# Biofuel do Brasil?

## Impact of Multinational Biofuel Mandates on Agri-food Trade

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***Selected Paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012.***

**Abstract:**
This paper analyzes the consequences of enhanced biofuel production in regions and countries of the world that have announced plans to implement or expand on biofuel policies. The analysis considers not only mandatory blending targets for transportation fuels, but also voluntary ones. The chosen quantitative modeling approach is two-fold: it combines a multi-sectoral economic model (LEITAP) with a spatial bio-physical land use model (IMAGE). This paper adds to existing research by considering biofuel policies in the EU, the US and various other countries with considerable agricultural production and trade, such as Brazil, India and China. Moreover, the combination of the two modeling systems allows for the observation of changes in both economic and bio-physical indicators.
The results show that some indicators with high political relevance, such as agricultural prices and greenhouse gas emissions from land use, do not necessarily react proportionally to increasing demand for agricultural products from the biofuel sector. This finding should be considered when designing biofuel policies because these indicators are directly relevant for food security and climate change.

**Keywords:**
Biofuel mandates
Land use changes
Greenhouse gas emissions

# 1 Introduction

Since 2001, rapid growth of biofuel production has been observed, driven by high crude oil prices and a growing interest in reducing greenhouse gas (GHG) emissions. High oil prices have encouraged innovations to reduce crude oil consumption, and governments worldwide have thought it necessary to stimulate the production and consumption of biofuel. To ensure a certain level of reduction of GHG emissions, policies have been established, such as blending targets. These quantitative measures set goals for the share of renewable fuels (biofuel) in fuel consumption. Mandatory and voluntary targets are currently imposed on the use of liquid biofuel in many major world economies, with the exception of Russia (Sorda et al. (2010)).

The consequences of biofuel policies on agricultural markets and GHG emissions have been analyzed in numerous papers. An extensive overview of earlier studies can be found in Rajagopal and Zilberman (2007). More recent studies include Elobeid et al. (2007), Banse et al. (2008), Dehue and Hettinga (2008), Eickhout et al. (2008), OECD (2008), Searchinger et al. (2008), Al-Riffai et al. (2010), EPA (2010), Hertel et al. (2010, 2010a), Mulligan et al. (2010), Beckmann et al. (2011) and Britz and Hertel (2011).

The majority of these studies analyze either the impact of the 2009 EU Directive on Renewable Energy (DRE) or the consequences of the 2007 US Energy Independence and Security Act (EISA). OECD (2008) and Hertel (2010) assess a joint implementation of both the US and the EU programs, but even these latter two studies ignore the fact that not only the US and the EU but also several other major world economies have announced biofuel targets. This is an important shortcoming because regions that are implementing biofuel targets that are not covered by these analyses are often significant players in agricultural markets. Consequently, changes in the demand for biofuel crops and biofuel in these countries are likely to have a considerable impact on international agricultural markets and on the environment.

Despite the importance of this issue, research on the consequences of simultaneous implementation of biofuel policies in several major world economies is scarce. A recent study by Timilsina et al. (2010) addresses this issue but lacks an analysis of environmental indicators, particularly GHG emissions. This is a major drawback because reducing GHG emissions is a core argument for political support of the biofuel industry. An analysis of the impact of the global implementation of all announced biofuel policies is provided by Beckmann et al. (2011), but their paper does not consider economic variables.

This paper intends to fill this gap. In this paper, we assess the economic and bio-physical impacts of the implementation of all announced biofuel policies using an integrated approach. To disentangle the effects and to establish a basis for comparison with other studies, the scenario is developed stepwise. First, we examine the effect of joint biofuel mandates in the EU and the US. Second, we add the policies of those countries that have announced mandatory biofuel targets, such as Canada, Brazil, India and others. Finally, the policies of countries with voluntary targets (i.e., Australia, China and Japan) are added. We analyze the impact of these joint biofuel mandates on land, food production, total GHG balance, trade and prices of agricultural commodities. By using the Computable General Equilibrium (CGE) model LEITAP together with the integrated assessment model IMAGE, we are able to treat the cross-sectoral effects of biofuel mandates, geographically explicit land use, and environmental effects, such as GHG balances and carbon stocks, in a consistent manner.

For a better understanding of the policy background against which this study was conducted, an overview of biofuel policies around the globe will be provided in the next section.

# 2 Biofuel policies

A wide range of policy instruments are used to encourage and support biofuel production, as seen in FAO (2008), Rajagopal and Zilberman (2007), and Sorda et al. (2010). The policy interventions exist because biofuel production is rarely economically viable, and it must be supported to become competitive. This is done by applying policy instruments such as subsidies and tax exemptions. Other forms of support include policy measures that influence the biofuel supply chain directly or indirectly via subsidies for technological innovation, production factor subsidies, government purchases and investments in infrastructure for biofuel storage, transportation and use. Furthermore, tariff barriers for biofuel are often implemented to protect domestic producers. These policy measures stimulate biofuel production but do not ensure that a country will meet the production level required to, for example, meet certain GHG emission reduction targets. Therefore, many countries set targets, known as biofuel blending mandates, for the share of renewable fuels (biofuel) in fuel consumption.

As mentioned earlier, mandatory and voluntary targets for liquid biofuels are currently imposed in all major world economies, with the exception of Russia. In the EU, the US, Canada, Brazil, Argentina, Colombia, India, Thailand, Indonesia and the Philippines, mandatory requirements have been introduced for both ethanol and biodiesel. Paraguay and Ecuador apply ethanol mandates, and Uruguay and Thailand apply biodiesel mandates. The targets are set at different levels. In the EU, a 10% share of energy from renewable sources in total transport energy consumption will be obligatory in 2020. By 2022, 36 billion gallons of renewable fuels must be used in US transportation. Canadian mandates require 5% renewable content in petrol by 2010 and 2% renewable content in diesel fuel and heating oil by 2012. In the remaining countries, targets are mainly set for E10 and B5[1] in 2010 and should increase over time to E10+ and B20+. For instance, the Brazilian target for 2013 is E25, and in Indonesia, the mandatory level of biofuel consumption is supposed to increase to E15 and B20 by 2025. China, Japan and Australia have set non-binding targets for biofuel production. A more detailed description of worldwide biofuel policies can be found in Sorda et al. (2010).

# 3 Quantitative Approach

## *3.1 Database*

The analysis is based on version 6 of the GTAP data, Dimaranan (2006). The GTAP database contains detailed bilateral trade, transport and protection data to characterize economic relations among regions, coupled with individual country input-output databases to account for intersectoral linkages. All monetary values of the data are in $US million, and the base year for version 6 is 2001. This version of the database divides the world into 87 regions and distinguishes 57 sectors in each of the regions. That is, for each of the 87 regions there are input-output tables with 57 sectors that depict the backward and forward linkages amongst activities.

The initial database was aggregated and adjusted to implement two new sectors, ethanol and biodiesel, represented by biofuels in the model. These new sectors produce two products each, the main product and a co-product or by-product. The ethanol by-product is Dried Distillers Grains with Solubles (DDGS), and the co-product associated with biodiesel is oilseed meal (BDBP). Other co-products, such as glycerol from biodiesel production, are not analyzed explicitly.

After aggregations, we distinguish 45 regions, 26 sectors and 28 products. The sectoral aggregation includes, among others, agricultural activities that use land (e.g., rice, grains, wheat, oilseed, sugar, horticulture, other crops, cattle, pork and poultry, and milk), the petrol industry that demands fossil resources (crude oil, gas and coal) and bioenergy inputs (ethanol and biodiesel), and biofuel production by-products. The regional aggregation includes all EU-15 countries (with Belgium and Luxembourg as one region) and all EU-12 countries individually, except for three regional aggregates: the Baltic countries, Malta/Cyprus and Bulgaria/Romania. Outside the EU, the analysis covers all important countries and regions from an agricultural production and demand point of view.

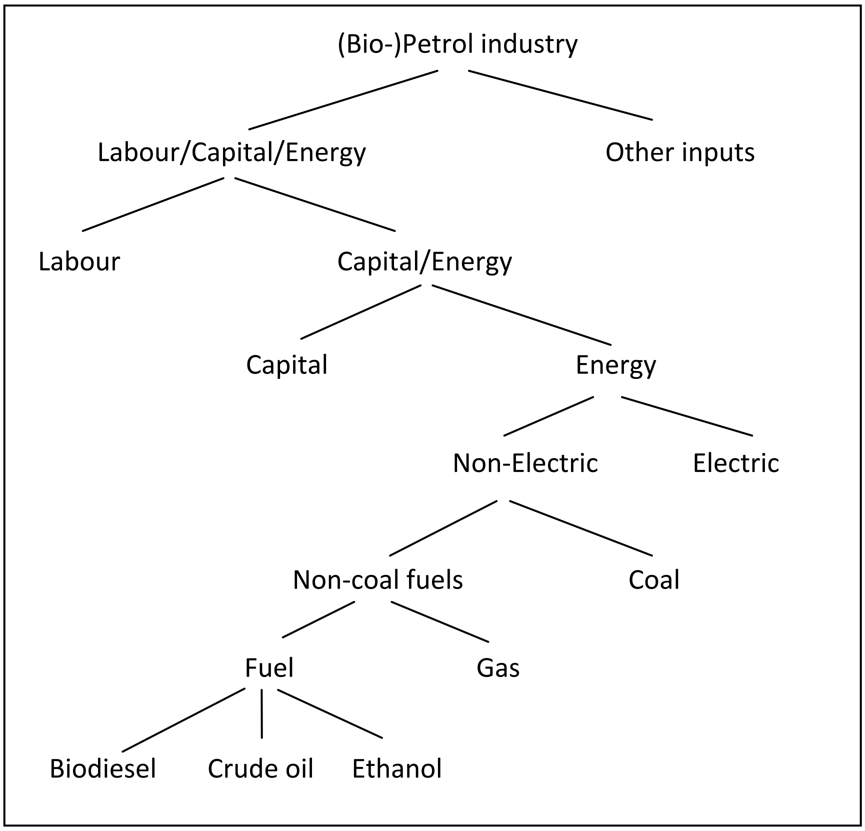
[1] E# describes the percentage of ethanol in the ethanol-petrol mixture by volume; for example, E10 stands for fuels with 90% petrol and 10% ethanol. B# describes the percentage of biodiesel in the biodiesel-diesel mixture by volume; for example, B5 stands for diesel fuel with 95% ('fossil') diesel and 5% biodiesel.

## 3.2 *Modeling framework*

### 3.2.1 The LEITAP model

In the combined economic and biophysical modeling approach adopted in this study, the LEITAP model is used to calculate the economic part of the approach. LEITAP is a multi-regional, multi-sectoral, static, applied general equilibrium model based on neo-classical microeconomic theory (see Nowicki at al. (2009) and van Meijl et al. (2006)). It is an extended version of the standard GTAP model, as described in Hertel (1997).

**Figure 1: The (bio-) petrol industry nested production structure**

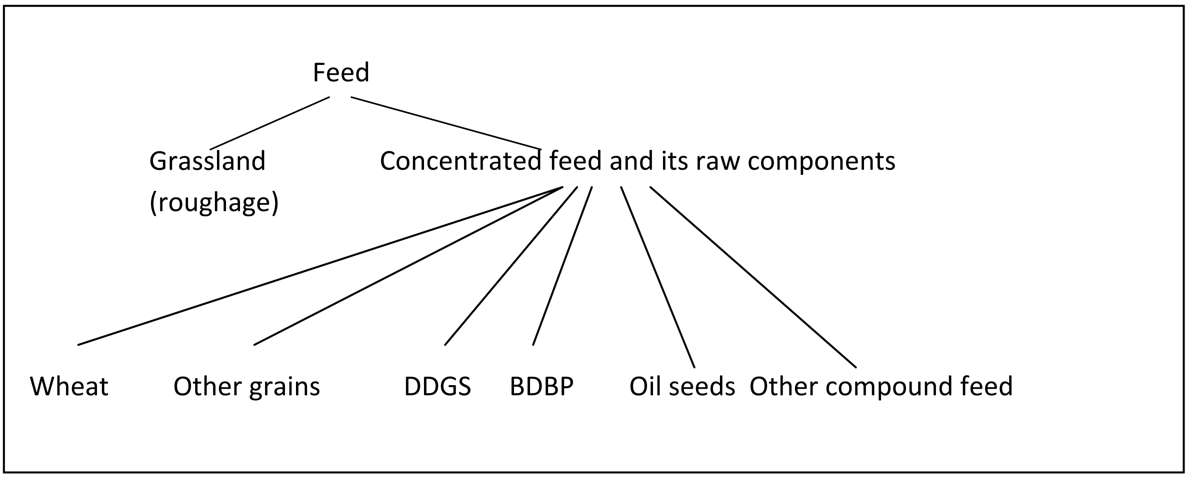



The core of the GTAP and LEITAP models is an input–output model that links industries in a value-added chain starting with primary goods, following continuously higher stages of intermediate processing, and ending with the final assembly of goods and services for consumption. Extensions incorporated in the LEITAP model include improved treatment of the agricultural sector (through, for example, various imperfectly substitutable types of land, an improved land allocation structure, endogenous land supply and the possibility of substitution between various animal feed components), agricultural policies (such as production quotas and different land-related payments) and the biofuel sector (capital - energy substitution, fossil fuel - biofuel substitution). On the consumption side, a dynamic CDE (Constant Difference of Elasticities) expenditure function was implemented that allows for changes in income elasticities when real GDP per capita changes. In the area of factor markets, the segmentation and imperfect mobility between agricultural and non-agricultural labor and capital was introduced.

To model biofuel use in fuel production, we adapt the nested CES function of the GTAP-E model from Burniaux and Truong (2002) and extend it for the petrol sector (Figure 1). To introduce the substitution possibility between crude oil, ethanol and biodiesel, we model different intermediate input nests for the petrol sector. The nested CES structure implies that biofuel demand is determined by the relative prices of crude oil versus ethanol and biodiesel, including taxes and subsidies.

The feed by-products of biofuel production (DDGS and BDBP) are demanded only by the livestock sectors in LEITAP. This demand is generated through the substitution process in the feed nest in the livestock sector. To model substitution between different feed components and feed by-products of biofuel production, we use a two-level CES nest describing the substitution between different inputs in the animal feed mixture production (Figure 2). The top level describes the substitution possibility between concentrated feed and its components and grassland (i.e., roughage). The lower intermediate level describes the composition of different types of feed commodities (cereal, oilseeds, by-products and other compound feed).

**Figure 2: The animal feed nested structure**




### 3.2.2 The IMAGE model

IMAGE is an integrated assessment model used for climate change and/or global land use analysis; see Alcamo et al. (1994), Alcamo et al. (1999), and MNP (2006). Together with LEITAP, IMAGE has been used in several studies, see Nowicki et al. (2006), Rienks (2007), and OECD (2008a), to simulate the biophysical consequences of policies, based on environmental indicators, such as agricultural land use, energy and land use emissions. The link between LEITAP and IMAGE is established in two ways. First, LEITAP uses a land supply curve for each region in such a way that it takes into account the scarcity of the land available for agriculture. These land supply curves are derived from IMAGE data according to the methods in van Meijl et al. (2006). Second, the results of LEITAP (i.e., changes in agricultural production (including biofuels) and in the productivity of agriculture) are fed into IMAGE to analyze changes in the land use system. In IMAGE, the land use system is simulated globally at a grid level (0.5 by 0.5 degrees) leading to land-specific $CO_2$ emissions and sequestration. For each grid cell, seven major carbon pools are distinguished in plants and in the soil, according to Klein Goldewijk et al. (1994). Furthermore, other land related emissions, such as $CH_4$ from animals and $N_2O$ from fertilizer use, are determined as in MNP (2006). Emissions feedback on the climate system is taken into account and ultimately results in changes in the productivity of agriculture and natural biomes, Leemans et al. (2002).

## *3.3 Scenario description*

The scenarios are built on a reference scenario (NoBFM) that assumes no mandatory use of biofuels in any part of the world. The assumptions concerning the development of real GDP and population growth for EU countries are taken from the AGMEMOD model database, AGMEMOD Partnership (2008) and from USDA (2011) for the rest of the world. Based on stylized facts about long-term economic growth, we assume that capital is growing at the same rate as the GDP, and employment is growing at the same rate as the population.

The crude oil price development, which also determines the competitiveness of biofuel vis-a-vis fossil energy, is determined endogenously in the model. However, it is significantly driven by assumed future crude oil production derived from IEA (2008, 2009). In the first stage, we translate the macroeconomic growth and crude oil production projections into the country-specific efficiency of natural resource utilization in the crude oil sector. The technological assumptions obtained in this way are used in the simulation experiments. They show decreasing productivity of natural resources in the crude oil sector for almost all regions, which is generally consistent with the observed and expected decline of output from oilfields, IEA (2008).

As far as the policy is concerned, we assume the continuation of all policies legislated in 2010 throughout the projection period, including agricultural policies as well as policies related to bioenergy. For example, we implemented the EU Renewable Energy Directive as well as the EU 2003 CAP reform.

In view of the description in Section 2, we conduct three biofuel- policy experiments:

- The first scenario comprises the DRE of the EU as well as the EISA of the US. We denominate this policy setting as **EU&US-BFM.**
- The second scenario implements biofuel targets for all countries in which they are mandatory. In addition to the US and the EU, this scenario covers Canada, Brazil, Argentina, Colombia, Paraguay, Ecuador, South Africa, India, Indonesia, Thailand and the Philippines. This scenario will be called the **Glob-BFM** scenario.
- The third scenario is established with mandatory and voluntary biofuel targets implemented for all countries. Specifically, in addition to the Glob-BFM scenario, we consider China, Japan and Australia, and we call this policy setting **Glob-BFM&Vol**. It is assumed that the voluntary targets are met and that voluntary biofuel blending is implemented in the same way as in binding targets.

This stepwise approach allows us to depict not only the global biofuel mandate effect but also to examine how much the effect of biofuel policies is misestimated when only the biofuel mandates for the EU and the US are investigated.

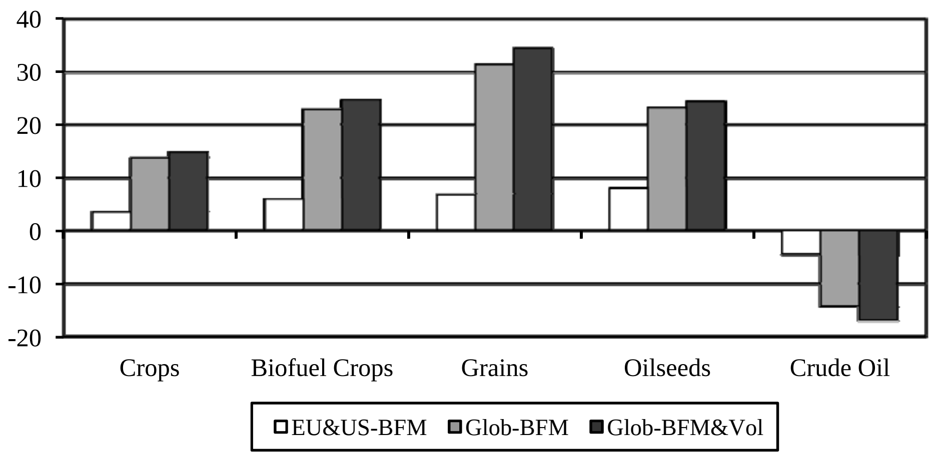
The following section presents the results for the reference scenario NoBFM, which does not assume any mandatory blending targets, and the three policy scenarios. Due to limited space, the impacts of biofuel policies are presented only at the aggregated regional and commodity level. Note that under the three policy scenarios, only the blending obligations for different countries or regions are altered. All other policy instruments remain unchanged compared to the reference scenario.

# 4 Results and discussion

## *4.1 Effects on agricultural markets*

Not surprisingly, world prices of agricultural products increase with enhanced biofuel consumption triggered by biofuel policies. This is especially the case for those products that are directly used as an input to the biofuel industry, such as cereals, oilseeds, sugar beet and sugar cane. Figure 3[2] shows the changes in real agricultural prices relative to the reference scenario.

**Figure 3: Change in real world prices, in percentages, 2020 relative to NoBFM Scenario**

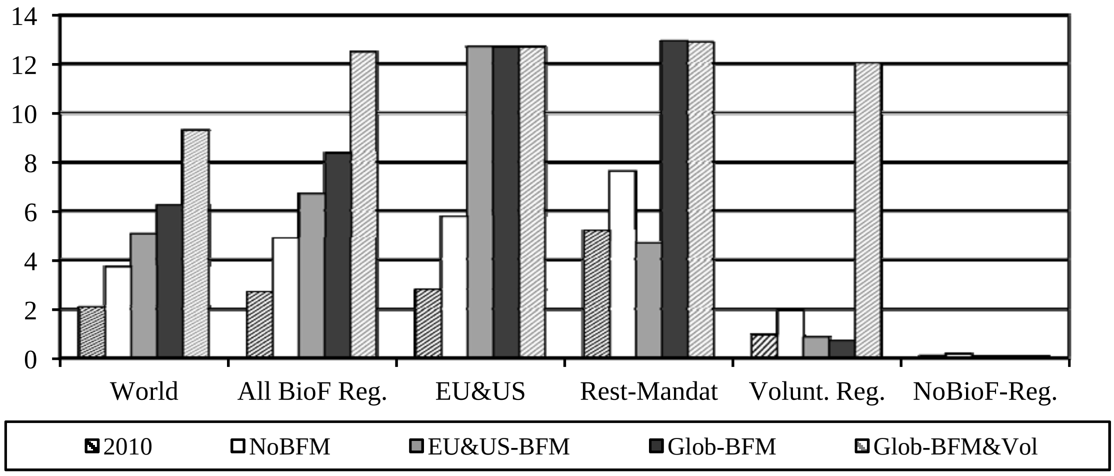



Source: Own calculations based on LEITAP.

Under the EU&US-BFM scenario, world prices rise relative to the reference scenario at only a moderate rate. Among agricultural products, the most pronounced effect is observed for oilseeds, which increase by roughly 8% above the level in the reference scenario. The impact of biofuel production on world prices becomes more obvious under the second policy scenario, in which all regions with mandatory blending policies implement their target. In this case, international grain prices, as opposed to oilseed prices, see the largest increase, more than 30% relative to the reference scenario. This reflects the fact that, at the global level, ethanol consumption dominates the biofuel sector. This situation contrasts with the situation in the EU, where biodiesel dominates the market for biofuels. The results also show that the price effect of the Glob-BFM scenario is stronger than that of the EU&US-BFM, despite the fact that the increase in the global biofuel share is similar.

2 An overview of the commodity aggregation can be found in Table 2 in the Annex.

**Figure 4: Share of biofuel in transportation fuel, 2010 and 2020**




Remark: The regional aggregate 'ALL BIOF REG.' comprises all regions with mandatory or voluntary biofuel policies. The regional aggregate 'REST-MANDAT.' comprises Canada, Brazil, Argentina, Colombia, Paraguay, Ecuador South Africa, India, Indonesia, Thailand, Philippines. The regional aggregate 'VOLUNT. REG.' comprises China, Japan and Australia.
Source: Own calculations based on LEITAP.

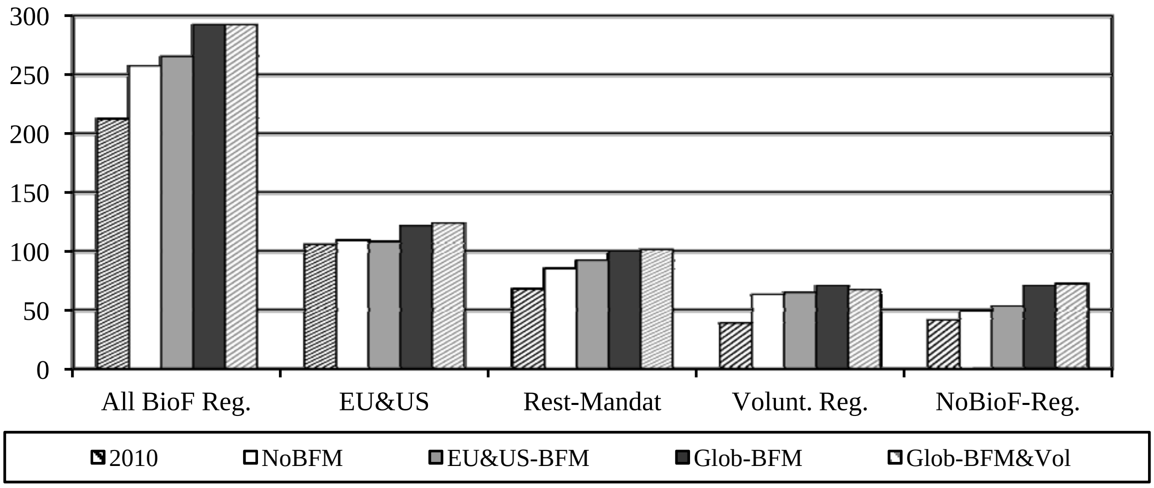
Considering the voluntary targets of China, Japan and Australia adds surprisingly little to the upswing of international prices. This result may be unexpected when the development of the share of biofuel in transportation fuel in the different scenarios is taken into account (Figure 4). This is because Chinese total domestic consumption of crops for biofuel in this scenario remains relatively stable, even under the strong increase in biofuel production. Chinese private household demand of food is relative price elastic and therefore the increase in domestic prices of biofuel crops leads to a significant shift in the composition of domestic demand rather than an expansion of total demand for biofuel crops. Driven by the Armington approach, this change in consumption pattern is only partially reflected in an increase in world prices.

Clearly, on a global level, the assumption that all countries with voluntary targets will achieve these targets by 2020 induces a strong increase in the global demand for biofuel. Conversely, the simulation of EU and US policies (EU&US) and the simulation of the biofuel policies in Canada, Brazil and other countries (Glob-BFM) increase the biofuel share of transportation fuels by less than 1.5 percentage points each. Adding China, Australia and Japan (i.e., the Glob-BFM&Vol scenario) leads to more than double the growth of the biofuel share. Given the size of the Chinese economy and its voluntary target of 15% in transportation fuel, much of this effect can be attributed to China.

Returning to Figure 3, it becomes clear that not only agricultural prices are affected. The crude oil price declines due to the introduction of the biofuel directive because the demand for crude oil diminishes. Again, the implementation of mandatory targets on a global level triggers the largest response. If only the EU and the US are considered, crude oil prices would drop by less than 5%, whereas the effect is more than doubled by adding the other countries with mandatory or voluntary targets.

One of the most important questions are: How much trade in agricultural products is induced by biofuel policy measures in different countries and will countries which introduce biofuel policies be able to produce enough biomass to fill their national mandates out of own resources or will national biofuel mandates induce large trade flows? Or – in a nutshell – will European or North American biofuel be 'Biofuel do Brazil'?

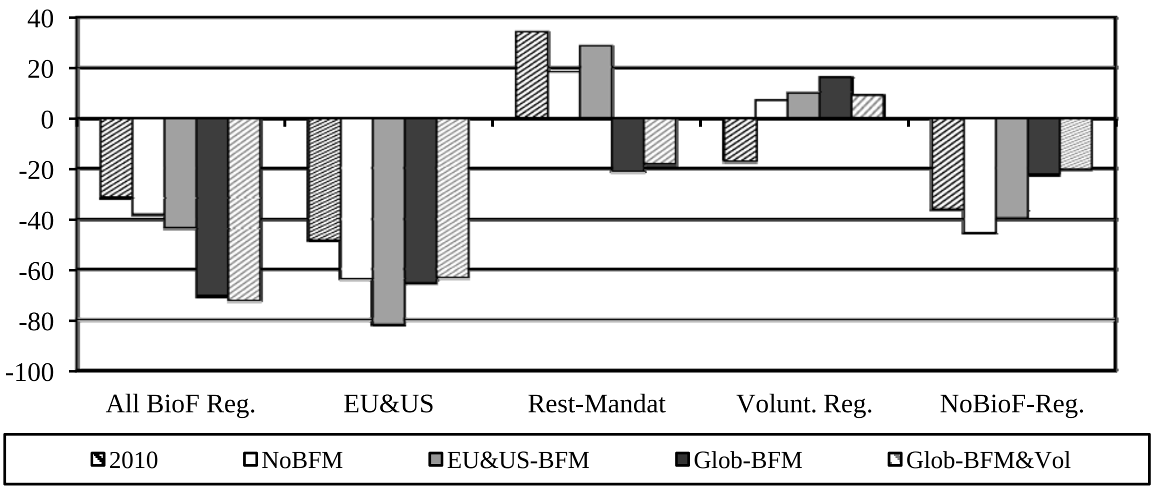
**Figure 5: Exports in primary agricultural products (in bill. US$, real 2010)**




Remark: 'NO BIOF-REG.' comprises all regions without any mandatory or voluntary biofuel policies. For further explanations of the regional aggregation see remarks for Figure 4.
Source: Own calculations based on LEITAP.

Under the reference scenario NoBFM total trade in primary agricultural products increases by more than 21% (Figure 5). This growth in agricultural trade is triggered by population and income growth at global level. Mandatory and voluntary biofuel policies provide an additional boost to agricultural trade this increase. Under the most 'extreme' scenario Glob-BFM&Vol exports in primary agricultural commodities grow by more than 43% relative to situation in 2010, i.e. the impact of multinational biofuel policies exceed the impact of growing per capita consumption on global agricultural trade.

**Figure 6: Trade balance in primary agricultural products (in bill. US$, real 2010)**

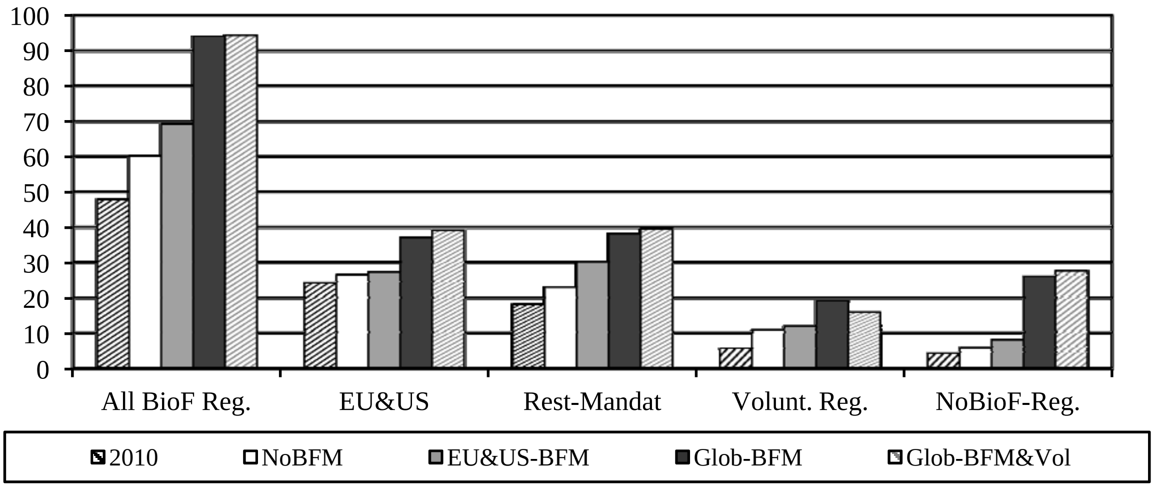



Remark: see Figures 4 and 5.
Source: Own calculations based on LEITAP.

This development is also shown in Figure 6, where the group of countries with biofuel policies runs into a large trade deficit for primary agricultural products under the biofuel policy scenarios. The aggregated region of the EU and the US show a growing trade deficit under a mandatory biofuel scenario. However, when other countries implement similar policies, e.g. under the Glob-BFM scenario, net-imports of the EU&US decline and production is increasing due to increasing agricultural prices. A similar development can be shown for those countries without biofuel incentives (NoBioF-Reg.). Here net-imports of agricultural commodities decline also.

As already discussed for Figure 5, biofuel policies have a significant impact on trade in agricultural products. This development is even stronger for 1st generation biofuel crops (wheat, coarse grain, oilseeds and sugar). Exports of this group of agricultural products increase by around 23% between 2010 and 2020 under the reference scenario. If biofuel policies are implemented, however, exports increase by more than 130% under the Glob-BFM&Vol scenario!

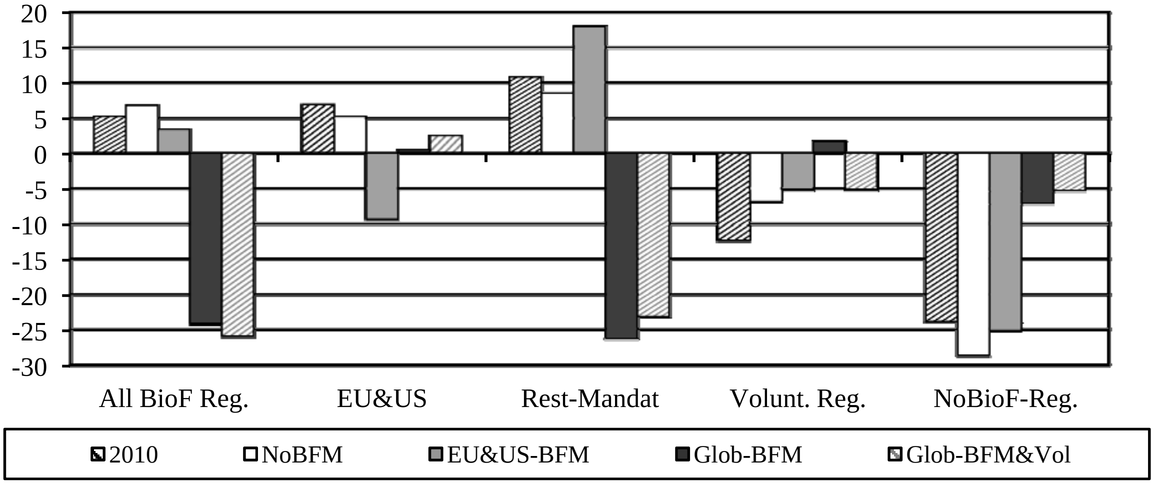
**Figure 7: Exports in biofuel crop trade (in bill. US$, real 2010)**




Remark: see Figures 4 and 5.
Source: Own calculations based on LEITAP.

Figure 8 shows a growing deterioration of the trade balance in biofuel crop products for those regions implementing biofuel policies. The EU&US will become net-importers of agricultural commodities used for the production of biofuels under the biofuel scenarios EU&US-BFM.

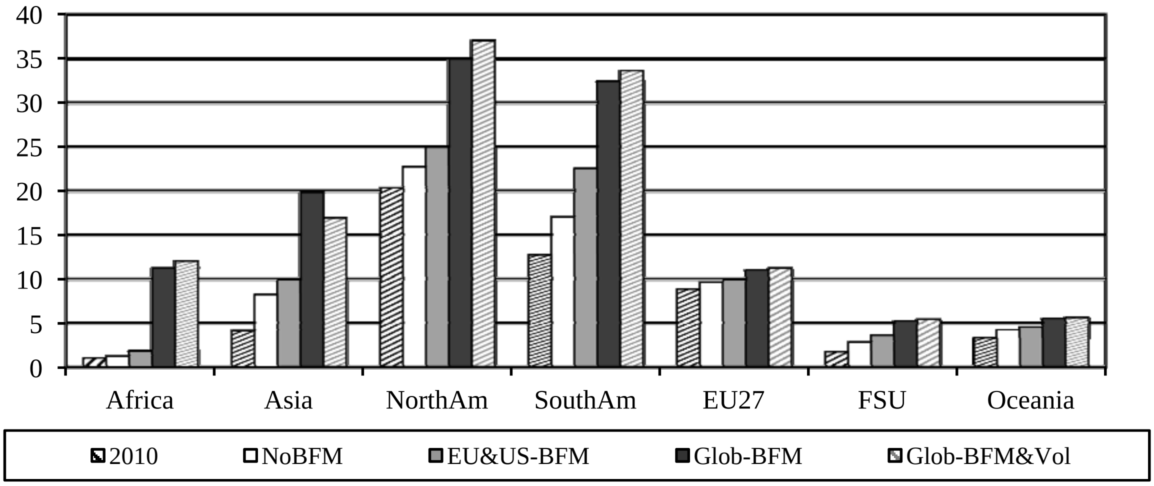
**Figure 8: Balance in biofuel crop trade (in bill. US$, real 2010)**




Remark: see Figures 4 and 5.
Source: Own calculations based on LEITAP.

Other regions, e.g., 'Rest Mandat.', as well as other high income countries, expand their net-exports in agricultural products for biofuel production under the EU&US-BFM scenario. However, as soon as these regions implement biofuel policies in their own countries, the positive balance in biofuel crop trade becomes negative, see 'Rest-Mandat' region under the Glob-BFM scenario.

**Figure 9: Exports in biofuel crop, per region (in bill. US$, real 2010)**




Remark: see Figures 4 and 5.
Source: Own calculations based on LEITAP.

While Figure 7described the changes in 1st generation biofuel crop trade for regions with different policy path-ways, Figure 9 shows the changes in biofuel crop exports for different regions. Exports in biofuel crops expand significantly in North and South America with an increase of 80% and 165% respectively between 2010 and 2020 under the Glob-BFM&Vol scenario. This result indicates that both Americas show the strongest expansion in biofuel crop trade and more than 60% of all traded 1st generation biofuel crop originate from North or South America.

The demand for agricultural products for biofuel production is certainly not satisfied only by redirecting existing trade flows but also by stimulating agricultural production. In all regions, mandatory blending leads to a moderate increase in total primary agricultural output, as Table 1 shows. Comparing the EU&US-BFM scenario with the reference scenario, the strongest relative increase in agricultural output occurs in the EU and the US. Here, biofuel crop production increases by more than 17% under the EU&US-BFM scenario, with the strongest impact on oilseeds. In the two other biofuel scenarios, the increase in agricultural production in the EU and US regions continues. Similarly, the other regions in which mandatory biofuel policies are implemented face an intensification of agricultural production, especially under the Glob-BFM&Vol scenario. The results show that, on a global level, biofuel production is dominated by bioethanol, as opposed to biodiesel. The largest increases of production, reaching almost 50% in some regions, are observed for grains, which serve as a feedstock for bioethanol production.

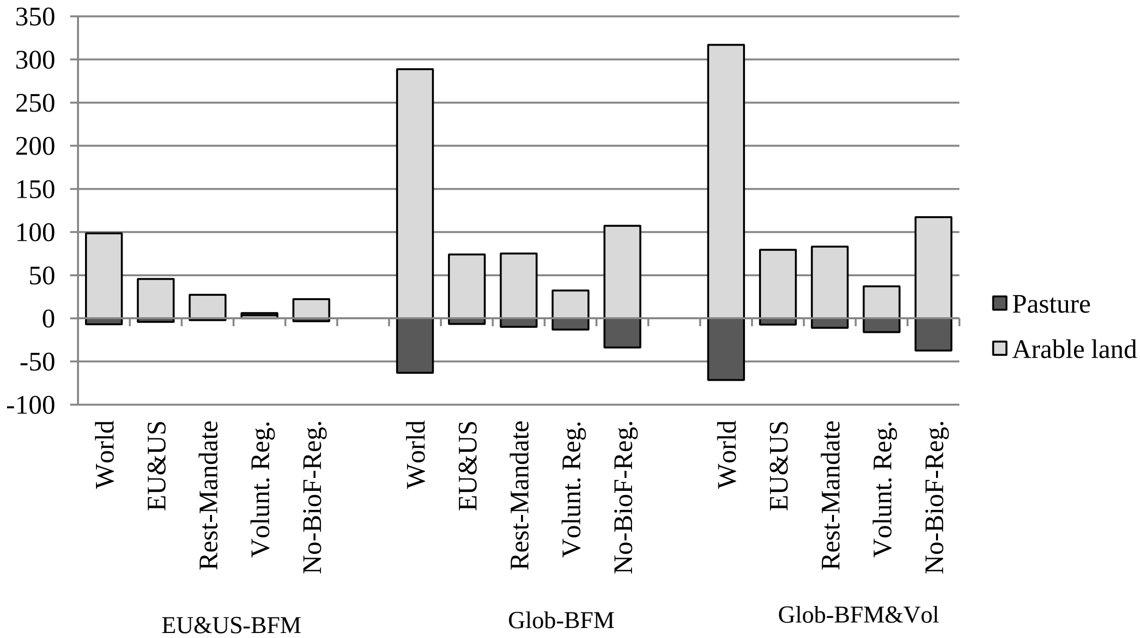
**Table 1: Change in agricultural production, in %, 2020 relative to NoBFM scenario**

| | World | All BioF Reg. | EU&US | Rest-Mandat. | Volunt. Reg. | NoBioF-Reg. |
|---|---|---|---|---|---|---|
| **Primary Agriculture** | | | | | | |
| EU&US-BFM | 0.6 | 0.8 | 0.8 | 0.8 | 0.1 | 0.5 |
| Glob-BFM | 1.2 | 1.3 | 2.0 | 0.1 | 0.5 | 1.6 |
| Glob-BFM&Vol | 1.3 | 1.4 | 2.2 | 0.2 | 0.6 | 1.7 |
| **Biofuel Crops** | | | | | | |
| EU&US-BFM | 6.7 | 10.5 | 17.5 | 4.9 | 1.7 | 2.5 |
| Glob-BFM | 16.7 | 19.1 | 25.0 | 14.2 | 15.4 | 13.3 |
| Glob-BFM&Vol | 18.2 | 20.5 | 26.4 | 15.5 | 17.5 | 14.6 |
| **Grains** | | | | | | |
| EU&US-BFM | 6.6 | 12.7 | 19.9 | 0.4 | -2.6 | 1.1 |
| Glob-BFM | 33.0 | 36.4 | 32.0 | 41.9 | 41.2 | 26.5 |
| Glob-BFM&Vol | 36.9 | 40.3 | 34.9 | 46.9 | 48.2 | 29.7 |
| **Oilseeds** | | | | | | |
| EU&US-BFM | 15.3 | 18.6 | 29.8 | 12.3 | 6.0 | 9.0 |
| Glob-BFM | 19.0 | 21.8 | 35.6 | 14.0 | 5.6 | 19.0 |
| Glob-BFM&Vol | 19.5 | 22.3 | 36.1 | 14.5 | 6.1 | 19.5 |

Remarks: For explanations of the regional aggregation see remarks for Figures 4-5.
/1: This aggregate summarizes total average production change of sugar beet/cane, cereals and oilseeds.
/2: This aggregate summarizes total average production change of biodiesel und ethanol.
Source: Own calculations based on LEITAP.

These developments in agricultural production are reflected in the pattern of land use developments (Figure 10). In all regions, land use increases compared with the reference scenario if the biofuel targets are implemented by a mandatory blending commitment. In the EU and the US, the slight decline in agricultural land use predicted in the reference scenario (not shown) reverses in the EU&US-BFM scenario. In the scenario in which both mandatory and voluntary biofuel policies are implemented (Glob-BFM&Vol), global land use for agricultural purposes is predicted to increase by almost 4% over the NoBFM scenario. Substitution between pasture and cropland does occur, but Figure 10 clearly shows that substantial expansion of agricultural land use occurs as well. This significant expansion of agricultural land use on a global scale has consequences for GHG emissions and biodiversity. The impact of increasing land demand, driven by enhanced biofuel production, is discussed at the end of this chapter.

**Figure 10: Change in agricultural land use, in million ha, 2020 compared to NoBFM scenario**

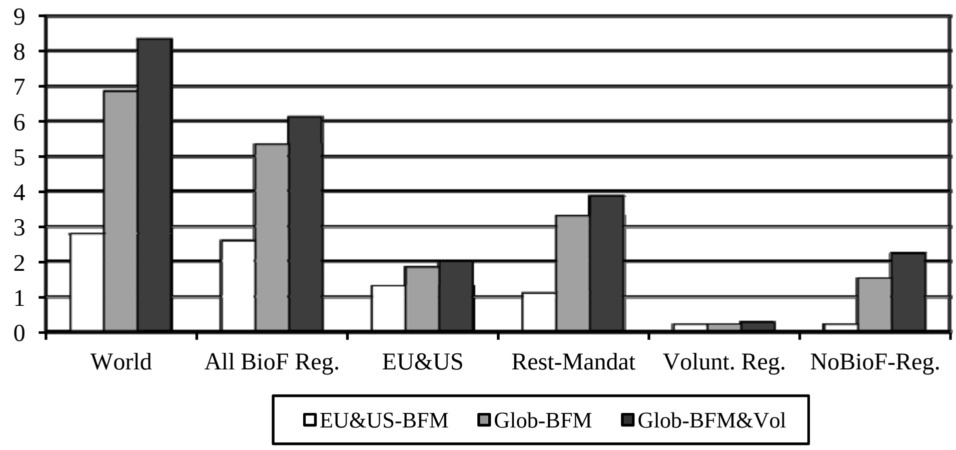



Remarks: For explanations of the regional aggregation see remarks for Figures 4-5.
Source: Own calculations based on LEITAP.

## *4.2 Impacts on GHG emissions*

As described above, the combined analysis of an economic model and a land use model at the grid-cell level allows for an analysis of changes in GHG emissions in different scenarios. The IMAGE model provides results for GHG emissions from various sources, such as energy, industry or land use. Figure 11 illustrates the increasing GHG emissions caused by the increase of agricultural land use across different regions presented in this analysis. As observed for some of the economic indicators, land use emissions do not grow proportionally with the total amount of biofuel produced. Because agricultural production in countries where there are no biofuel regulations contributes to fulfilling the blending targets in countries with mandatory biofuel policies, cumulative land use GHG emissions also increase in this part of the world.

**Figure 11: Change in cumulative land use GHG emissions, in Pg C eq, 2020 compared to NoBFM scenario**




Remarks: For explanations of the regional aggregation see remarks for Figures 4-5.
Source: Own calculations based on IMAGE.

## *4.3 Discussion*

As mentioned in the introduction, a number of studies analyze the impact of biofuel policies on agricultural markets as well as on environmental indicators. These studies can be broadly grouped into three categories. The first group considers the impact of DRE and EISA and is similar to the EU&US-BFM scenario in this study. The second type of analysis covers all currently announced biofuel policies, including Brazil, Japan and others, which roughly corresponds to the Glob-BFM&Vol scenario. Studies from the third group examine the two programs separately, a perspective that was not taken here.

The findings in this paper from the LEITAP and IMAGE simulations are only partially in line with the results from other authors. This is not surprising because differences in model design and parameters, including regional and product aggregation, data input, base year and baseline, assumptions about important exogenous variables and details of the scenario set-up, necessarily lead to different results. Direct comparison is further hampered because, as Witzke (2010) points out, it is difficult, if not unfeasible, to identify which factors or combinations of factors actually cause the discrepancies.

However, for a joint implementation of DRE and EISA, the OECD (2008) finds price increases for coarse grains and oilseeds that are broadly in line with the findings from this study for the EU&US-scenario. In contrast, the expansion of crop area dedicated to biofuel expected by the authors of the OECD (2008) is less than half of what was found here. Similarly, the OECD expects a lower increase in biofuel production. Of course, comparability between the two studies is hampered by the differences in time horizons. Although the OECD (2008) reports an average over 2013-2017, this paper considers only 2020, when both policies are assumed to be fully implemented and a larger impact is logically consistent. Moreover, the OECD study assumes that a second generation of biofuel will be produced in the EU and in the US and consequently specifies lower targets for the share of first generation biofuel than does our paper.

A comparison with the evaluation of EISA and DRE by Hertel et al. (2010a) is complicated by diverging policy assumptions. We assume that the EU 10% target is reached and that EISA reaches its goal of using 36 billion gallons of corn ethanol, whereas Hertel et al. assume a significantly smaller policy shock, particularly for the US. However, Hertel et al. find that the changes to oilseed production in the US and the EU are significant, as in this study. The changes to coarse grain production are lower than in this study. Similar to our results, the trade balance for biofuel crops in the US and the EU deteriorates and cropland expands, although at lower rates than what was found in the simulations for this paper.

Timilsina et al. (2010) investigate the impact of a worldwide implementation of all biofuel targets that had been announced by the year that the study was published, a policy environment that comes close to the Glob-BFM&Vol scenario in this analysis. Despite the similarity in the policy scenario, the impact on the production of biofuels and agricultural goods, prices for agricultural goods and crude oil, and the food supply found by Timilsina et al. are remarkably lower than our simulations. The same holds true for the impact on land use. Part of this discrepancy is likely due to different assumptions in the baseline scenario. Whereas Timilsina et al. incorporate some biofuel policies into their baseline, the point of comparison for this study is a world without any biofuel mandates, which necessary leads to a larger impact.

A recent IFPRI study, see Al-Riffai et al. (2010), applies a modified version of a global computable general equilibrium model MIRAGE. Comparison is difficult because it assesses only the effect of DRE implementation and assumes a lower target of biofuel to be used in transport in EU by 2020. Logically, the changes in many economic and bio-physical variables are lower than those found here.

Another study that considers only the EU´s DRE is Banse (2008). Detailed comparison seems undue since the reference scenario differs considerably from the one used here. The reference scenario in Banse (2008) assumes a conclusion of the World Trade Organization (WTO) negotiations and significant tariff reductions by 2020. The impact of DRE against this background can be expected to differ significantly from the impact of DRE in a world without a large reduction in trade barriers. However, economic variables, such as the prices for grains and oilseeds, the import share of biofuel crops, agricultural land use and agricultural production, move in the same direction as they do in the simulations conducted for this paper. Dehue and Hettinga (2008) focus their work on the impact of EU policies on land use and find that roughly 10 million hectares of additional land would be needed to match the requirements of the DRE, which is again lower than what was found for this study but can be explained by the smaller policy shock. The same holds true for Eickhout et al. (2008), who anticipate an increase up to three times as large as Dehue and Hettinga (2008) but still below the results from this study.

Britz et al. (2011) apply a combination of the CAPRI model and GTAP to a scenario that can be described as a partial implementation of the EU´s DRE. Given that the primary goal of the authors is to illustrate an innovative modeling approach rather than to provide a thorough impact assessment, a comparatively limited number of results are discussed. The authors find that the price of oilseeds increases in a more pronounced manner than the prices we find in this study, a surprising outcome because the policy shock is smaller than the one implemented here. Cropland cover expansion is less than in our study, which seems a logical consequence of the smaller policy shock. As in our study, EU net exports of oilseeds decline.

On the US side, a study focused on the impact of EISA was conducted by the US Environmental Protection Agency (EPA, 2010). The rise in world corn prices is in a similar range as the one found in this study for grain prices under the EU&US-BFM scenario. Although this may seem surprising because a combination of EU and US policies suggests a larger impact than a US-only change, the similarity is probably because the aggregate rise is mainly due to a rise in corn prices. Corn plays a predominant role in biofuel production in the US, but not in the EU. With regard to land use, the authors of EPA 2010 find a worldwide increase of roughly 1 million hectares of cropland in response to EISA. Although this number is considerably lower than what is estimated here, part of the discrepancy can be explained by the different scenario specifications. The same reasoning is likely to explain the lower impact on world food consumption compared to a joint implementation of US and EU biofuel policies.

A study focusing on the question of food security was conducted by Elobeid et al. (2007). The authors investigate the impact of higher crude oil prices on food security, assuming that this would trigger a significant increase in US corn-based bioethanol production. The results are not directly comparable to the ones in this analysis because only the impact on the cost of the food basket, but not the change in consumption, is investigated. Nevertheless, a common conclusion seems to be that food consumption patterns are predominantly affected in regions where food price elasticities are high and crops represent a comparatively large share of the food basket.

Hertel et al. (2010) study the consumption impact of an increase in US corn-based ethanol production and find a global decrease of coarse grain consumption in the range of the simulation in this study. The authors also investigate the effects on land use and find a global expansion of crop area by 3.8 million hectares, which is lower than in our study. Furthermore, on the land issue, Searchinger et al. (2008) estimate an increase of 10.8 million hectares of additional land brought into cultivation due to increased demand for US corn ethanol. Although both figures are below our estimate, only US policies are simulated in Searchinger et al. (2008), and the shock for the US is less than half of what we assume.

With regards to emissions, Plevin et al. (2010) estimated the range of indirect land use change emissions to be 10 to 340 g $CO_2$ $MJ^{-1}$ (including an uncertainty in production of 15 to 45 years). Several (mostly economic) modeling exercises in Prins et al. (2010) show a range for land use change emissions of 4 – 242 g $CO_2$ $MJ^{-1}$ (payback time of 30 years). Overmars et al. (2012) estimated an indirect land use change factor based on monitoring data with a range of 26-154 $CO_2$ $MJ^{-1}$ for bioethanol and 30-204 $CO_2$ $MJ^{-1}$ for biodiesel (over 20 years). Finally, Edwards et al. (2010) reports specific indirect land use change values for several feedstocks of 14 -337 $CO_2$ $MJ^{-1}$ for biodiesel and 19-151 $CO_2$ $MJ^{-1}$ for bioethanol (over 20 years).

Summarizing, the increase in land use seems to be where the results differ the most between various sources in the literature. Why are the projections so different? Edwards et al. (2010) analyzed reasons for these differences and noted, “The major factors causing dispersion of model results are: by-product effects (mostly affecting LEITAP), how much yields increase with price, and how much crop production is shifted to developing countries.” Another reason for this wide range of results is the differences in the assumptions about land productivity and availability. If one assumes a large amount of potential agricultural land that can be made accessible in the short or medium term, increasing land demand for biofuel crops will lead neither to a significant increase in land price nor to an increase in food prices. The problem of diverging results is further underlined by a study by Mulligan et al. (2010) that shows that crop area changes differ significantly for a marginal change in demand for particular biofuels produced by different models.

# 5 Conclusions

This paper shows the consequences of enhanced biofuel production in the regions and countries of the world that have implemented biofuel policies. These policies involve both voluntary and mandatory blending targets for transportation fuels. The quantitative modeling approach applied here is a joint economic and bio-physical analysis with a combination of the multi-sectoral economic LEITAP and the spatial bio-physical land use model IMAGE.

The simulation results of the combined model show that biofuel policies have a pronounced impact on the markets for grains, oilseeds and sugar but a rather limited impact on the production level of aggregated primary agricultural output. At the global level, the EU and US biofuel policies contribute to the increasing demand for biofuel crops. However, other countries that introduced mandatory biofuel targets, such as Brazil, Canada, India, Thailand, the Philippines and South Africa, contribute to increasing world prices for agricultural products driven by food use for fuel.

With increasing agricultural output, total agricultural area is projected to increase by approximately 4%. The great increase in crop demand in countries that implement biofuel policies exceeds domestic supply and the imports of biofuel crops from other parts of the world that do not implement biofuel policies are projected to increase significantly.

The analysis shows that, apart from direct effects of an enhanced demand for bioenergy on production and land use, the indirect effects of biofuel policies dominate. Additional production of biofuel crops within and outside countries with voluntary and mandatory biofuel policies leads to strong indirect land use changes and associated GHG emissions.

With multinational biofuel policies at global level agricultural trade significantly increases. Especially for those products which are processed to biodiesel and ethanol, which are cereals, oilseeds and sugar. With biofuel policies in place North and South American biofuel crop exports more than doubles between 2010 and 2020. Therefore, biofuel crops from Brazil and both Americas significantly contribute to the growing demand of biofuel around the world and ‘Biofuel do Brasil?’ should be recalled by ‘Biofuel da América’!

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# Annex

**Table 2: Commodity break-down**

| Crops | Biofuel Crops | Grains | Oilseeds |
|---|---|---|---|
| Rice | Wheat | Grains other than wheat | Oilseeds |
| Wheat | Sugar crops | | |
| Other Grains | Other Grains | | |
| Oilseeds | Oilseeds | | |
| Sugar | | | |
| Horticulture | | | |
| Other crops | | | |

**Table 3: Regional break-down of different aggregates**

| EU& US | Rest-Mandate | Volunt. Reg. | All BioF. Reg. | NoBioF-Reg. | HIC | BRIC | Africa | Asia |
|---|---|---|---|---|---|---|---|---|
| EU | Argentina | Australia | Argentina | Albania | Australia | Brazil | Botswana | Bangladesh |
| US | Brazil | China | Australia | Bangladesh | Canada | China | Madagascar | China |
| | Canada | Japan | Brazil | Botswana | EU | India | Morocco | India |
| | Chile | NZ | Canada | Croatia | Japan | Russia | Mozambique | Indonesia |
| | Colombia | | Chile | Korea | Korea | | Rest of North Africa | Japan |
| | India | | China | Madagascar | Korea | | Rest of SADC | Korea |
| | Indonesia | | Colombia | Malawi | New Zealand | | Rest of South African CU | Malaysia |
| | Malaysia | | EU | Mexico | Rest of EFTA | | Rest of Sub-Sahara Africa | Philippines |
| | Peru | | India | Mozambique | Rest of Europe | | South Africa | Rest of Former Soviet Union |
| | Philippines | | Indonesia | Rest of EFTA | Switzerland | | Tunisia | Rest of Middle East |
| | Rest of South America | | Japan | Rest of Europe | US | | Uganda | Rest of South Asia |
| | Rest of South-East Asia | | Malaysia | Rest of former Soviet Union | | | Zambia | Rest of South-East Asia |
| | Singapore | | New Zealand | Rest of Middle East | | | Zimbabwe | Singapore |
| | Thailand | | Peru | Rest of North Africa | | | | Sri Lanka |
| | Uruguay | | Philippines | Rest of SADC | | | | Thailand |
| | Venezuela | | Rest of South America | Rest of South African CU | | | | Vietnam |
| | Vietnam | | Rest of South-East Asia | Rest of South Asia | | | | |
| | | | Singapore | Rest of Sub-Sahara Africa | | | | |
| | | | Thailand | Russia | | | | |
| | | | Uruguay | South Africa | | | | |
| | | | US | Sri Lanka | | | | |
| | | | Venezuela | Switzerland | | | | |
| | | | Vietnam | Tanzania | | | | |
| | | | | Turkey | | | | |
| | | | | Uganda | | | | |
| | | | | Zambia | | | | |
| | | | | Zimbabwe | | | | |