The Impact of First and Second Generation Biofuels on Global Agricultural Production, Trade and Land Use

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Abstract:

This paper assesses the global and sectoral implications of the growing demand for bio-based inputs for energy and fuel production. More specifically, the purpose of this paper is to assess the global and sectoral implications of policy initiatives in different countries or regions (e.g. the U.S., the EU, Canada, South Africa or Japan) to enhance bioenergy demand and production in a multi-region computable general equilibrium framework. Apart from policies such as mandatory blending requirements this paper identifies the importance of relative prices between bio-based and fossil inputs in the petroleum and electricity sector as an endogenous driver in the use of bio-based inputs in the fuel and energy sector.

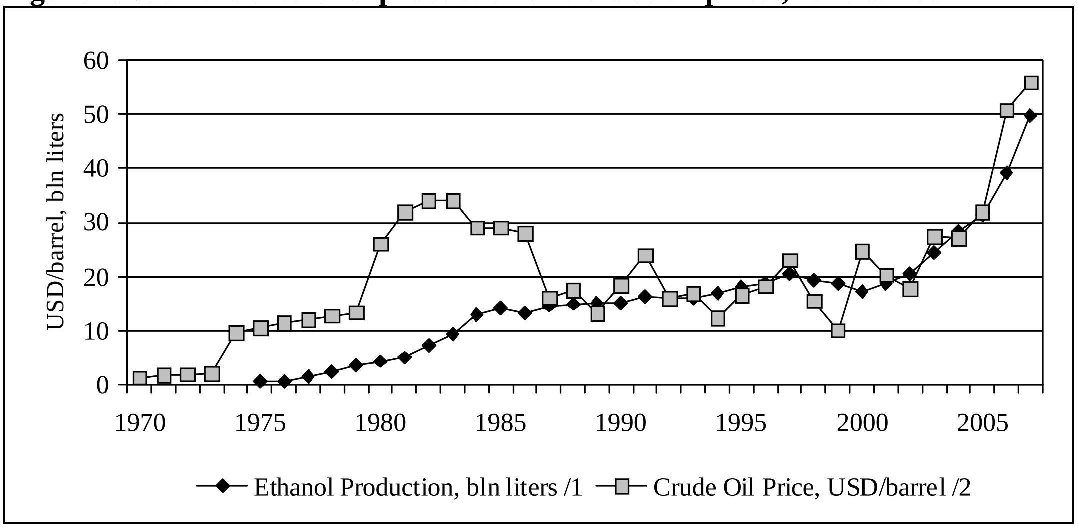
Key words: biofuels, biofuel policies, agricultural markets, computable general equilibrium modeling

1 Introduction

World-wide production of biofuels is growing rapidly. From 2001 to 2007, world production of ethanol tripled from 20 billion liters to 50 billion liters (F.O. Licht, 2007), and world biodiesel production grew from 0.8 billion liters to almost 4 billion liters. The production of biodiesel in Europe is growing more rapidly than the production of ethanol, with a current level of more than 5.5 million tonnes of biodiesel and only 2.0 million tones of ethanol (F.O. Licht, 2007).

The initiation of biofuels production was a response to the high oil prices of the 1970s, which were due to supply restrictions by the Organization of the Petroleum Exporting Countries (OPEC) cartel (Figure 1). High oil prices encouraged innovations that saved oil or replaced oil with cheaper or more reliable substitutes, such as biofuels, and world bioethanol production reached approximately 15 billion liters in 1985. In 1987 crude oil prices almost halved and fluctuated around $20 per barrel until the beginning of the new millennium. The level of biofuel production, however, did not decline but was stable, increasing only marginally after 1985. The recent increase in the price of oil, in conjunction with environmental concerns, led to the recent biofuel boom. The only mature, integrated biofuel market in practice is Brazil's cane-based ethanol market. In this ethanol/electricity cogeneration system, sugar cane is a competitive energy provider at crude oil prices around USD $35 per barrel (Schmidhuber, 2005).

Figure 1: World fuel ethanol production and crude oil prices, 1970 to 2007



/1 F.O. Licht (2007).
/2 Nominal prices. Saudi-Arabian Light-34°API.

Source: http://www.eia.doe.gov/emeu/aer/txt/ptb1107.html (14.02.2008)

The driver for biofuel production in the EU, the United States, and Canada is mainly political, including tax exemptions, investment subsidies, and obligatory blending of biofuels with fuels derived from mineral oil. For the United State the replacement of ethanol as a gasoline oxygenate for highly toxic MTBE (methyl tertiary butyl ether) tended to trade at a premium price even above its value of energy. As the current supply of ethanol exceeds the amount needed to replace MTBE the oxygenate premium dropped sharply and US ethanol markets became more vulnerable (Birur *et al.*, 2007).

High energy prices further enhance biofuel production and consumption in other countries and regions. Arguments for biofuel promoting policies include, but are not limited to, reduction of greenhouse gas emissions, diversification of sources of energy, improvement of energy security and a decreased dependency on unstable oil suppliers, and benefits to agriculture and rural areas.

Until very recently, biofuels were produced by processing agricultural crops with available technologies. These first-generation biofuels can be used in low percentage blends with conventional fuels in most vehicles and can be distributed through the existing fuel infrastructure. The second generation biofuels, which will require advanced conversion technologies, is expected to use a wider range of biomass resources—agriculture, forestry, and waste materials—and promises to achieve higher reductions in greenhouse gas emissions and the cost of fuel production (Smeets *et al.*, 2006; Hoogwijk *et al.*, 2005).

Apart from the assessment of the global and sectoral implications of the EU Biofuel Directive (European Commission, 2003) this article analyses government initiatives promoting biofuel production and consumption in Canada, the US, Brazil, South Africa, Japan (IEA, 2008) in a multi-region, computable general equilibrium framework. In most cases national biofuel initiatives calls to ensure that biofuels and other renewable fuels attain a minimum share of total transport fuel consumed. With a focus on the impact of the world-wide initiatives to promote biofuel production this paper assesses the impact on production, land use, and trade, and contributes to the current discussion surrounding the growing competition between agricultural products and land used for food, feed, and fuel purposes.

The economic literature on the impact of biofuels on agricultural markets is scarce, as the biofuel boom is quite recent; in a comprehensive survey Rajagopal and Zilberman (2007) conclude that the current literature is lacking in many respects, especially in terms of capturing the dynamic interactions between agricultural and energy markets in most economic models. By using a global, multi-region, multi-sector model, this paper seeks to increase the understanding of international trade aspects of biofuels and biofuel policies. In this first attempt, this paper focuses on first generation biofuels only. In addition to the extensions directly related to modeling biofuels, some key characteristics of related markets have been included. A distinguishing feature of the method applied here is the introduction of a land supply curve to include the process of land conversion and land abandonment endogenously (Meijl *et al.*, 2006; Eickhout *et al.*, forthcoming).

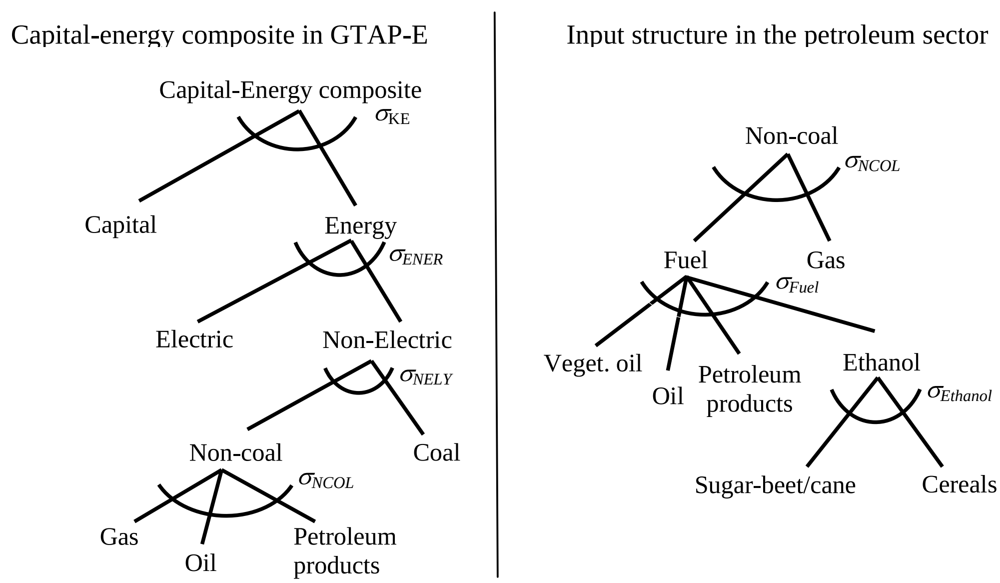
This paper includes four additional sections. Section 2 describes the methodological improvements of the modeling tools as applied in this analysis. The analyzed scenarios are introduced in section 3. Section 4 provides the scenario results of implementing global biofuel initiatives. Finally, Section 5 summarizes the outcome and results of this paper.

2 Modeling of biofuels

So far, many analyses have been done with partial equilibrium models. This approach has been to extend existing models of the agricultural sector by incorporating the demand for biofuels in the form of an exogenous increase in demand for feedstock (e.g., maize, sugar cane, wheat, sugar beet, oilseeds, etc.) to determine the changes in long-run equilibrium prices and the implications for welfare (OECD, 2006 or European Commission, 2007). A first category of computable general equilibrium (CGE) studies analyzed the impact of biofuel and carbon targets on the national economy (Dixon *et al.,* 2007; McDonald *et al.,* 2006; Reilly and Paltsev, 2007), and a second emphasized international trade (Elobeid and Tokgoz, 2006; Gohin and Moschini, 2007; Birur *et al.,* 2007). Rajagopal and Zilberman (2007) identify the need for a better understanding of the dynamics and international trade aspects of biofuels. The existing studies treat land exogenously, whereas economic (competitiveness and trade) and environmental (especially biodiversity) impacts are related to land use. Therefore, the methodology improvements introduced here focus on the integration of the energy and land markets, with special attention to land-use change.

This section describes the methodological improvements that are crucial for modeling biofuels in a global general equilibrium model. First, we introduce the standard general equilibrium model (including the data) that is used as a starting point. Second, the extensions of the energy markets necessary to model biofuel demand are discussed, and third, improvements to the modeling of crucial factor markets are discussed with an emphasis on land markets.

Figure 2: Nesting structure in energy modeling



The implementation of biofuels builds on a modified version of the GTAP multi-sector multi-region CGE model (Hertel, 1997). This multi-region model allows the capture of inter-country effects, since the enhanced biofuel use influences demand and supply, and therefore prices on world markets and hence will affect trade flows, production, and GDP. The multi-sector dimension enables to study the link between energy, transport, and agricultural markets. The model is extended through the introduction of energy substitution into production by allowing energy and capital to be either substitutes or complements (GTAP-E; Burniaux and Truong, 2002). Compared to the standard presentation of production technology, the GTAP-E model aggregates all energy-related inputs for the petrol sector—such as crude oil, gas, electricity, coal, and petrol products—in the nested structure under the value added side. At the highest level the energy-related inputs and the capital inputs are modeled as an aggregated 'capital-energy' composite (Figure 2, left panel).

To introduce the demand for biofuels, the nested constant elasticity of substitution (CES) function of the GTAP-E model has been adjusted and extended to model the substitution between different categories of oil (oil from biofuel crops and crude oil), ethanol, and petroleum products in the value added nest of the petroleum sector. The model presents the fuel production at the level of non-coal inputs differently compared to the approach applied under the GTAP-E model (Figure 2, right panel). The non-coal aggregate is modeled the following way: 1) the non-coal aggregate consists of two sub-aggregates, fuel and gas; 2) fuel combines vegetable oil, oil, petroleum products, and ethanol; and 3) ethanol is made out of sugar beet/sugar cane and cereals.[1]

This approach models an energy sector where industry's demand of intermediates strongly depends on the cross-price relation of fossil energy and biofuel-based energy. Therefore, the output prices of the petrol industry will be, among other things, a function of fossil energy and bio-energy prices. The nested CES structure implies that necessary variables of the demand for biofuels are the relative price developments of crude oil versus the development of agricultural prices. Also important is the initial share of biofuels in the production of fuel. A higher share implies a lower elasticity and a larger impact on the oil markets. Finally, the values of the various substitution elasticities (σ_{Fuel} and $\sigma_{Ethanol}$) are crucial. These represent the degree of substitutability between crude oil and biofuel crops. The values of the elasticity of substitution are taken from Birur *et al.*, (2007), who—based on a historical simulation of the period 2001 to 2006—obtained a value of the elasticity of substitution of 3.0 for the US, 2.75 for the EU, and 1.0 for Brazil.

In addition, prices for outputs of the petroleum industry will depend on any subsidies/tax exemptions affecting the price ratio between fossil energy and bio-energy. Finally, and most important for current biofuel policies, the level of demand for biofuels will be determined by

[1] Ethanol is not modeled as a product for final demand but only as an aggregated composite input in the petrol industry.

any enforcement of national targets through, for example, mandatory inclusion rates or the provision of input subsidies to the petrol industries.

In this paper biofuel policies are modeled as mandatory blending obligations fixing the share of biofuels in transport fuel. It should be mentioned that this mandatory blending is budget neutral from a government point of view. To achieve this in a CGE model two policies were implemented. First, the biofuel share of transport fuel is specified and made exogenous such that it can be set at a certain target. A subsidy on biofuel inputs is specified endogenously to achieve the necessary biofuel share. The input subsidy is needed to change the relative price ratio between biofuels and crude oil. If the biofuel share is lower than the target, a subsidy on biofuels is introduced to make them more competitive. Second, to implement this incentive instrument as a 'budget-neutral' instrument, it is counter-financed by an end user tax on petrol consumption. The end user tax on petrol is made endogenous to generate the necessary budget to finance the subsidy on biofuel inputs necessary to fulfill the mandatory blending. Due to the end user tax, consumers pay for the mandatory blending as end user prices of blended petrol increase. The higher price results from the use of more expensive biofuel inputs relative to crude oil in the production of fuel.

Data base used for Modeling Biofuel Policies: Version 6 of the GTAP data for simulation experiments was used. The GTAP database contains detailed bilateral trade, transport, and protection data characterizing economic linkages among regions that are connected to individual country input-output databases, which account for inter-sectoral linkages. All monetary values of the data are in USD millions, and 2001 is the base year for version 6. The social accounting data were aggregated to 37 regions and 13 sectors and the sectoral aggregation distinguishes agricultural sectors that can be used for producing biofuels (e.g., grains, wheat, oilseeds, sugar cane, sugar beet), and are important from a land use perspective, and energy sectors that demand biofuels (e.g., crude oil, petroleum, gas, coal, and electricity). The regional aggregation includes all EU15 countries (with Belgium and Luxembourg as one region) and all EU12 countries (with the Baltic countries aggregated to one region, Malta and Cyprus as one region, and Bulgaria and Romania as one region), as well as the most important countries and regions outside the EU from an agricultural production and demand point of view (i.e., Brazil, NAFTA, East Asia and the Rest of Asia, and three regions within Africa).

Due to the extremely rapid developments in the biofuel sector, the GTAP database has been updated to include recent developments. The calibration of the use of biofuel crops in the model is based mainly on sources published in F.O. Licht (2007). For implementing first generation biofuels, the GTAP database has been adjusted for the input demand for grain, sugar, and oilseeds in the petroleum industry. Under the adjustment process, the total intermediate use of these agricultural products at the national level has been kept constant while the input use in non-petroleum sectors has been adjusted in an endogenous procedure to reproduce 2004 biofuels shares in the petroleum sector (corrected for their energy contents).

3 Description of scenarios

To assess the impact of biofuels and related polices, the 'Global Economy' scenario of the EURURALIS project is used as a reference scenario for this analysis (Wageningen UR and Netherlands Environmental Assessment Agency, 2007). The 'Global Economy' scenario is an elaboration of one of the four emission scenarios of the Intergovernmental Panel on Climate Change (IPCC), as published in its Special Report on Emission Scenarios (SRES) (Nakicenovic *et al.,* 2000). Under the 'Global Economy' scenario, which elaborates the A1 scenario of the SRES, the World Trade Organization (WTO) negotiations are assumed to have concluded successfully and global trade is assumed to be moving toward full liberalization.

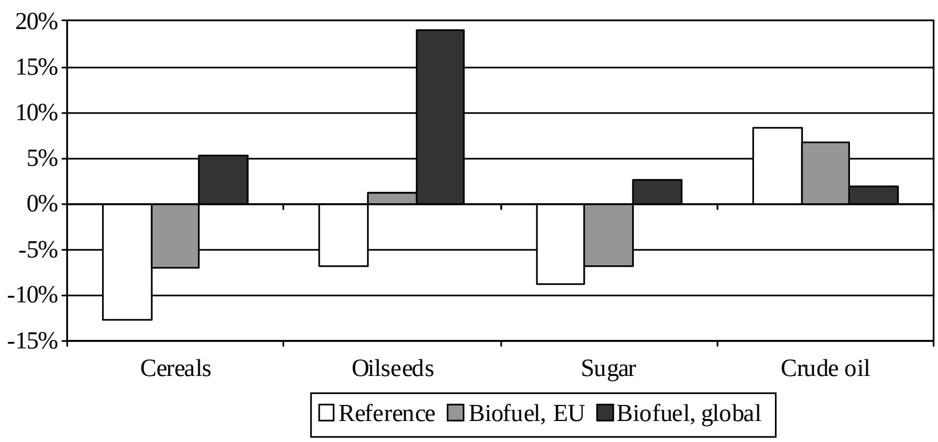
In the reference scenario there is a strong increase in GDP per capita across all regions covered in this analysis. Important driving forces are the demographic, macro-economic, and technological developments and policy assumptions taken from studies that implement the SRES.

In the policy scenarios, the implementation of the biofuel initiatives is analyzed for the EU, the US, Canada, South Africa as well as Japan in two different scenarios. The policies are modeled as mandatory blending obligation and illustrate the consequences of biofuel policies on the national and international markets for agri-food products. The 'Biofuel, EU' scenario assumes the implementation of the 10% target in 2020 for the EU without implementation of mandatory blending policies outside the EU, while under the 'Biofuel, global' mandatory targets are set in the EU and in other countries. Based on IEA (2008), we assume a 10% blending target for the US, Canada, Japan and South Africa. In IEA (2008), a 25% blending target for Brazil is also indicated. Due to the fact that in the initial period the blending rate in Brazil exceeds already this target, we model mandatory blending as a complementarity condition.

4 Scenario results

With enhanced biofuel consumption as a result of the world-wide biofuel policies, prices of agricultural products tend to increase. This is especially the case for those products that are directly used as biofuel crops. Under the reference scenario, real world prices for agricultural products tend to decline and conform to their long-term trend (Figure 3). This is caused by an inelastic demand for food in combination with a high level of productivity growth (Schmidhuber, 2007).[2] Under the biofuel scenarios, world prices rise relative to the reference scenario. Under 'Biofuel, global' the real price of oilseeds shows an increase of 26% in contrast to the long-term trend projected in the reference scenario. Compared to the US and Brazil, where ethanol consumption dominates the biofuel sector, EU biofuel is based on bio-diesel, which is reflected by the increase in prices of the bio-based inputs in the production of biofuels. The increase in world prices for cereals is more than 18% under the 'Biofuel, global' scenario which is in line some other global studies (i.e., Rosegrant *et al.,* 2007) where oilseed and sugar prices rise 18% and 10%, respectively. The increase in crude oil price is smaller under the 'Biofuel, global' scenario as demand for crude oil diminishes due to the introduction of the BFD. Similarly, Dixon *et al.* (2007) showed a decline in the world crude oil price of 4.5% due to US biofuel policies.

Figure 3: Change in real world prices, in percent, 2020 relative to 2001



Even without enforcing the use of biofuel crops through mandatory blending, the share of biofuels in fuel consumption for transportation purposes increases (Figure 4). This endogenous increase in biofuel production is due to the fact that the ratio between the crude oil price and prices for biofuel crops changes in favor of biofuel crops (Figure 3). Under the reference scenario biofuel shares increase. The highest increase is in the already integrated market of Brazil, where the initial 2001 share of greater than 28%, expands to more than 31% in 2020. These results reveal that without a mandatory blending the biofuel targets will not be met in most of the countries covered in this analysis.

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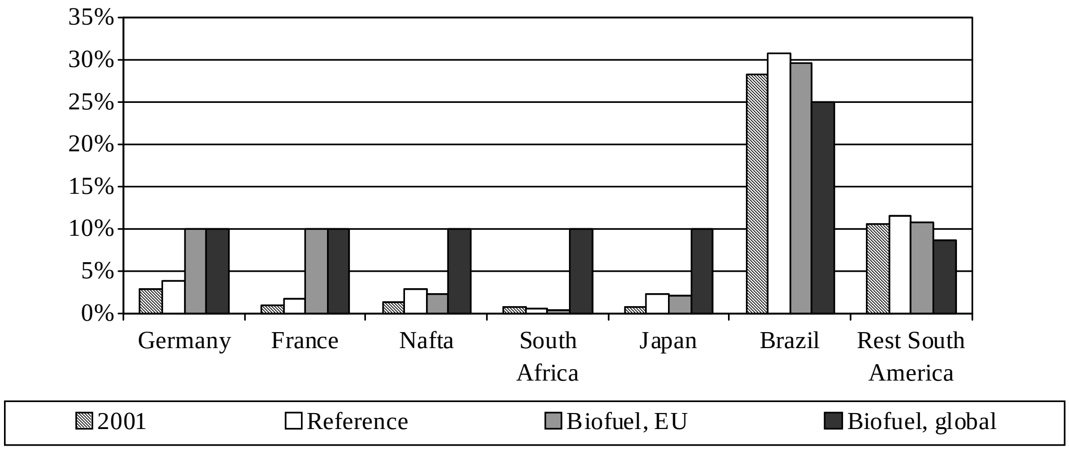
[2] The reference scenario of this paper is based on the projection of long-term trends on global agriculture and food markets and therefore does not include the current high price development on agri-food markets.

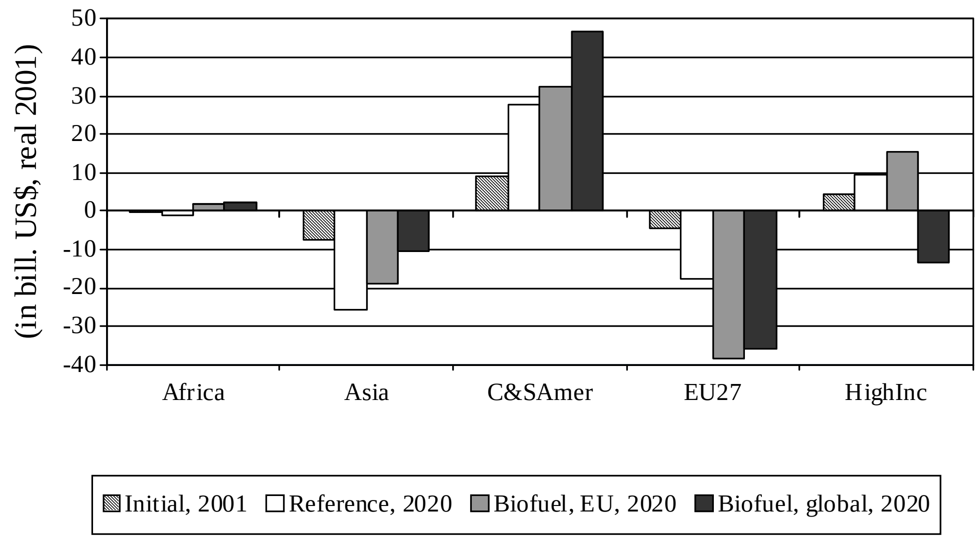
Figure 4: Development of percent share of biofuels in fuel consumption for transportation for selected regions, 2001 and 2020



With biofuel policies the – above mentioned – countries fulfill the required targets; however, this occurs at the expense of those countries which do not impose a mandatory blending target. By meeting the national targets the share of biofuel use declines in Brazil by almost 5 percentage points under the 'Biofuel, global' scenario and the 25% mandatory blending share becomes binding. The decline in biofuel consumption in countries without biofuel policies is due to the increase in relative prices between biofuel crops and crude oil. The enhanced demand for biofuel crops under the biofuel scenario leads to an increase in world prices for these products and, hence, to a decline in the profitability in fuel production compared to crude oil. However, the increase in biofuel crop demand in the countries impose biofuel policies overcompensates for the decline in countries without biofuel policies, and at global level the use of biofuel crops for fuel production increases under the biofuel scenarios. A good indicator for this development is the decline in crude oil price under the biofuel scenario compared with the reference scenario (Figure 3).

To meet the ambitious future targets of the biofuels initiatives, large scale production of biofuel crops will be necessary and the dependency on import to meet the biofuel targets increases in most countries and regions. Figure 4 shows that in some regions the trade deficit for agricultural commodities used for the production of biofuels will increase dramatically under the biofuel scenarios. South and Central America as a land abundant region will expand their net-exports in agricultural products for biofuel production. The availability of land enables these countries to increase their production without drastic increases in land and product prices, whereas this is not possible in land-scarce countries.

Figure 4: Balance in biofuel crop trade (in bill. US$, real 2001)



Compared to world income growth, the annual growth rates of agricultural production are quite moderate in the reference scenario (Table 1). In the EU and in the high income countries (HighInc region), agricultural production is negatively affected in terms of relatively low output growth which is due to the liberalization implemented in the reference scenario. At the aggregated level, total arable production increases in the reference and both policy scenarios. The decrease in biofuel crops (i.e., oilseeds, grains, and sugar) in the EU under the reference scenario is caused by the huge decline in sugar production due to liberalization (see also Nowicki *et al.*, 2007). In all regions, mandatory blending also leads to an increase in total arable output. Table 1 presents the results for changes in oilseed production, which expands significantly under the policy scenarios as EU biofuel is based on bio-diesel. Oilseed production in the EU increases from almost 6% in the reference to 47% in the 'Biofuel, global' scenario. Under the 'Biofuel, global' scenario biofuel crop production increases significantly at global scale.

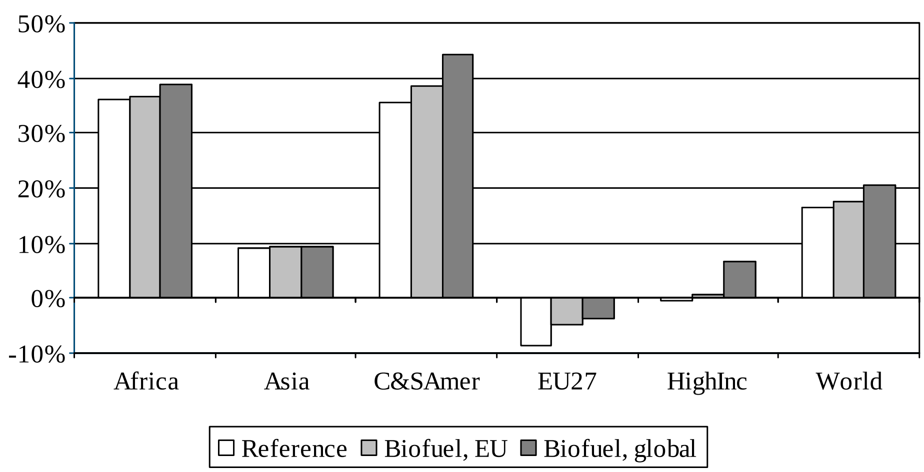
Table 1: Percent changes in agricultural production, 2020 relative to 2001

	Africa	Asia	C&SAmer	EU	HighInc	NAFTA	World
Arable Crops							
Reference	68.2	46.9	51.4	14.2	18.5	39.3	36.2
Biofuel, EU	68.8	47.0	56.5	17.7	19.7	41.2	37.5
Biofuel, global	70.5	47.6	63.9	17.6	29.7	58.6	40.8
Biofuel Crops /1							
Reference	103.3	68.0	73.1	-12.2	22.5	26.8	41.0
Biofuel, EU	111.3	70.0	86.1	6.4	25.4	29.8	48.6
Biofuel, global	128.5	76.9	121.4	11.5	52.1	57.4	65.6
Oilseeds							
Reference	91.0	61.4	66.0	5.6	56.8	58.6	55.1
Biofuel, EU	102.7	63.7	84.7	41.3	65.4	67.6	66.1
Biofuel, global	165.9	73.3	110.8	46.6	124.4	129.7	91.9
Grains							
Reference	80.7	51.3	59.9	10.2	29.5	29.7	39.3
Biofuel, EU	83.3	54.1	75.4	23.2	32.0	31.8	45.7
Biofuel, global	92.7	58.0	95.4	27.3	59.4	59.7	59.2

/1: This aggregate summarizes total average production change of sugar beet/cane, cereals and oilseeds.

The production developments lead to a similar pattern of land use developments, as land is a key input in production (Figure 5). Land use increases under the biofuel scenarios in all regions compared with the reference scenario; therefore, land use also increases at global level. In the EU, the decline in agricultural land use as a consequence of the liberalization in the reference scenario, is reduced significantly under the biofuel scenarios. This expansion of agricultural land use on a global scale—and especially in land-abundant South America—might indicate a decline in biodiversity as land use is an important driver for biodiversity (see CBD, 2006).

Figure 5: Change in total agricultural land use, in percent, 2020 relative to 2001



5 Summary and conclusions

This analysis shows that enhanced demand for biofuel crops under the world-wide biofuel programmes has a strong impact on agriculture at global level. The long-term trend of declining real world prices of agricultural products reverses for the feedstock used for biofuels. The incentive to increase agricultural production will tend to increase land prices and farm output in all regions covered in this analysis. Land-scarce countries and regions, such as the EU will not produce the feedstocks needed to generate the required biofuel crops domestically and will run into a higher agricultural trade deficits. Biofuel crop production and land use will expand in land-abundant countries—NAFTA and especially in South and Central America (e.g., Brazil)—due to increased demand for biofuel crops. The resulting higher feedstock prices will reduce biofuel consumption outside countries with biofuel targets. However, at a global level the use of biofuels increases and crude oil demand decreases, leading to a decline in the world price of oil. The expansion of agricultural land use on a global scale, and especially in land-abundant South America, might indicate a decline in biodiversity, as land use is an important driver for biodiversity.

Without additional policies to stimulate the use of biofuel crops in the petroleum sector, such as mandatory blending, the targets of the countries and regions covered here will not be met. A mandatory blending policy leads to higher consumer prices for petrol, as agricultural feedstock are not profitable for use in fuel production given the current technologies. The increased demand for feedstock raises their price relative to the oil price and therefore adds to the challenge of making biofuels competitive.

The magnitude of the impacts depends on the substitutability of biofuels and crude oil and on the trade elasticities. Furthermore, all the results depend on the relative land availability of countries worldwide. Including a endogenously determined land supply curve is crucial if one studies the impacts of increased demand for biofuels on prices, trade, production, land use, and, ultimately, biodiversity.

Therefore, if biofuels must be competitive in the long run, investments in research and development are needed to obtain higher yields or better conversion technologies. However, in this paper the analysis focuses only on first generation biofuels. Decisions on research and development investments should account for the second generation biofuels, as these promise to be both better and more cost effective in reducing greenhouse gas emissions, although second generation biofuels will yield less by-products than first generation biofuels.

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