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Economic challenges for the future relevance of biofuels in transport in EU countries

A. Ajanovic*, R. Haas

Vienna University of Technology, Energy Economics Group, Gusshausstr. 25-29/373-2, 1040 Vienna, Austria

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ABSTRACT

The discussion on the promotion of biofuels is ambiguous: on the one hand benefits like reduction of greenhouse gas emissions and increase of energy supply security are expected, on the other hand low effectiveness with respect to reducing greenhouse gas emissions and high costs are being criticized. The core objective of this paper is to investigate the market prospects of biofuels for transport in the EU in a dynamic framework till 2030. The major results of this analysis are: (i) Under current policy conditions – mainly exemption of excise taxes – the economic prospects of 1st generation biofuels in Europe are rather promising; the major problems of 1st generation biofuels are lack of available land for feedstocks and the modest ecological performance; (ii) Large expectations are currently put into advanced 2nd generation biofuels production from lignocellulosic materials. With respect to the future costs development of 2nd generation biofuels, currently it can only be stated that in a favourable case by 2030 they will be close to the costs of 1st generation biofuels. However, because of the increasing prices for fossil gasoline and diesel in all international scenarios – given remaining tax exemptions – biofuels will become competitive already in the next few years.

1. Introduction

1.1. Motivation

The interest in renewable energy based on low carbon fuels, mostly bioethanol and biodiesel, has increased in the last decades in many countries all over the world for the following reasons:

- About 95% of the world energy consumption in the transport sector is based on petroleum products. Since 1990, the transport sector's CO_2 emissions worldwide have increased by 36%. On a well-to-wheels basis (i.e. including emissions from feedstock and fuel production and distribution to vehicles), in 2007 transport greenhouse gas (GHG) emissions accounted for close to 27% of total emissions [1]. So today we still face increasing greenhouse gas emissions and other problems in transport sector, such as growing consumption of limited fossil fuels and growing import dependency from politically instable countries;
- Biofuels are considered to have the potential to alleviate the above mentioned problems in the transport sector, such as growing consumption of fossil fuels, growing import dependency from political instable countries and increasing greenhouse gas emissions at least to some extent;
- Yet, so far biofuels have been more expensive than petroleum fuels, so that government incentive programs have been and are still necessary to allow biofuels to play a role in the market place. In 2006, total support of biofuels (market price support and subsidies) associated with policies of the EU and the Member States were around 3.7 billion EUR [2].

Currently, the share of biofuels is relatively small in almost all countries except the USA and Brazil. The share of biofuels in total transport fuels demand in 2007 was about 20% in Brazil, 3% in the USA and less than 2% in the EU, [3,4]. Many countries have set the goal to replace a significant part of fossil fuels by biofuels. In the European Union by the end of this year (2010) 5.75 percent of the energy used for transportation should be biofuels [5].

A number of EU Member States have introduced targets and mandates for the use of biofuels, see Table 1.

Demand for road-transport fuels is expected to increase further in the coming decades. According to the IEA[1] [1], by 2030, global energy use in transport sector is expected to be 3331 Mtoe, which is 45% higher than in 2007 (2297 Mtoe) in the Reference Scenario (RS) and 30% higher than in the Alternative Policy Scenario (AS) (2994 Mtoe).

* Corresponding author. Tel.: +43 1 58801 37364; +fax: +43 1 58801 37397.
E-mail address: ajanovic@eeg.tuwien.ac.at (A. Ajanovic).

[1] IEA – International Energy Agency, Paris.

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Table 1
EU member states biofuel targets.

Country	2010 target (%)
EU Target	5.75
Austria	5.75
Cyprus	5.75
Czech Republic	5.55
France	7
Germany:ethanol	3.6 mandate
Germany:biodiesel	6.17 mandate
Greece	5.75
Italy	2.5
Latvia	5.75
Lithuania	5.75
Luxembourg	5.75
Netherlands	5.75 mandate
Poland	5.75
Slovakia	5.75
Slovenia	5
Sweden	5.75
United Kingdom	3.5

In this context it is also of interest to see how the expectations of the IEA for biofuels have developed. There are two major references: A sound analysis on biofuels worldwide has firstly been conducted in the WEO[2] of 2006 [3], an update was published in the WEO of 2009 [1]. In both analysis biofuels are expected to play an increasingly important role in meeting transport demand, see Table 2, but not necessarily in the EU. For the EU countries in the WEO 2006 it was expected that energy from biofuels increases from 2 Mtoe in 2004 to 15 Mtoe in RS and to 16 Mtoe in AS by 2010 and than to 26 Mtoe in RS or 36 Mtoe in AS by 2030. Comparing the expected shares of the EU in the RS of 2030 in the WEO 2006 were 29% (and less percent in the more ambitious AS). The upward revised numbers in the WEO 2009 include a share of 19% for EU countries with total potential remaining constant at 26 Mtoe. It can be noted that while the production in North America, Brazil and Asia is expected to increase significantly the expectations for the EU countries are rather moderate.

1.2. *Objective of the paper*

The core objective of this paper is to investigate the economic prospects of biofuels in the transport fuel market in the EU countries up to 2030.[3] The analysis of cost developments is conducted in a dynamic framework till 2030. The most important impact factors on biofuel costs are: feedstock costs, investment costs, fixed and variable O&M costs, distribution and retail costs, as well as policies (subsidies, taxation respectively tax exemption of (bio)fuels).

Therefore the major focus of this paper is economic analysis. However, for a sound appraisal of the future market prospects issues of potentials, land availability, ecological performance and ethical aspects ("food versus fuels") have to be considered as well. Hence, these issues are considered only by referring to the existing literature. A full in-depth analysis of these additional dimensions would go beyond the scope of this paper.

1.3. *Some background on historical biofuels production*

The production of biofuels in the EU is relatively low; the share of biofuels in total transport fuels demand in 2007 was less than 2%.

[2] WEO – World Energy Outlook.
[3] This paper is based on the authors' in-depth contribution to the WEO 2006 of the IEA, (2006) [3] and provides updates for 2010.

Table 2
World biofuels consumption by scenario (Mtoe), [1,3].

	2004	2007	2010 RS	2010 AS	2030 RS	2030 AS or 450 scenario
WEO 2006						
USA	7	–	14.9	16	23	43
Brazil	6	–	8.3	9	20	23
EU	2	–	14.8	16	26	36
World	**16**	–	**41.5**	**49**	**92**	**147**
WEO 2009						
USA	–	15	–	–	44	Ca. 65
Brazil	–	8	–	–	26	Ca. 40
EU	–	8	–	–	26	Ca. 36
World	–	**34**	–	–	**133**	**278**

The bold values are total world biofuels consumption.

With respect to bioethanol, the EU is today the third largest producer in the world after the United States and Brazil, but its production is much lower than in the first two. In 2008 the production of bioethanol in EU-27 amounted to 2.816 million litres (60 PJ). After a rather moderate growth in 2007 (+11% with respect to 2006), European bioethanol production increased considerably in 2008 (+56% compared to 2007).

The total number of bioethanol producing Member States in 2008 was 17. Currently France is the largest bioethanol producer in the EU followed by Germany and Spain, see Fig. 1. All other countries together contribute to only one third.

For the EU 2008 was a record year in terms of imports, which are estimated to have reached almost 1.9 billion litres in 2008, i.e. an increase of 400 million compared to 2007. About 75% of the ethanol came from Brazil only [6].

Fig. 2 shows the evolution of bioethanol production over the past seven years in the ten major producing countries in the EU.

Almost all European countries have started biodiesel production. Currently the largest biodiesel producer in the EU is Germany, followed by France and Italy, see Fig. 3. These three countries alone contribute to about two-third to total production.

Total production of biodiesel in the EU was 7.75 million tonnes (285 PJ) in 2008. This is relatively large quantity compared to total biodiesel production in the world. The largest part of the total biodiesel amount, about 60%, is produced in the European Union. Recent trends in biodiesel production in the EU are shown in Fig. 4.

In addition to indigenous production imports of biofuels have increased in recent years. In 2006 184.000 tonnes of bioethanol (from Brazil by Sweden and the United Kingdom) and 400.000 tonnes of biodiesel (from the United States) were imported by the

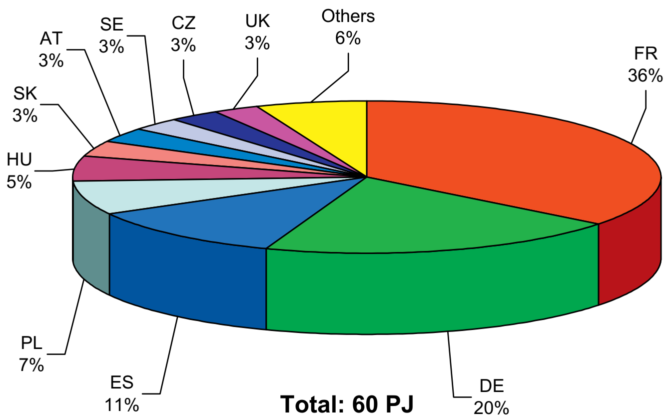

Fig. 1. Bioethanol production in the EU-27, 2008, by country [6].

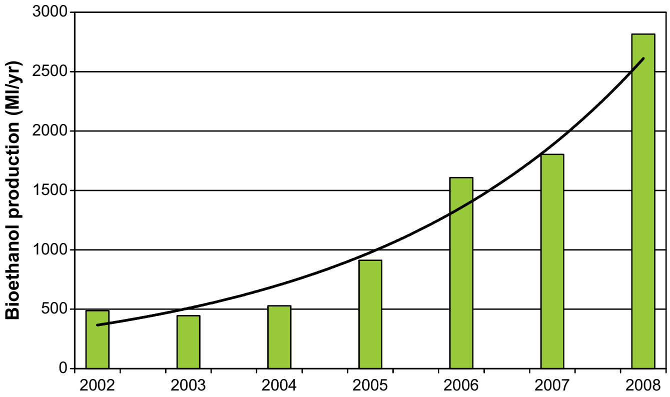

Fig. 2. Recent trends in bioethanol production in EU-27 [6].

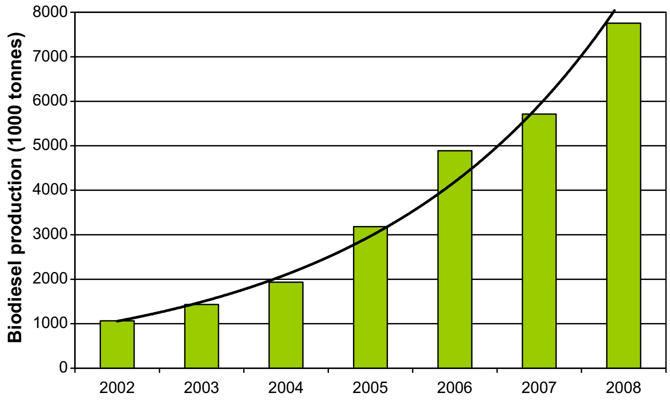

Fig. 4. Recent trends in biodiesel production in EU [6].

EU countries [2,7,8]. Currently the amount of imported biofuels is relatively low comparing to the production of biofuels. In 2008, about 4% of overall consumed biodiesel was imported. The share of imported ethanol in 2008 was about 13 percent of bioethanol production in the European Union [9].

2. Method of approach

The core objective of this paper is to investigate the future economic prospects of biofuels in the EU. The most important impact factors on biofuel costs are: feedstock costs, investment costs, fixed and variable O&M costs, distribution and retail costs as well as policies. The economic analysis in this paper consists of the following major parts:

1. For every year of investigation the specific costs of biofuels are calculated;
2. Over time we consider learning effects for technologies which will bring down the capital costs in the future.

We consider the following components to calculate the costs of biofuels (BF), see also [10]:

- Net feedstock costs (FC)
- Gross conversion costs (GCC)
- Distribution and retail costs (DC)
- Subsidies for biofuels (Sub_{BF})

Net feedstock costs are calculated for every year as:

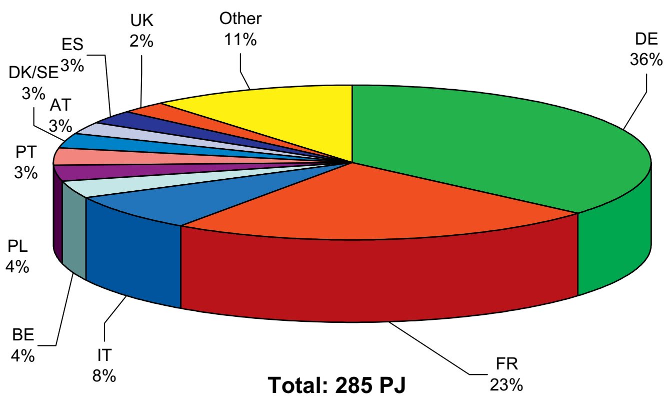

Fig. 3. Biodiesel production in the EU-27, 2008, by country [6].

$$FC = FP \times FQ \times f_{TC} - R_{FS\_by-product} \quad [EUR/ton\ BF] \tag{1}$$

where: FP – Feedstock market price [EUR/ton FS]; FQ – Feedstock quantity used per ton biofuels [ton FS/ton BF]; $R_{FS\_by\text{-}product}$ – Revenues for feedstock-by-product (e.g. rapeseed-cake) [EUR/ton BF]; f_{TC} – Factor for considering feedstock transaction costs

Gross conversion costs for converting feedstock into biofuel are calculated as:

$$GCC = CC + LC + EC + MC - R_{BF\_by-product} \quad [EUR/ton\ BF] \tag{2}$$

where: CC – Capital costs; LC – Labour costs; EC – Chemicals, energy, water costs; MC – Costs for maintenance and insurance; $R_{BF\_by\text{-}product}$ – Revenues from biofuel production by-products (e.g. glycerine or DDGS)

Capital costs depend on specific investment costs (IC) and capital recovery factor (CRF). Specific investment costs are calculated as a sum of national (IC_{Nat}) and international (IC_{Int}) investments costs. It is assumed that 60% of the investment costs are same in all regions and 40% of investment costs (NC) are dependent on countries' or regions' specific circumstance.

$$CC = IC \times CRF = (IC_{Int} + IC_{Nat}) \times CRF \tag{3}$$

Finally total biofuel production costs (BFC) for every year are calculated as follows[4]:

$$BFC = FC + GCC + DC - Sub_{BF} \quad [EUR/ton\ BF] \tag{4}$$

Future biofuel production costs will be reduced through technological learning. Technological learning is illustrated for many technologies by so-called experience or learning curves. The usual formula to express an experience curve is using an exponential regression:

$$IC_t(x) = a \cdot x_t^{-b} \tag{5}$$

where: $IC_t(x)$ – Specific investment cost; x_t – Cumulative capacity produced up to year t; b – Learning index; a – Specific investment cost of the first unit.

The learning index b defines the effectiveness with which the learning process takes place. It constitutes one of the key parameters in the expression above. For the part of national costs the calculation has been done with the learning rate of 15% and for international costs with the learning rate of 20%.

[4] Note, that in these analyses no explicit carbon costs are included.

This learning approach is applied to the specific investment costs and the costs of feedstock production.

3. Results

3.1. The impact of feedstock

Currently preferred feedstocks for biofuels production in Europe are wheat, rapeseed oil, corn, barley, soybean oil, rye and sunflower oil. Depending on climatic factors different feedstocks are used in different regions. The shares of different feedstocks in bioethanol and biodiesel production in the EU in 2008 are shown in Figs. 5 and 6.

Biodiesel production in the EU is based on rapeseed oil, Fig. 5. Only about 3% of biodiesel in the EU is produced from sunflower oil and 18% from soybean oil.

In the EU-27 wheat is the major feedstock for bioethanol production, Fig. 6. In 2008 70% of total European bioethanol production was based on wheat. On the second place is barley, followed by corn and rye.

The fact is that all these feedstocks are used in food production. With the growing demand for these feedstocks, due to increasing biofuels production, food prices could increase and food supply especially in emerging and developing countries could be disturbed. In order to produce these feedstocks arable land is required, which is very limited in regions with high population density such as Europe. For a more in-depth discussion of the "fuel versus food" issue see Ajanovic et al., 2010 [11].

The largest fraction of biofuel costs is feedstock costs and these are largely dependent on prices on agricultural markets. The main raw material for bioethanol production in Brazil is sugar cane, in the United States corn and in Europe wheat and barley.

Feedstock costs are different by the type of crop used, harvesting technologies, and agricultural subsidies for crops and regions and were in general very volatile in recent years. The development of feedstock prices (in figures of 2008) for the period from 1996 to 2009 is shown in Fig. 7.

Two major features can be identified in Fig. 7: (i) there was a huge volatility: highest prices were more than three times higher then lowest; (ii) overall, prices were virtually the same as at the beginning and the end of the period!

As shown in Fig. 7, feedstock prices are very volatile and in some cases significantly different by countries even within Europe, see Fig. 8. This has, of course, impact on the total costs of biofuels, as well as on the economic attractiveness of biofuels for different countries.

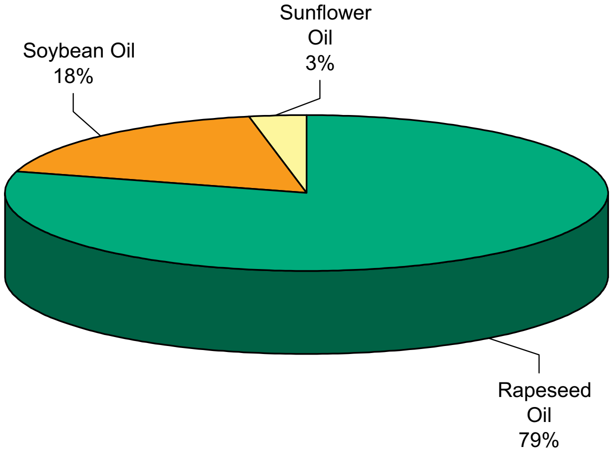

Fig. 5. EU-25: Feedstock use in biodiesel production in 2008 [9].

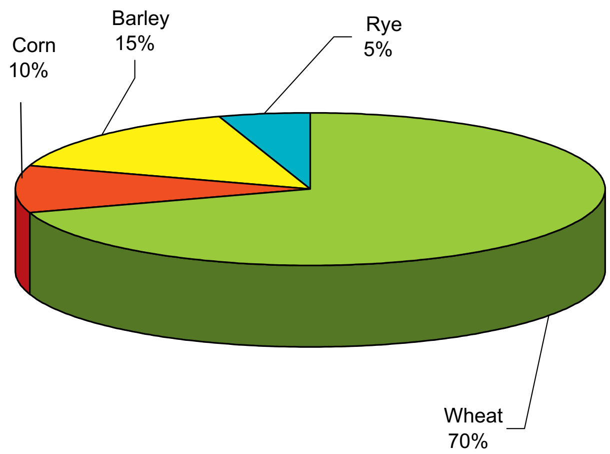

Fig. 6. EU-25: Feedstock use in bioethanol production in 2008 [9].

The feedstock producer prices are not only volatile over time. They also vary by region and country. In Fig. 8 producer prices for rapeseed, wheat, maize and sunflower seed in selected European countries are illustrated in comparison to corresponding yields. Across the European countries the agricultural yield of feedstocks is – with the exception of maize – very different, see Fig. 8. For example, yield of wheat in Spain is two times lower than in Germany. On the other hand rapeseed yield in Germany is much higher than in Italy and Spain. It can be stated that for the analysed feedstocks there is no clear correlation between producer prices and yields.

3.2. Costs of biofuels and economic assessment

European bioethanol production is more expensive then production in Brazil and the United States. Reasons for this are significantly higher feedstock and energy costs in Europe.

With respect to the competitiveness of biofuels in the market two features are of major relevance: First how they perform in comparison to fossil fuels and second how the feedstock prices which are the most uncertain and volatile impact parameter development.

Figs. 9 and 10 compare these two features for the past decade.

Depending on feedstock prices and policy framework biofuels could be more or less competitive with petroleum fuels. In Fig. 9 biodiesel costs (including 20% tax) are shown, as well as fossil

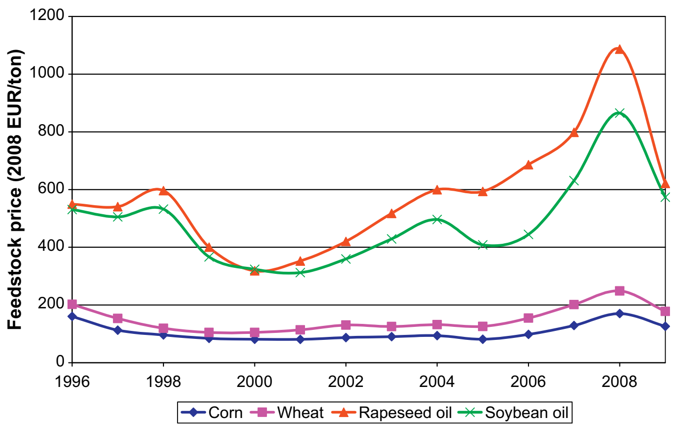

Fig. 7. Feedstock price development over the period 1996–2009 [9,12] (in prices of 2008).

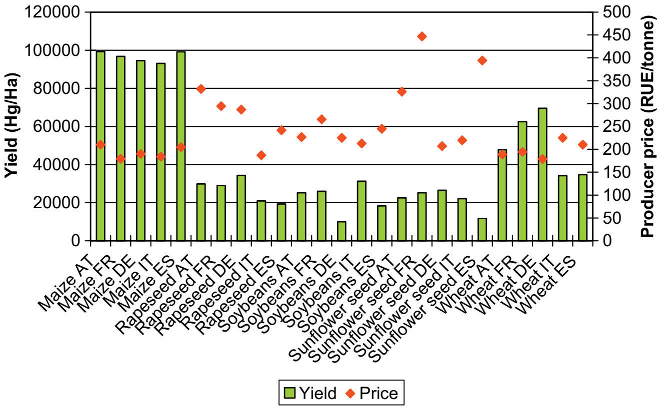

Fig. 8. Feedstock prices versus yields in selected European countries 2007 [13].

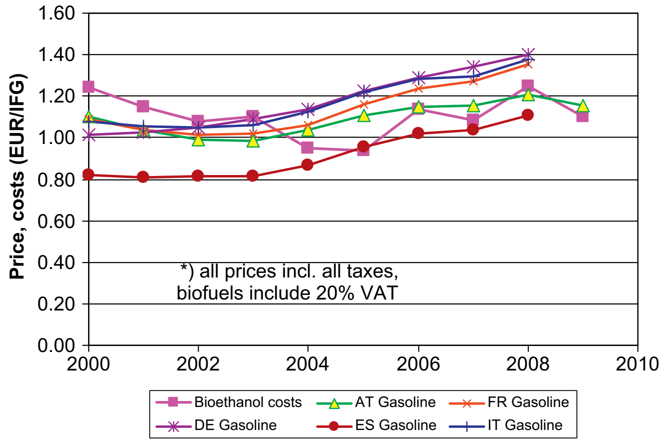

Fig. 10. Average costs of bioethanol in Central Europe versus price of premium unleaded gasoline (FG)-in prices of 2008. (Source for gasoline prices: [14]).

fuels prices in selected European countries (Austria, Germany, France, Spain and Italy) for the period 2001–2008. Feedstock used for biodiesel production in one case is rapeseed oil and in the other soybean oil.

A similar analysis for bioethanol from wheat and maize is presented in Fig. 10.

Three major features can be identified from these figures:

(i) Due to oil price volatility and volatility of feedstock prices economic competitiveness of biofuels can change year by year;
(ii) In the last few years, under current policy conditions, biofuels in some of the selected European countries were already economically competitive on the market;
(iii) Feedstock prices are volatile, and this volatility has an impact on biofuels prices, but only in the range ±15 percent.

For the future development of feedstock prices the following reflections are important: On the one hand, there is still some technological learning potential for feedstock production in the magnitude of about 10% in total up to 2030 due to e.g. better harvesting and growing technologies and better transport efficiencies. On the other hand, there is an increase in marginal costs to be expected due to the switch to areas with lower yields if more 1st generation biofuels should be produced. This can be seen in Fig. 11. In total these two effects will lead in the optimistic scenario to constant marginal costs of feedstock production over time – and straightforward constant feedstock prices.

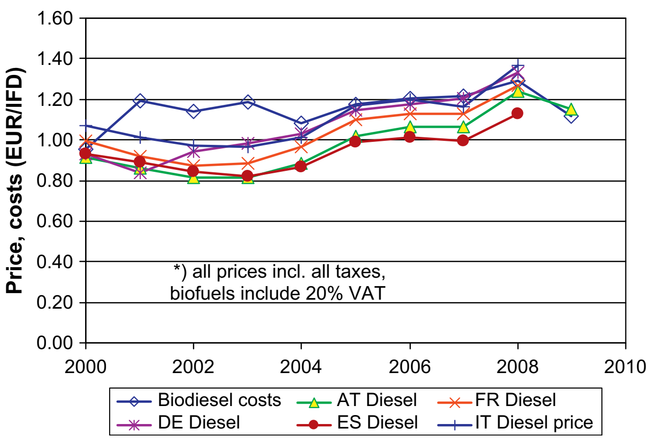

Fig. 9. Average costs of biodiesel in Central Europe versus price of diesel (FD) for households -in prices of 2008. (Source for diesel prices: [14]).

With respect to development up to 2030 a decrease in capital costs will take place mainly due to technological learning. Technological learning of biofuels production does not only take place in Europe but to a large extent in other areas as well. We consider the existence of both a national (European) and an international (worldwide) learning component. This especially applies for bioethanol, whereas for biodiesel almost half of the technological learning is due to capacity increases in Europe. The overall effects can be seen in Figs. 12 and 13. Finally, the total ranges for cost reduction are rather small.

For the feedstock prices used in Figs. 12 and 13 for 2010 the average of the last years has been taken: 220 EUR per tonne rapeseed[5] and 130 EUR per tonne maize for 1st generation biofuels production.

The investment costs used are: 620 EUR per tonne biodiesel capacity and 550 EUR per tonne bioethanol capacity (of 2008). These figures coincide with those reported in the literature e.g. see [15–17]. For all other cost categories the numbers are also compiled from these databases.

The share of credits for by-product (i.e. the sales value of rapeseed-cakes, electricity, glycerine, animal feeds etc.) in total biofuels costs is very low, about 2–5%. In our calculations it is estimated that up to 2030 credits for by-products will not change significantly. In the future this share could be even lower due to oversupply. For example, the demand for glycerine is limited for a number of food, beverage, personal care and oral products, as well as pharmaceutical and other industrial uses [18]. With the increasing biodiesel production it will be necessary to create additional markets for the glycerine. According to the researchers at the Rice University the waste glycerine could be used for ethanol production [19].

Yet, the way in which by-products are used has a significant impact on overall greenhouse gas emissions, see Chapter 3.5.

The production costs for biodiesel are also dependent on feedstock prices. The share of feedstock costs in total biodiesel production costs in the European Union is about 76%.

The cost structure of the biodiesel costs in the Reference and Alternative Scenarios for the EU is shown in Fig. 12. Until 2030 biodiesel costs could be slightly lower comparing to the current ones.

[5] Note, that here we refer to rapeseed while in Fig. 10 the prices are for rapeseed oil. Also our investment costs include all steps of the conversion process including oil mills.

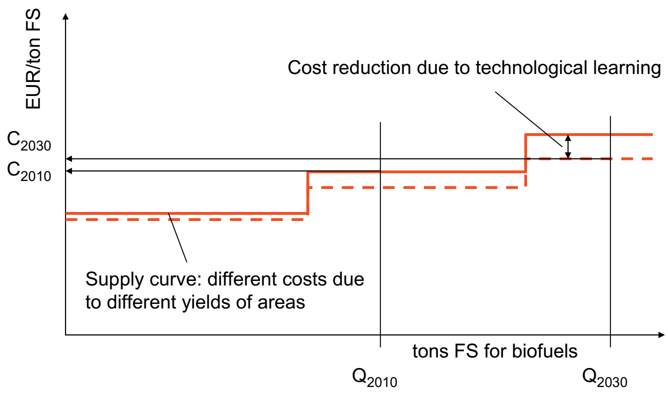

Fig. 11. Change in feedstock (FS) prices for biofuel production due to technological learning and higher marginal costs due to switch to areas with lower yields.

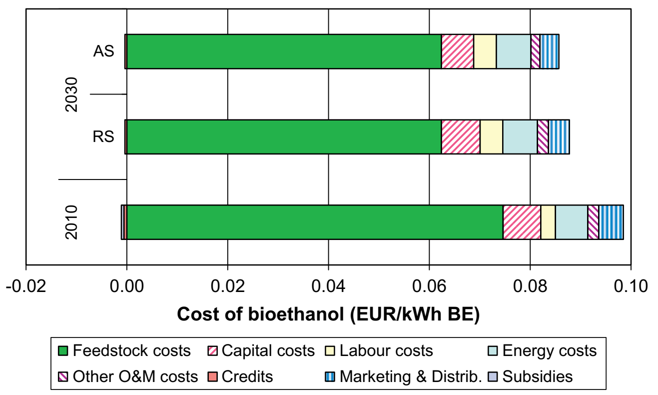

Fig. 13. Costs of bioethanol 2010 vs. 2030 (in prices of 2008).

The feedstock costs are also the largest part of the bioethanol production costs. In the European Union the share of feedstock costs in total bioethanol costs is about 77%, see Fig. 13. This part is higher or lower in different regions depending on land availability, energy crop yield and agricultural subsidies. The rest are capital costs, labour costs and other operating- and energy costs.

In the future, through technical improvements and optimisation, bioethanol cost will continue to decline. In 2030 bioethanol production costs in Europe are expected to be about 15% percent lower than now – mainly due to technological learning and scale-effects of production, but Brazil will remain the cheapest bioethanol producer.

Summing up, for the 1st generation biofuels it can be stated that in the most favourable scenario by 2030 they will be – in 2008 prices – slightly cheaper than today. Yet, this will only occur if the additional areas used for biofuels production don't have yields lower than 10% comparing to currently used areas, see Fig. 11.

With respect to development of the costs of the 2nd generation biofuels the optimistic expectations prevailing for the past five years has been reduced to some extent. As e.g. reported by Trechow [20] neither the expected magnitude of investments in biorefineries for BTL in Europe nor the promised technological progress took place since 2005. Moreover, the following reflections are important:

1. Currently only rough estimates are possible for the actual production costs. Reported investment costs of the 2nd generation production plants vary strongly and are, of course, available only from pilot projects. From practical figures it is not always clear whether and to what extent they are influenced by subsidies and R&D money. Furthermore, no reliable figures for the actual conversion efficiency (tons feedstocks required per ton of biofuel) are available.
2. In our most optimistic scenario the 2nd generation biofuels could become slightly cheaper than the 1st generation biofuels and more competitive with conventional fuels sometime between 2020 and 2025. Fig. 14 documents the possible range of scenarios for development of biofuel costs up to 2030 in a stylised way.
3. Currently it is not possible to conduct a serious prediction about the realistic cost differences and cost levels in 2030. From today's point of view it can only be stated that the costs of 2nd generation biofuels will in a favourable case be close to the costs of 1st generation biofuels, while in a less favourable one they will remain significantly higher, see Fig. 14 [6]. This is also in coincidence with other analyses, e.g. [21–23].

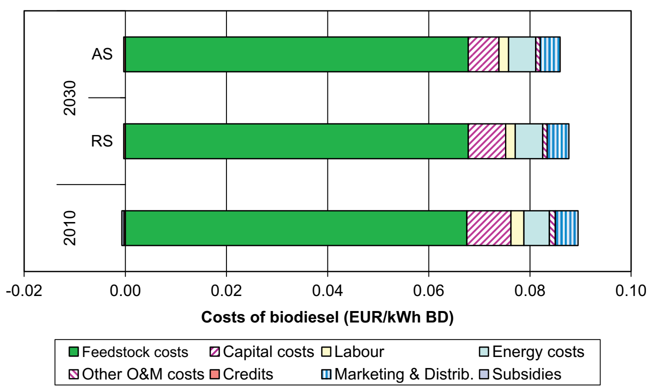

Fig. 12. Costs of biodiesel (BD) 2010 vs. 2030 (in prices of 2008).

It can be stated that by 2030 neither 1st nor 2nd generation biofuels costs will be significantly below today's production cost level of the 1st generation biofuels.

However, this does not necessarily represent a major barrier for becoming competitive in the market compared to fossil fuels. These prices are slightly increasing in all international scenarios. Even moderate increases of gasoline and diesel prices will make the 1st generation biofuels competitive already in the next few years.

The major problems for the 1st generation biofuels are lack of available feedstocks and the modest ecological performance, see Figs. 17 and 18.

3.2.1. *Error analysis*

For the error analysis we have investigated the sensitivity of the impact parameters as follows:

(i) Feedstock prices remain rather constant in our scenario until 2030. This is a very stable trend based on two effects: On the one hand about 10% cost reduction due to technological learning for growing, producing fertilizer and harvesting is achieved. On the other hand a marginal yield reduction – additional areas used as e.g. current fallow land have lower yields – of about 10% leads to corresponding marginal cost increases. Hence, if no additional areas would be used and straightforward production would remain by and large

[6] Note that no explicit carbon costs have been included in these analyses.

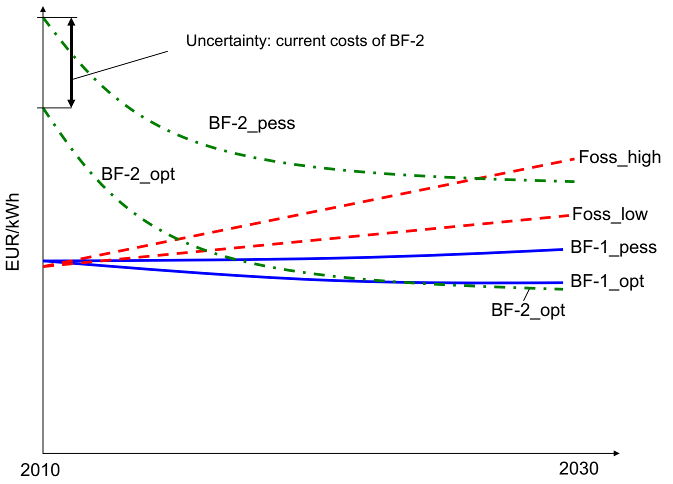

Fig. 14. Possible range/scenarios for development of 1st (BF-1) and 2nd (BF-2) generation biofuels costs up to 2030.

constant no significant learning would take place and prices also remain rather constant.

(ii) For investment cost development we have assumed a production increase as indicated in the (alternative) 450 scenario in the WEO of the IEA (see Table 2 and [14]) and a learning rate of 22%.

For first generation biodiesel this leads to 30% cost reduction for capital costs in 2030 compared to today. If we would assume deployment as of reference scenario overall cost reduction of capital costs would be 15% by 2030.

For first generation bioethanol cost reduction of capital costs in 2030 is 43% compared to today. If we would assume deployment as of reference scenario overall cost reduction would be 30%.

(iii) All other cost categories do not play a significant role given the assumption that electricity, as well as fuels for transport, are also based on (own-generation from) biofuels and not on purchase of fossil fuels from the retail market.

3.3. Support systems for biofuels

To make biofuels competitive with conventional fuels different public support measures, such as import tariffs, fuel excise tax exemption, subsidies, mandates and targets are needed. To support the domestic bioethanol industry many countries apply tariffs to imported biofuels. All EU member states provide concessions or fuel excise tax exemptions for biodiesel, as well as for bioethanol with the exemptions of the Czech Republic, Finland, Greece, Italy and Luxemburg. Production subsidies for biofuel production are currently provided only in Latvia and the Czech Republic, [24].

The attractiveness of biofuels is also very dependent on national policies for transport. In most European countries biofuels are almost fully exempted from fossil fuel taxes. Moreover, across Europe fossil fuel taxes are very different, see Table 3. The EU minimum rate for unleaded petrol is 0.36 EUR per litre, and maximum is 0.70 EUR per litre. Minimum rate for diesel is 0.30 EUR per litre and maximum 0.66 EUR per litre. Share of tax in total fuel price is higher than 50 percent in most of the countries. Due to these differences fossil fuel prices are vary significantly in the EU.

To make biofuels more attractive different support policy measures are implemented by the European Commission, such as border protection, output payments, aid to energy crops and other

Table 3
Excise duties on fuels in €/1000 L [25].

Country	Unleaded petrol	Diesel
Austria	442	347
Belgium	592	318
Bulgaria	350	307
Cyprus	299	245
Czech Republic	483	406
Germany	655	470
Denmark	561	382
Estonia	359	330
Spain	360	330
Finland	627	364
France	607	428
Greece	359	302
Hungary	448	368
Ireland	509	368
Italy	564	423
Lithuania	434	330
Luxembourg	462	302
Latvia	379	330
Malta	459	352
The Netherlands	701	413
Poland	488	339
Portugal	583	364
Romania	336	284
Sweden	568	446
Slovenia	403	383
Slovakia	515	481
United Kingdom	661	661

agricultural policies affecting the supply and price of biomass feedstocks, support for research and development, and various regional and rural development initiatives. Two main policy instruments that provide support to market prices for biofuels in the EU are border protection, mainly through tariffs, and mandatory biofuel blending or content requirements.

The rate of the EU border protection varies significantly depending on the type of biofuel imported. High tariff barriers (0.102 EUR/litre or 0.192 EUR/litre, depending on whether it is denatured) protect the European ethanol market against imports from third countries, particularly Brazil. Tariffs on bioethanol are relatively high: € 19.2 per hectolitre and € 10.2 per hectolitre (or 63 percent and 39 percent ad valorem equivalent in 2004–2005). Tariff on biodiesel imports is only 6.5 percent ad valorem equivalent in 2004–2005 and tariffs on pure vegetable oils for the production of biodiesel range from 0 to 3.2 percent [2].

In 2006 184.000 tonnes bioethanol were imported in the EU (from Brazil by Sweden and the United Kingdom) and 400.000 tonnes of biodiesel (from the United States) [2,7,8].

3.4. Biomass potentials and land requirements for biofuels production

In 2006 about 14 million hectares of land (about 1% of the world's available arable land) have been used for the production of biofuels and by-products. Given that about 2% of global transportation fuels are currently derived from biomass, increasing the share to 100% is clearly impossible unless fuel demand is reduced, land productivity dramatically increased, large areas of pasture converted to arable land or production is shifted from conventional sources of biomass to new ones, such as crop residues or trees and grasses that can be grown on non-arable land. The large-scale use of biofuels will probably not be possible unless second-generation technologies based on lignocellulosic biomass that requires less arable land can be developed commercially [3] (Fig. 15).

Total land area in the EU could be divided in five groups: arable land (13%), permanent crop (1%), permanent meadows and pastures (8%), forest area (45%) and other land (33%), see Fig. 8.

The conventional biofuels are based on the feedstocks grown on arable land, which is very limited in Europe, 277 million hectares. However, when it comes to the second-generation of biofuels, other land areas such as meadows, pastures and forest area could also be used for biofuels production, so that total land potential for biofuels production could be significantly higher.

According to the IEA, biomass potential from all sources could be between 1000 and 26 200 Mtoe in 2050. The share of the world's arable land used to grow biomass for biofuels is projected to rise from 1% at present to 2.5% in 2030 in the Reference Scenario (share of biofuels in transport demand is 3%) and 3.8% in the Alternative Policy Scenario (share of biofuels in transport demand is 5%), based on the assumption that biofuels are derived solely from conventional crops [3], see Fig. 16.

In case that the 2nd generation biofuels are widely in use before 2030, required amount of arable land could be much lower due to the higher efficiency of this technology and use of feedstocks from other areas such as forest area, pasture land, meadows etc. It has to be stated that it is the major advantage associated with the use of the 2nd generation biofuels.

The future land requirements for biofuels production in the EU in Reference Scenario (RS) and Alternative Policy Scenario (AS), as well as in Second-Generation Biofuels Scenario (SG) are shown in Fig. 16 [3]. The share of biofuels in transport demand in the 2nd generation scenario is 10% by 2030. In the WEO 2009 [1] total figures for 2030 are virtually the same as in WEO 2006 [3] and so are the required areas.

Due to population growth, limited land and water resources, the security of food supply is a major concern, especially in developing countries. With the increasing biofuels production this problem is becoming more severe. Since second-generation biofuels are based on lignocellulosic feedstocks, such as woody and herbaceous plants, as well as waste materials from agriculture and forestry they could relive this problem significantly.

Moreover, land conversion for biofuels production could imperil biodiversity and even result in increasing greenhouse gas emissions due to carbon losses from soils and vegetation. Conversion of annual crop land into perennial lignocellulosic energy feedstock plantations needs careful consideration from agronomic and economic point of view. In Europe the use of arable land for lignocellulosic feedstocks will involve modifying current regulations and policies at the national level and in the Common Agricultural Policy [24].

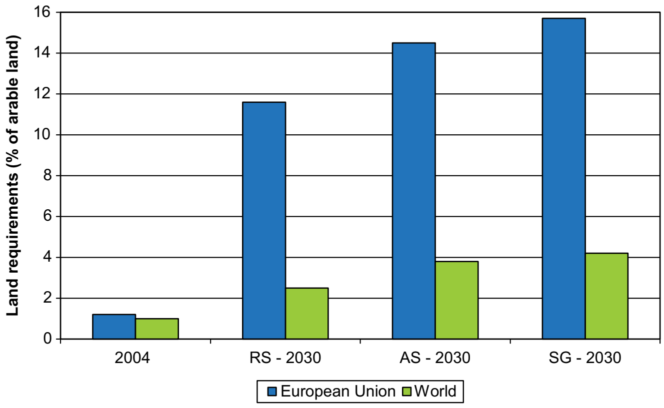

Fig. 16. Land requirements for biofuels production [3].

Biofuels have to be produced in ways which do not damage the environment or create social conflict. Therefore, it would be unacceptable to clear rainforest to grow feedstock for biofuels or to endanger food supply security. It is essential that future biofuels use is sustainable from environmental, social and economic point of view [26].

3.5. Ecological dimension

A major reason for using biofuels is its potential to reduce greenhouse gas emissions in transport sector. Starting from very high expectations to achieve this goal by means of using energy from biofuels, currently it can be noticed that with the increasing biofuels production some new problems, such as water pollution from fertilizers and pesticides, soil erosion, competition between food and fuel production, may be provoked.

So to ensure the benefit from biofuels agronomic, environmental, economic and social evaluation of the complete cycle including up-front land use changes, and global and regional impacts must be included [27].

In principle no biofuel is fully carbon-neutral. The total Well-to-Wheels GHG emissions for some bioethanol production paths are illustrated in Fig. 17. The range of the GHG emissions is very wide due to the different production technology, different feedstocks and the way of using by-products.

As shown in Fig. 17, conventional bioethanol production in Europe gives reduction of GHG emissions, in the range of 45%–55% of the gasoline's GHG emissions. Higher GHG emission reductions

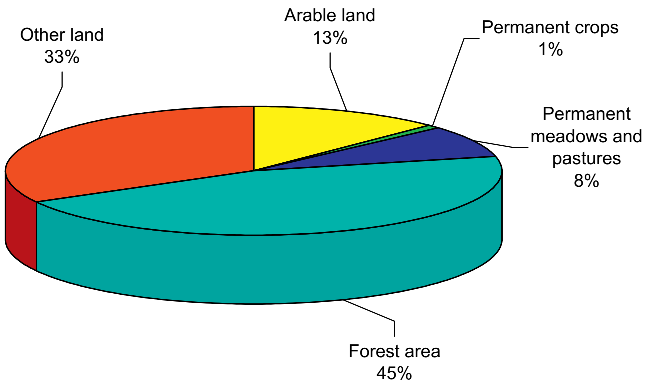

Fig. 15. Land area in Europe [12].

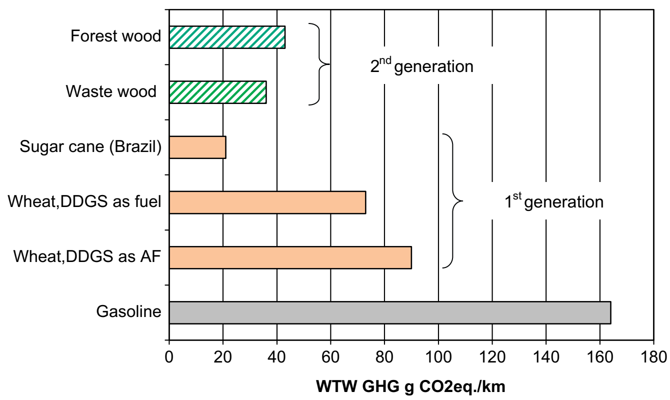

Fig. 17. WTW GHG emissions for bioethanol pathways [28].

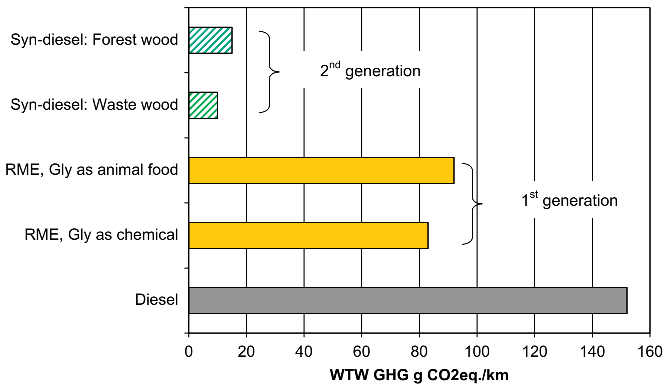

Fig. 18. WTW GHG emissions for biodiesel pathways [28].

could be achieved in case of by-products being used as fuel instead of as animal feed. However, for the 2nd generation biofuels using lignocellulosic material, such as forest or waste wood in advanced processes, GHG emissions could be much lower, mostly because these processes use part of the biomass intake as fuel and therefore involve less input of fossil energy [28].

Comparing to bioethanol biodiesel is a little bit less energy intensive. In Fig. 18 GHG emissions for biodiesel are shown. Again 2nd generation biofuels – in this case synthetic diesel (BTL) – are expected to have a much more favourable GHG emissions balance.

4. Conclusions

The major conclusions of this analysis are:

Currently worldwide, only Brazil is able to produce market competitive bioethanol. In the EU countries biofuel costs are higher than fossil fuels costs. To make biofuels a relevant player in the fuel market this gap is covered mainly by tax exemptions and other policy instruments, like quotas. Under the current policy conditions economic prospects of the 1st generation biofuels in Europe are rather promising already in the next couple of years.

Major problems of the 1st generation biofuels are limited quantity of available feedstocks and modest ecological performance. Biofuels production is very land intensive and, hence, its production capacity is very limited in most of the EU countries. Moreover, despite current production technologies for bioethanol based on starchy and sugar crops, as well as for biodiesel based on oil seeds, which are considered to be relatively mature, there is still a considerable potential for further optimisation and improvements of conversion technology, which has to be tapped as soon as possible.

The largest expectations are currently put into advanced 2nd generation bioethanol and biodiesel production from wood and other lignocellulosic materials. This production technology could enable the use of a wide range of new feedstocks such as waste cellulosic materials, wood residues, whole plants and trees.

Yet, the current costs of 2nd generation biofuels are still rather high, mainly because of the high investment costs and low conversion efficiencies of feedstocks into biofuels.

It can be stated that by 2030 neither 1st nor 2nd generation biofuels costs will be significantly below today's production cost level of the 1st generation biofuels. However, prevailing tax policies and/or continuous increases of fossil fuel prices could make them market competitive.

Finally, we state that biofuels can provide a significant contribution to alleviating today's transport problems especially when accompanied by comprehensive efficiency improvements and continuous development towards 2nd generation biofuels.

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