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On the future prospects and limits of biofuels in Brazil, the US and EU

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HIGHLIGHTS

- Market prospects of biofuels are investigated up to 2030 for Brazil, the US and EU.
- 1st generation biofuels are cost-effective under current tax policies.
- Their potentials are restricted especially due to limited crops areas.
- R&D especially for second generation biofuels has to be intensified.

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ABSTRACT

In the early 2000s high expectations existed regarding the potential contribution of biofuels to the reduction of greenhouse gas emissions and substitution of fossil fuels in transport. In recent years sobering judgments prevailed. The major barriers for a further expansion of biofuels are their high costs (compared to fossil fuels), moderate ecological performances, limited feedstocks for biofuel production and their competition with food production.

The objective of this paper is to investigate the market prospects of biofuels up to the year 2030. It focuses on the three currently most important regions for biofuels production and use: the US, EU and Brazil which in 2010 accounted together for almost three-quarters of global biofuel supply.

Our method of approach is based on a dynamic economic framework considering the major cost components of biofuels and corresponding technological learning with respect to capital costs. Moreover, for the analysis of the competitiveness of biofuels with fossil fuels also taxes are considered.

The most important result is that under existing tax policies biofuels are cost-effective today and also for the next decades in the regions investigated. However, their potentials are restricted especially due to limited crops areas, and their environmental performance is currently rather modest.

The major final conclusions are: (i) To reveal the real future market value of biofuels, a CO_2 based tax system should be implemented for all types of fuels providing a neutral environmental incentive for competition between all types of fossil and renewable fuels; (ii) Moreover, the research and development for all types of biofuels, but especially for second generation biofuels, has to be intensified.

1. Introduction

First attempts with biofuels started in the late 19th century, producing bioethanol from corn and biodiesel from peanut oil. Until the 1940s, biofuels were seen as viable transport fuels, but plummeting fossil fuel prices stopped their further development. Interest in commercial production of biofuels for transport rose again in the mid-1970s, when bioethanol began to be produced from sugarcane in Brazil and since the 1980s from corn in the United States.

Due to supporting policies implemented during the 1990s in North America and Europe, biofuel production increased rapidly [1]. The motivation for increased biofuel production was different by regions, but the core reasons were:

(i) to reduce fossil fuel consumption,
(ii) to increase energy diversity in transport,
(iii) to enhance energy supply security,
(iv) to reduce greenhouse gas (GHG) emissions,
(v) to support farmers.

Usually emissions of biofuels are lower than those of fossil fuels. Biofuels burn cleaner than gasoline or diesel, resulting in fewer GHG emissions. The range of the life-cycle GHG savings associated with

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different types of biofuels is very broad, from about +85% to −30%. GHG savings are mostly dependent on the feedstock used and biofuels conversion methods [2]. According to the Renewable Energy Directive of the EC, in the EU use of biofuels must lead to overall GHG reduction of 35% to qualify it for the 10% biofuels targets by 2020. This level will rise to 50% in 2017 for existing production, and to 60% for new plants from 2017 [3]. However, more ambitious expectations prevail regarding second generation biofuels which have the potential to cut GHG emissions by more than 80% [4].

The usage of biofuels entails various problems such as competition between food and fuel, limited land availability, especially for first generation biofuels and negative environmental impacts. An additional problem is that over the last decades in most of the biofuel-producing regions biofuels have been more expensive than fossil fuels, so that governmental support programs have been and mostly still are necessary to allow biofuels to play a role in the market place. For example, in 2011 in the EU a significant amount of public money (between €9.3 and €10.7 billion) is used to subsidize biofuels. The main subsidy programs supporting the biofuels industry are (i) market price support, (ii) tax exemptions for biofuels and (iii) research and development grants. In 2011, bioethanol was subsidized between 48 and 54 euro-cents per litre and biodiesel between 44 and 51 euro-cents per litre [5].

The advantages and problems of biofuels have been discussed in several scientific papers. Environmental benefits and sustainability issues of biofuels are often discussed in the literature [6–10]. Hammond et al. [11] have investigated carbon and environmental footprinting of global biofuel production. Water footprint of biofuels has been exterminated by Ayres [12]. Land use have been analysed by Wise et al. [13] and Nibliac et al. [14]. The food versus fuel discussion has been conducted by Srinivasan [15], Rathmann et al. [16], and Ajanovic [17].

Political, economic and environmental impacts of biofuels are analysed by Demirbas [10]. Vedenov and Wetzstein [18] have analysed benefits from the current fuel subsidy in the US. Perspectives of biofuels consumption and trade are investigated by Walter et al. [19]. Bioethanol industry, cost reductions and sustainability of Brazilian bioethanol have been analysed by Hira and Oliveira [20], van de Wall Bake et al. [21], and Smeets et al. [22].

In opposite to the majority of the papers which are focusing on biofuels issues related to specific countries [23–27], this paper provides a comparison of different regions. The specific goal is to investigate the market prospects of biofuels in different regions. The focus is put on the currently most important regions for biofuel production and use: the US, EU and Brazil.[1] A core focus in this context is put on the difference in tax and subsidy structures in these regions. Up to our knowledge this aspect has so far not been discussed in this way in any other work.

In this paper, firstly, an evaluation of current biofuel production and related problems is presented. Secondly, applied methodology for the economic analysis is provided. Thirdly, the economic prospects in the investigated regions are discussed. Key conclusions complete this work.

2. Biofuels: current situation

Since the early 2000s interest in biofuels has been growing worldwide. The two most important biofuels nowadays are first generation biodiesel and bioethanol.

Fig. 1 shows total bioethanol production by country or region, from 2007 to 2012. Global production hit a peak in 2010. The United States is the world's largest supplier of bioethanol, having produced over 4450 million tonnes in 2012. Together with Brazil, they provide 87% of the world's bioethanol. The largest part of bioethanol in the US comes from corn, while Brazil's bioethanol is mostly based on sugarcane [29]. Nowadays only 5% of the total bioethanol is produced in Europe.

Total biodiesel production grew almost exponentially from less than 1 million tonne in 2000 to over 16 million tonnes in 2010. However, it is small compared to bioethanol. In 2010, the largest amount of biodiesel was generated in the European Union, 58% (6% in the US, and 13% in Brazil). Progress of the global biodiesel production in the period 2000–2010 is sketched in Fig. 2.

Although production of biofuels is increasing all over the world, the share of biofuels in total road fuel consumption is currently relatively low in almost all countries with the exception of Brazil. In 2009, worldwide the fraction of biofuel in total energy consumption of vehicles was about 3%, see Fig. 3. Brazil and the US together accounted for about three-quarters of the global biofuel supply.

According to the International Energy Agency [31] a significant expansion of the biofuels use in transport is expected in the future. However, the deployment of biofuels have a range of negative effects, such as direct and indirect land use change, loss of biodiversity and eco-systems [32,33], and competition with food production.

In recent years environmental footprints have been widely used as a partial measure of the extent to which an activity (in this case biofuel production) is sustainable, and carbon footprints are used as a measure of carbon emissions associated with such activities [11].

The popularity of footprint analysis has grown in the EU and US over the last few years. The environmental footprint analysis done by Hammond et al. [11] involves beside carbon emissions, several components such as bio-productive and built land, embodied energy, materials and waste, transport and water. They have estimated the total environmental footprint for the global production of biofuels to be about 0.7 billion gha for 2010. The largest component of this overall footprint is bio-productive land with about 0.4 billion gha in 2010. The contribution of the waste, built land and embodied energy to the total environmental footprint is almost irrelevant.

3. Method of approach

The methodology applied in this investigation of the market prospects of biofuels builds on the approach used in Ajanovic/Haas [34]. The formal framework is based on a dynamic model in which all relevant cost categories of converting feedstock into biofuels are included. The most important categories of costs are feedstock costs, conversion costs, operating and maintenance (OM) costs as well as distribution and retail costs. Furthermore existing policies for the promotion of biofuels (such as tax exemptions, crops and biofuels subsidies) are considered. The possible future costs reductions are calculated depending on technological learning.

The feedstock costs (C_F) are dependent on feedstock market price (P_F), amount of feedstock used per ton of biofuels (Q_F), revenues from feedstock by-products (R_{FS_BP}) as well as a factor for transaction costs (f_{TC}):

$$C_F = P_F \cdot Q_F \cdot f_{TC} - R_{FS\_BP} \quad [€/\text{ton biofuel}] \tag{1}$$

The overall costs (C_{GC}) for transforming feedstock into biofuels depend on capital costs (C_C), labor costs (C_L), costs for different material and energy inputs (C_I), operating and maintenance costs ($C_{O\&M}$) and revenues from biofuel by-products (R_{BF_BP}). These costs are calculated as:

$$C_{GC} = C_c + C_L + C_I + C_{O\&M} - R_{BF\_BP} \quad [€/\text{ton biofuel}] \tag{2}$$

The annual capital costs are dependent on specific investment costs (IC), depreciation time and interest rate. These specific investment costs are divided in two parts: an international part

[1] This analysis builds on Ajanovic and Haas [28].

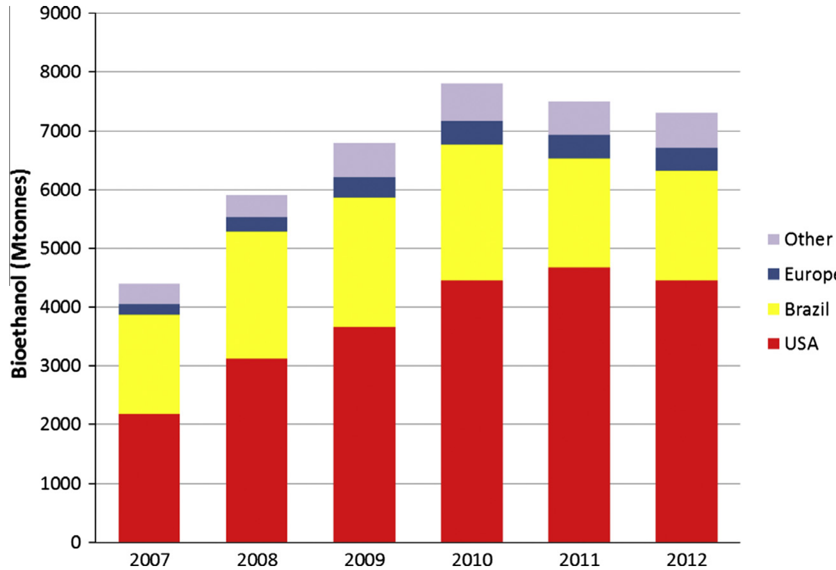

Fig. 1. Production of first generation bioethanol worldwide over the period 2007–2012 [29].

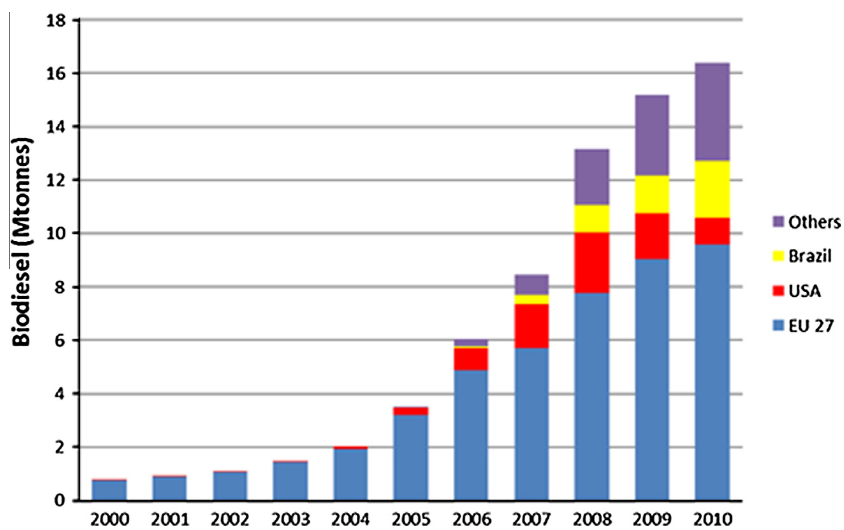

Fig. 2. Production of first generation biodiesel worldwide over the period 2000–2010 [30].

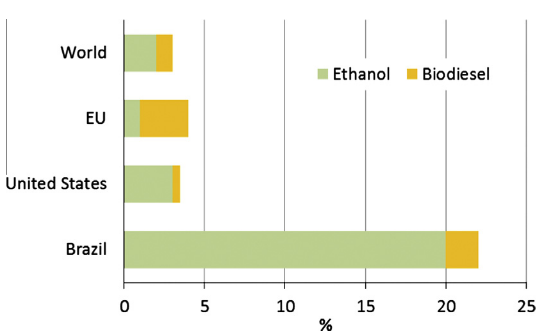

Fig. 3. Fraction of first generation biofuels in total energy consumption of vehicles in major regions, 2009 [31].

of 60% and national part of 40%. Hence, 60% of the specific investment costs are influenced from worldwide development and the rest of the investment costs are dependent on countries' or regions' specific conditions.

$$C_c = \frac{IC \cdot CRF}{P \cdot T} = \frac{(IC_{nat} + IC_{int}) \cdot CRF}{P \cdot T} \quad [€/\text{ton biofuel}] \tag{3}$$

where CRF is the capital recovery factor, P is capacity of the biofuel plant, and T are full load hours per year.

The specific biofuel production costs (C_{BF}) are[2]:

$$C_{BF} = C_F + C_{GC} + C_D - Sub_{BF} \quad [€/\text{ton biofuel}] \tag{4}$$

where C_D are distribution costs, and Sub_{BF} are subsidies for biofuels.

For the calculation of future biofuels costs a technological learning approach is applied to the specific investment costs as well as on feedstock production costs. This approach plays a major role for the dynamic of economics. Future production costs of biofuels could be reduced through technological learning. Technological learning is modelled by learning curves. We apply technological learning in the following way:

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

Usually every technology has some conventional technology components ($IC_{Con\_t}(x)$) and same new and innovative technology components ($IC_{New\_t}(x)$).

$$IC_t(x) = IC_{Con\_t}(x) + IC_{New\_t}(x) \tag{5}$$

For conventional mature technology components no more technological learning is expected. In the case of new technology components a national and international learning effects are considered:

$$IC_{New\_t}(x) = IC_{New\_t}(x_{nat\_t}) + IC_{New\_t}(x_{int\_t}) \tag{6}$$

where $IC_{New\_t}(x_{nat\_t})$ is specific national part of new technology components, and $IC_{New\_t}(x_{int\_t})$ is specific international part of new technology components. For both components of $IC_{New\_t}(x)$ we use the following formula to express an experience curve by using an exponential regression:

$$IC_{New\_t(x)} = a \cdot x_t^{-b} \tag{7}$$

where $IC_{New\_t}(x)$ is specific investment cost of new technology components (€/kW), x_t is cumulative capacity up to year t (kW), b is learning index, and a is specific investment cost of the first unit (€/kW). The learning index b is one of the key parameters in the expression above and defines the effectiveness with which the learning process takes place. For the national part of the investment costs the calculation has been done with the learning rate of 15% and for international part of the specific investment costs with the learning rate of 20%.

4. Economic assessment

For a broader use of biofuel it is essential that their total costs are competitive with conventional fossil fuels. However, the economic profitability of biofuels in most of the above-mentioned regions is currently only possible due to government interferences. The only exemption is bioethanol produced from sugarcane in Brazil [1]. According to the International Energy Agency, estimates for global renewable subsidies for biofuels reached $22 billion in 2010. The largest part of these subventions are provided in the form of tax credits for production and premiums over market prices with the goal of covering the higher production costs compared to those of conventional fossil fuels [1].

The economic competitiveness of biofuels differs greatly from region to region. It depends mainly on two important impact parameters: policies and costs. With respect to costs the dominating impact factor is the feedstock price on the market. Economic success also depends on the efficient use of by-products and the availability of markets for them.

The largest share of biofuel costs are expenses for feedstock, which have been very volatile and increased in the last few years, see Fig. 4. Feedstock costs differ according to the type of crop used, agricultural subsidies for crops and regions, harvesting technologies, specific yields per year and speculation on commodity markets. Moreover, feedstock prices may depend also on the development of the crude oil price. A comparison of the development of feedstock prices and crude oil prices for the period October 1998–April 2013 is shown in Fig. 4 in absolute terms. We can see the volatility of all feedstocks as well as the crude oil price, and some signs of correlation.

An even more clear picture of the coincidence in the volatility of crude oil price and feedstock prices can be seen in Fig. 5, where the numbers of the year 2000 are set equal to 1. Especially since 2008 the shapes of development are very similar. This indicates that feedstock prices have a very strong dependence on the crude oil price.

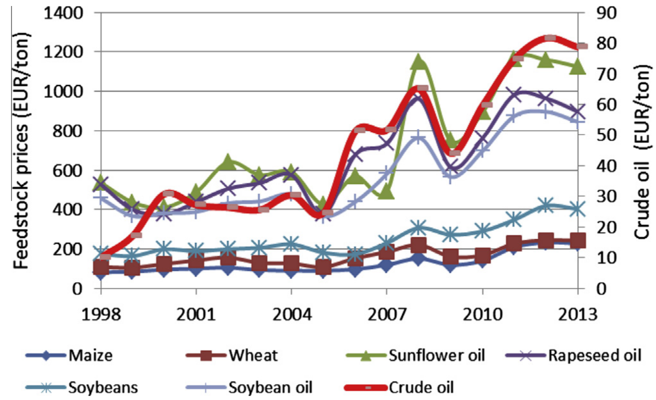

Fig. 4. Development of feedstock and crude oil prices over the period 1998–2013 (current prices, data source: [35]).

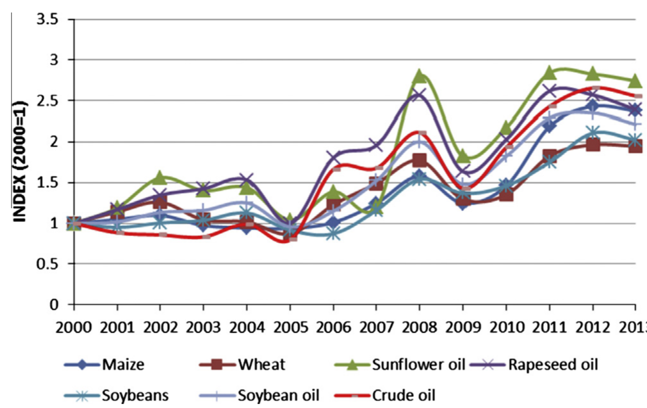

Fig. 5. Normalized development of feedstock and crude oil prices in the period 2000–2013.

With respect to 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 year 2030 due to factors such as better growing and harvesting technologies and increased transport efficiencies, for example. On the other hand, a rise in marginal costs is expected due to a switch to areas with lower yields if more first generation biofuels should be produced. In total these two effects will lead to increasing marginal production costs of feedstock production and consequently feedstock market prices. With respect to capital costs the future expectations are that they decrease further mainly due to larger production scales and technological learning (see [34]).

Fig. 6 depicts a cost comparison for bioethanol (exclusive taxes) for the regions investigated in the year 2010 and 2030 based on the formal framework described in the previous section. As seen there are remarkable differences between regions analysed.[3] The current as well as the expected future production costs are lowest in Brazil; about two times lower than in the EU.

Fig. 7 provides a similar comparison for biodiesel (exclusive taxes). However, in this case differences in production costs in regions analysed are smaller. Similar to bioethanol, also here, production cost of biodiesel are dependent on type of feedstock used (and its price), type of conversion technology and plant size. The current (2010) cost of producing biodiesel in Europe from rapeseed are estimated at about €930 per tonne biodiesel, and in the US

[3] The following analysis builds on [28].

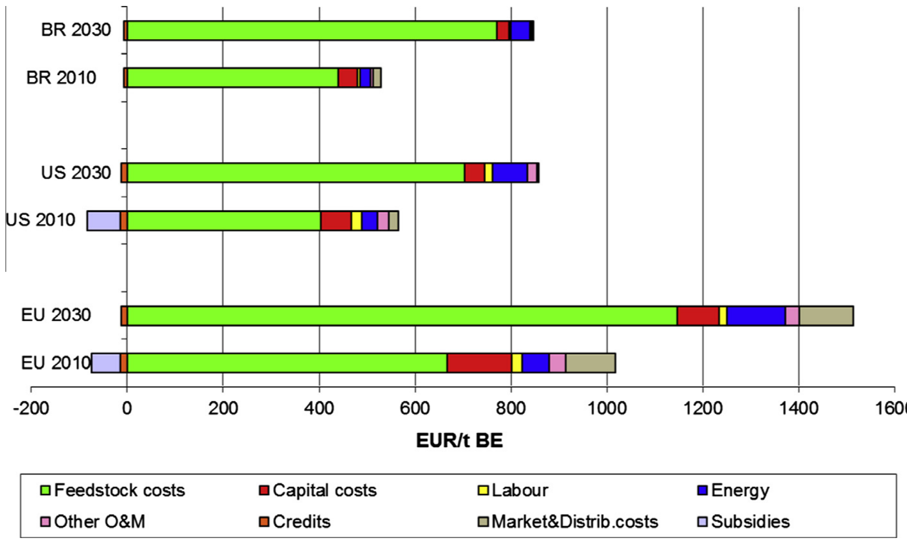

Fig. 6. Structure of average bioethanol production costs in the EU, US and Brazil in 2010 and 2030 (prices of 2010 in EUR per ton bioethanol).

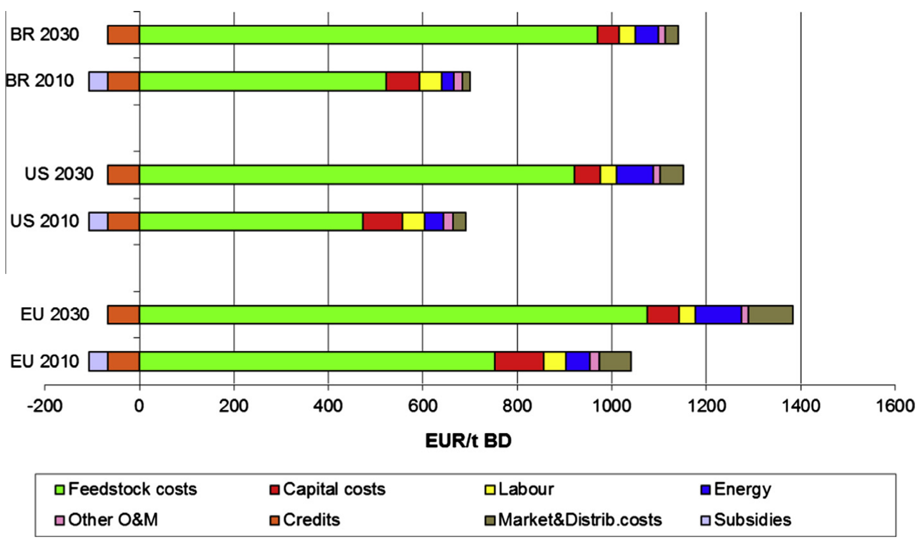

Fig. 7. Structure of average biodiesel production costs in the EU, US and Brazil in 2010 and 2030 (prices of 2010 in EUR per ton biodiesel).

(from soybeans) at about €580 tonne. In Brazil biodiesel costs are slightly higher than in the US, about €590 per tonne. In our scenarios up to the year 2030 production costs are projected to increase to €1300 per tonne of biodiesel in the EU, to about €1080 per tonne in the US and €1070 per tonne in Brazil.

As seen from Figs. 6 and 7 the share of feedstock costs on total biofuel costs is by far the highest compared to other cost components in all investigated regions. Since feedstock prices have been very volatile over time, it is interesting to analyse how a change in feedstock prices affects biofuel prices. Therefore, the impact of the changes in feedstock prices on biofuel costs is analysed in detail in three different regions for 2010. The results of this sensitivity analysis are presented in Figs. 8a and 8b.

A change in feedstock price of ±50% results in an increase/decrease of bioethanol costs between 36% and 42%, see Fig. 8a. The higher magnitude applies to Brazil and the US (where the impact is virtually the same), the lower to the EU. This implies that the impact of capital and other cost components is clearly higher in Europe than in other regions.

Regarding biodiesel it can be noticed that a change in feedstock prices of ±50% results in increases/decreases of biodiesel costs in

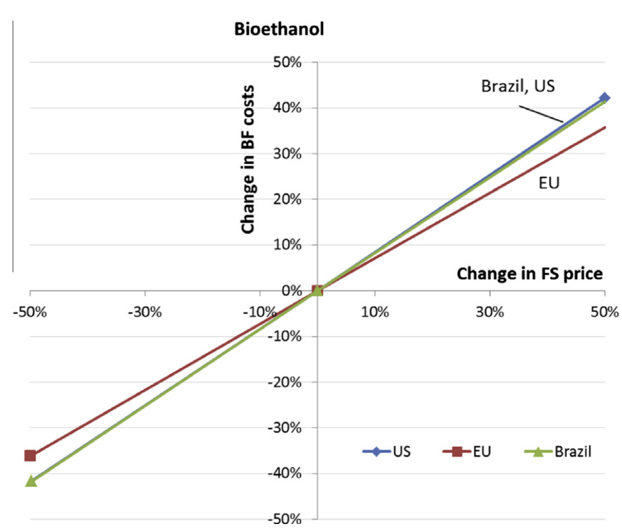

Fig. 8a. Sensitivity of bioethanol costs with respect to feedstock prices in the EU, US and Brazil for conditions of 2010.

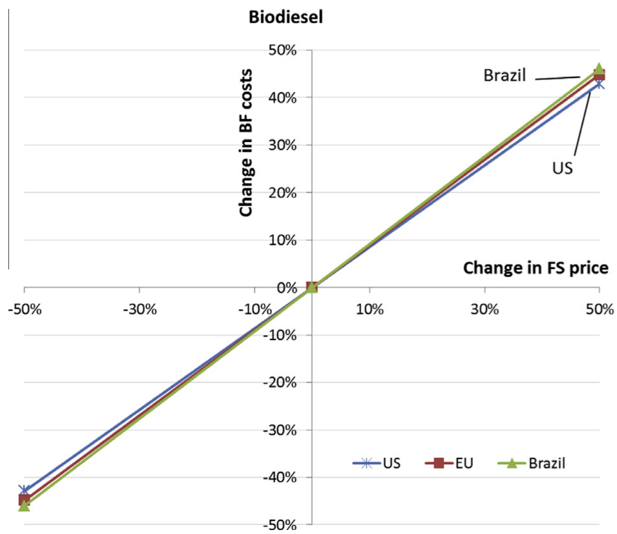

Fig. 8b. Sensitivity of biodiesel costs with respect to feedstock prices in the EU, US and Brazil for conditions of 2010.

range between 43 (US) and 46 (Brazil) percent, Fig. 8b. The EU lies in between.

Comparing bioethanol and biodiesel the finding is that the impact of feedstock prices is slightly higher for biodiesel than for bioethanol. Summing up, the sensitivity analysis conducted in this work has shown that feedstock prices have the by far largest impact on biofuel costs in all regions. Yet, the differences of impact are too small to pick a clear winner in the sense of a recommendation which biofuel to promote specifically and where.

Next, the dynamic developments in recent years and up to 2030 in the regions investigated are analysed. With respect to Europe it is important to mention that despite very high costs of biofuels compared to the US and Brazil, due to favourable tax policies (especially high taxes on fossil fuels), biofuels are already cost-effective compared to gasoline and diesel, (see Fig. 9). The major reason is that biofuels has been exempted from the excise tax which is very high in the EU, about 40–60% of the total fossil fuel price. As seen from Fig. 9 without taxes bioethanol and biodiesel are by far more expensive than fossil fuels.

If we compare the total costs of bioethanol with the end-user price of gasoline in Europe (inclusive taxes) after 2010 we can

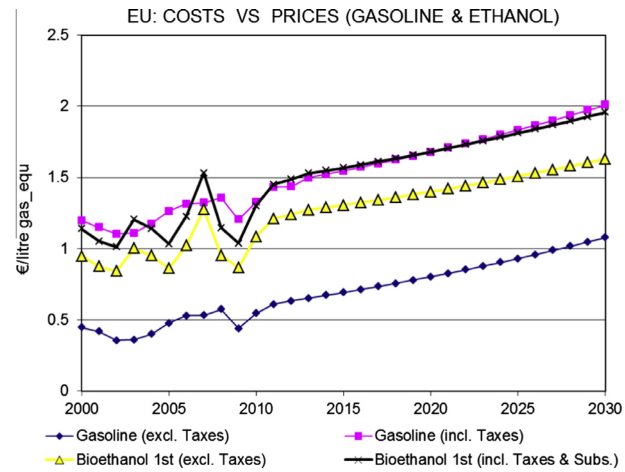

Fig. 9b. EU: Scenarios for development of average gasoline prices and bioethanol costs in period 2000–2030 (in prices of 2010).

see many cross-over points. Bioethanol was in some years, for example in 2005, cheaper than gasoline. The major reason was the high volatility of the feedstock prices. As shown above the feedstock price is by far the largest part of the costs of bioethanol. For gasoline the high excise tax – which is from the magnitude constant and not dependent on the fuel price – has a dampening effect on the overall price volatility. This results in a higher volatility of bioethanol prices than of gasoline. However, the steep increase in feedstock prices recently between 2010 and 2012 has brought the bioethanol costs again very close to the price of gasoline.

For biodiesel the situation is similar. Since about 2005 in the EU biodiesel was in many years cheaper than fossil diesel. In recent years the price increase of rapeseed oil was more moderate than of wheat and maize. The effect is a better economic performance of biodiesel than bioethanol.

Looking at the figures for the US the major finding is at a glance that the price range is much smaller (see Fig. 10). The major reason is that taxes play a less important role in the US than in Europe. The excise tax on fossil fuels is much smaller and on biofuels, virtually no tax exists. Biofuel production in the US is cheaper than in Europe and for bioethanol as well as for biodiesel the production costs (including subsidies) are since about 2005 closer to the prices of

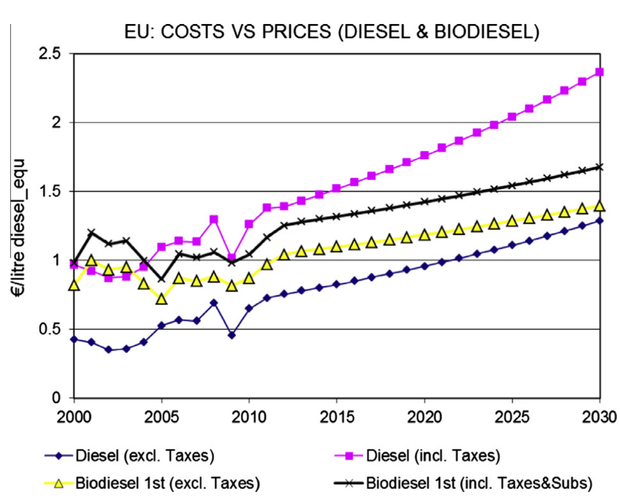

Fig. 9a. EU: Scenarios for development of average diesel prices and biodiesel costs in period 2000–2030 (in prices of 2010).

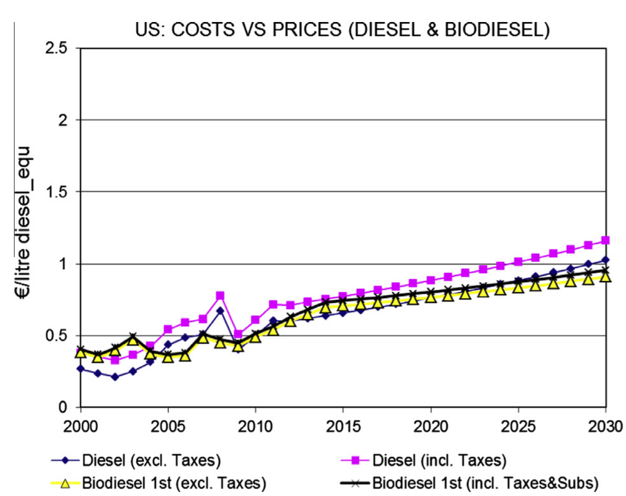

Fig. 10a. US: Scenarios for development of average diesel prices and biodiesel costs in period 2000–2030 (in prices of 2010).

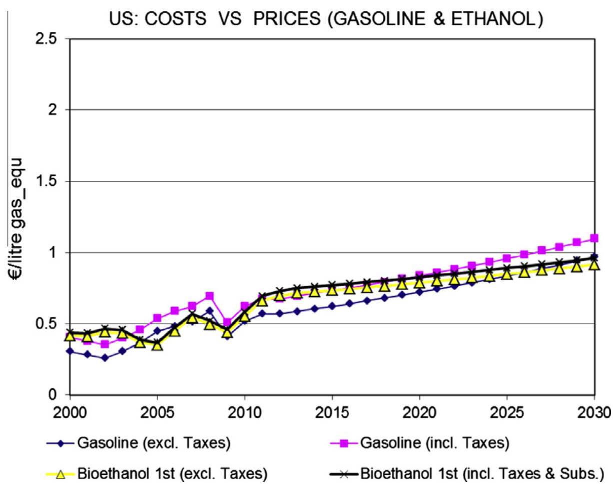

Fig. 10b. US: Scenarios for development of average gasoline prices and bioethanol costs in period 2000–2030 (in prices of 2010).

fossil fuels (without taxes). But, due to the steep increase in maize prices in recent years the bioethanol costs have come close to the price of gasoline.

Brazil has the longest success story with respect to biofuels production, especially bioethanol. Since about 2005 bioethanol is without subsidies cheaper than gasoline, Fig. 11b. Yet, total tax on bioethanol is lower (no excise tax) than on gasoline and without the favourable tax system bioethanol is still more expensive than gasoline, see Fig. 11b. In recent years some shade has been laid over the bioethanol success story in Brazil. Most important is that for wheat and maize in the US and Europe, and in Brazil the price for the most important feedstock, sugarcane, increased significantly from 2010 to 2012. This has led to the situation that bioethanol costs were again close to the price of gasoline.

Regarding biodiesel produced from soybeans in Brazil the feedstock price also plays a dominating role. After 2005 the situation looked bright but in recent years biodiesel is again far away from cost-effective, see Fig. 11a. Without subsidies it will be difficult for biodiesel to survive in the Brazilian market.

With respect to projections the assumed price increase of fossil oil products is 3% per year. For feedstock production the learning rate is higher which leads to a lower yearly price increase of 2%. This is supported by the finding of Fig. 5 which shows a lower increase of feedstock prices than oil prices.

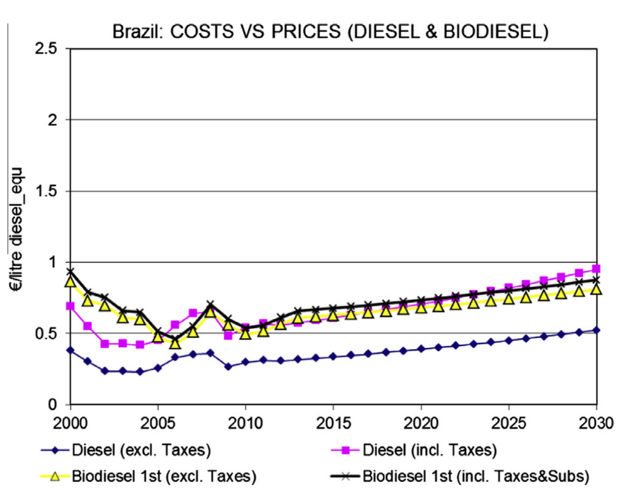

Fig. 11a. Brazil: Scenarios for development of average diesel prices and biodiesel costs in period 2000–2030 (in prices of 2010).

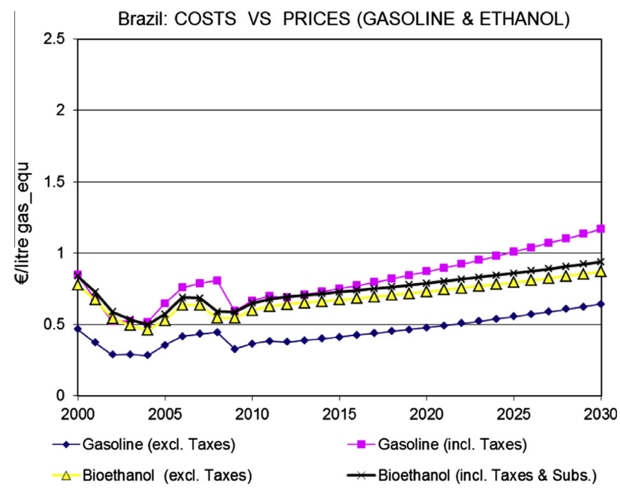

Fig. 11b. Brazil: Scenarios for development of average gasoline prices and bioethanol costs in period 2000–2030 (in prices of 2010).

All in all, currently policies play an important role for the economic competitiveness of biofuels in the countries investigated. Of special interest is the huge difference between the US, and EU. The major point is: Despite significantly lower production costs of biofuels in the US also in Europe biofuels are on the edge of competitiveness mainly due to high excise taxes on fossil fuels, see Figs. 9 and 10.

5. Conclusions

The market prospects of biofuels are different across the regions analysed. Currently, only in Brazil bioethanol production is cost-effective. In the US the market penetration of biofuels was and still is mainly driven by favourable agricultural policies. Among the regions investigated biofuels' costs are highest in Europe. However, under the conditions of 2010 – high fossil fuel taxation (and tax exemption on biofuels) – also in many European countries biofuels are competitive with fossil fuels already today and will be also in the next years.

The major economic impact parameter on biofuel costs is the feedstock price. After 2005 the price level of feedstock as well as of fossil fuels increased remarkably (see Fig. 5). Due to the fact, that especially in Europe and Brazil, taxes on fossil fuels are higher than on biofuels (and excise taxes do not depend on fossil fuel prices), these price increases were more unfavourable for biofuels.

Another major barrier for biofuels is competition with food production. In this context second generation biofuels are of specific interest because they are mainly based on biomass residues and non-arable land areas. However, currently there are no signs that they will become technologically mature and cost-effective in the next decades to fully substitute first generation biofuels before 2030.

The major final conclusion is: to reveal the real future market value of biofuels, in all countries a CO_2-based tax system should be implemented for all types of fuels instead of the current complex system of subsidies and tax exemptions. Such a tax system – widely harmonized on an international level – would also answer the question which type of biofuel to grow preferably and where. A sensitivity analysis conducted in this work has shown that feedstock prices have the by far largest impact on biofuel costs in all countries. Yet, the differences of impact are too small to give clear recommendation which biofuel to produce and where. Yet, a CO_2-based tax system could serve as a major guideline for biomass utilization world-wide. Based on the whole life-cycle emissions a CO_2 tax is a neutral incentive for competition between all types of fossil and renewable fuels. Moreover, regarding biofuels it also provides a motivation to improve their overall CO_2 balance. However, one may argue that introducing a world-wide harmonized tax system is impossible. This is true, but our suggestion is primarily focussing on transport fuels. Within a country it is just necessary to ensure that the fuel taxes account for the differences in CO_2 emissions. Regarding cross-border trade the tax differences between countries can be considered in a first step by import fees. In addition, further research and development related to all types of biofuels, but especially regarding second generation biofuels, has to be intensified.

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