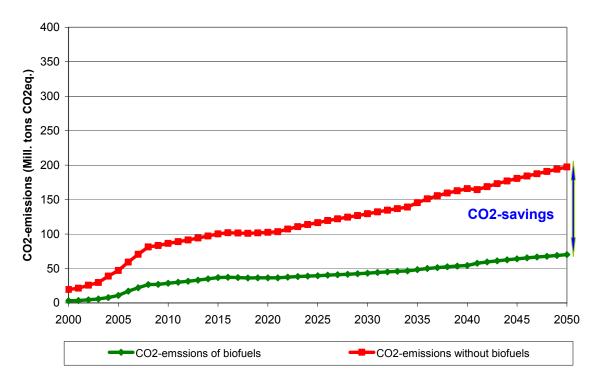
From Figure 15 it can be seen that savings in CO$_2$ emissions in 2050 could be about 260 Mill. tons CO$_2$-eq. In the Policy Scenario due to the use of biofuels total CO$_2$ emissions in road passenger transport in EU-15 could be about 50% lower. In the BAU-Scenario the corresponding savings are about 25% (130 Mill. tons CO$_2$).

In the BAU Scenario the total reduction of CO$_2$ emissions is almost half of the reductions realized in the Policy Scenario, see Figure 16.

Figure 15. Total CO_2 emissions from biofuels in EU-15 from 2000 to 2050 in the Policy Scenario in comparison to total CO_2 emissions without the use of biofuels.

Figure 16. Total CO_2 emissions from biofuels in EU-15 from 2000 to 2050 in the BAU Scenario in comparison to total CO_2 emissions without the use of biofuels.

8. Conclusions

The major conclusion of this analysis is that the overall potential for biofuels in EU-15 is about 4600 PJ. This is a rather modest reduction compared to total energy consumption of 50,000 PJ in 2008. Even with the switch to 2nd generation biofuels, the additional biofuels potential is moderate. Regarding the magnitude of biofuel potentials the following conclusion is important: whether arable land can be used for biofuels production is more relevant than the impact of tax policy. The latter mainly influences the possible switch from 1st to 2nd generation biofuels.

Regarding costs in general it can be stated that no significant cost reduction can be expected for BF-1 and BF-2 in Europe by 2050. However, proper tax policies and continuous increases of fossil fuel prices could make BF-2 economically competitive between 2020 and 2030. Yet, this can only be achieved if the following aspects are reached: (1) achievement of significant learning effects leading to considerably lower plant costs; (2) significant improvement of conversion efficiency from feedstock to fuel leading to lower feedstock costs and better ecological performance (see also [18]); (3) increases in conventional diesel and gasoline prices, e.g., due to CO_2 based taxes.

Appendix

Table A1. Overview on typical sizes for large plants for the production of biofuels and corresponding investment and specific costs in 2010 [1].

Large-scale	Capacity		Investment costs	
	Convent. units	MW$_f$	Total	Specific
Biodiesel 1st gen.	200,000 t BD	260 MW$_f$	110 Mio EUR	550 EUR/t BD
Bioethanol 1st gen.	200,000 t BE	200 MW$_f$	110 Mio EUR	500 EUR/t BE
Biogas	16,000 MWh/yr	2.0 MW$_f$	51 Mio EUR	3200 EUR/kW$_f$
Biodiesel 2nd gen.	400,000 t BD	520 MW$_f$	2400 Mio EUR	6000 EUR/t BD
Bioethanol 2nd gen.	400,000 t BE	400 MW$_f$	1000 Mio EUR	2500 EUR/t BE
SNG	-	80 MW$_f$	640 Mio EUR	8000 EUR/kW$_f$
Electricity (from biomass)	-	30 MW$_{ele}$	75 Mio EUR	2500 EUR/kW$_{ele}$

Note: f—fuel.

References

1. Ajanovic, A.; Haas, R.; Beermann, M.; Jungmeier, G.; Zeiss, C.; *ALTETRÄ—Perspectives for Alternative Energy Carriers in Austria up to 2050*; Final Report for The Austrian Research Promotion Agency (FFG): Vienna, Austria, 2012.
2. Ajanovic, A.; Haas, R. Economic challenges for the future relevance of biofuels in transport in EU-Countries. *Energy* **2010**, *35*, 3340–3348.
3. Ajanovic, A. Prospects for alternative energy carriers based on biomass sources in EU-15 up to 2050. In *Proceedings of Conference on Sustainable Development of Energy, Water and Environment Systems*, Ohrid, Macedonia, 1–7 July 2012.
4. Ajanovic, A.; Haas, R. On the future relevance of biofuels for transport in EU-15 countries. In *Energy and Sustainability III*; Villacampa, Y., Mammoli, A.A., Brebbia, C.A., Eds.; WIT Press: Southampton, UK, 2011; pp. 97–108.

5.   Hamelinck, C.N.; Faaij, A.P.C. Production of advanced biofuels. *Int. Sugar J.* **2006**, *108*, 168–175.

6.   Hamelinck, C.N.; Faaij, A.P.C. Outlook for advanced biofuels. *Energy Policy* **2006**, *34*, 3268–3283.

7.   Hamelinck, C.N.; van Hooijdonk, G.; Faaij, A.P.C. Future prospects for the production of ethanol from ligno-cellulosic biomass. *Biomass Bioenergy* **2005**, *28*, 384–410.

8.   Mourelatou, A.; Wiesenthal, T. *How Much Bioenergy Can Europe Produce without Harming the Environment*; Technical Report for European Environment Agency: Copenhagen, Denmark, 2006.

9.   International Energy Agency (IEA). *World Energy Outlook 2009*; IEA: Paris, France, 2009.

10. International Energy Agency (IEA). *World Energy Outlook 2006*; IEA: Paris, France, 2006.

11. International Energy Agency (IEA). *Energy Technology Perspectives 2008: Scenarios and Strategies to 2050*; IEA/OECD: Paris, France, 2008.

12. International Energy Agency (IEA). *World Energy Outlook 2011*; IEA: Paris, France, 2011.

13. Panoutsou, C.; Eleftheriadis, J.; Nikolaou, A. Biomass supply in EU27 from 2010 to 2030. *Energy Policy* **2009**, *37*, 5675–5686.

14. Kaltschmitt, M. *Technische Potenziale für flüssige Biokraftstoffe und Bio-Wasserstoff* [in German]; Institut für Energetik und Umwelt: Leipzig, Germany, 2004.

15. Funk, C. 2009: *Versorgung des Europäischen Marktes Durch Synthetische Kraftstoffe aus Biomasse* [in German]; VDI-Verlag: Berlin, Germany, 2009.

16. FAOSTAT Home Page. Available online: http://faostat.fao.org/ (accessed on 15 August 2012).

17. EUROSTAT Home Page. Available online: http://epp.eurostat.ec.europa.eu/ (accessed on 15 August 2012).

18. *Directive 2009/30/EC of the European Parliament and of the Council*; Official Journal of the European Union: Brussels, Belgium, 2009.