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GTAP Annual Conference on Global Economic Analysis
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**Paper prepared for the 14th Annual Conference on Global Economic
Analysis
"Governing Global Challenges: Climate Change, Trade, Finance and
Development"
Venice, June 16-18, 2011**

**Global impact of multinational biofuel mandates on land use,
feedstock prices, international trade and greenhouse gas
emissions**

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1 Introduction

Since 2001, a rapid growth of biofuel production has been observed, driven by high crude oil prices, as well as by growing interest in reducing Greenhouse-Gas-Emissions (GHG). High oil prices encouraged innovations to reduce crude oil consumption and triggered governments all over the world to stimulate the production and consumption of biofuel. To assure a certain level of reduction of GHG emissions, mandatory targets, e.g., in terms of binding blending targets, have been established. These quantitative measures set targets for the share of renewable fuels (biofuel) in fuel consumption. Mandatory, but also voluntary, requirements are currently imposed for liquid biofuel in many major world economies except for Russia, Sorda et al. (2010).

The consequences of biofuel policies on agricultural markets and GHG emissions have been analyzed in numerous papers. The extensive overview of such studies can be found in Rajagopal and Zilberman (2007). As Rajagopal and Zilberman point out, most of these studies focus on simulating the impact of renewable fuel mandates either at national or at global level. The majority of these studies, however, 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) or both; e.g., OECD (2008), Al-Riffai et al. (2010), Banse et al. (2008), Hertel et al. (2010).

However, none of the studies simultaneously assess the global consequences of biofuel policies in those countries mentioned above. This is an important shortcoming because regions not covered by these analyses, but implementing biofuel targets, are often very important producers and exporters of agricultural commodities. The important question is: how will biofuel programs in these countries affect their future exports if more agricultural commodities are used for domestic purposes, e.g., as feedstocks for biofuel production, and how will the world prices of these products respond? In this paper, we address these questions by analyzing the consequence of obligatory biofuel mandate implementation in all regions having such a policy. As far as we know, this paper is a first attempt to do this.

This paper explicitly examines the joint effect of obligatory biofuel mandates in the EU, the US, Canada, Brazil, the Rest of South America, India, and South-East Asia on land, food production, total GHG balance, trade and prices of agricultural commodities. We will also look at how these policies will influence biofuel production in regions where biofuel targets are voluntary, e.g., China, Japan, Australia and New Zealand. By using the CGE-model LEITAP, coupled to the integrated assessment model IMAGE, cross-sectoral effects of biofuel mandates, geographically explicit land use, and environmental effects like GHG balances and carbon stocks will also be taken into account.

1.1 *Biofuel policies*

The wide range of policy instruments is used to encourage and support biofuel production; FAO (2008), Rajagopal and Zilberman (2007), Sorda et al. (2010). Since biofuel production is not profitable in all countries, with the exception of Brazil, it has to be supported to become competitive. This is done by applying such policy instruments as subsidies and tax exemptions. Other forms of support include the policy measures influencing the biofuel supply chain directly or indirectly via subsidies for technological innovation, production factors subsidies, government purchases and investments in infrastructure for biofuel storage, transportation and use. Also, tariff barriers for biofuel are often implemented to protect domestic producers. These policy measures stimulate biofuel production but do not assure meeting a production level required to, e.g., meet certain GHG emission

reduction targets. Therefore, many countries set targets - biofuel blending mandates - for the share of renewable fuels (biofuel) in fuel consumption.

The mandatory but also voluntary requirements are currently imposed for liquid biofuel in all major world economies except for Russia. In the EU, the US, Canada, Brazil, Argentina, Colombia, India, Thailand, Indonesia and the Philippines, the mandatory requirements for both ethanol and biodiesel are introduced. Paraguay and Ecuador employ an ethanol mandate and Uruguay and Thailand a biodiesel mandate. The targets are differently formulated in different countries. In the EU, the US, Canada, Brazil, Argentina, Colombia, India, Thailand, Indonesia and the Philippines, mandatory requirements for both ethanol and biodiesel have been introduced. Paraguay and Ecuador employ ethanol mandates and Uruguay and Thailand apply biodiesel mandates. In these countries the targets are set at different levels. In the EU, 10% biofuel in transport in 2020 are obligatory; by 2022 36 billion gallons of fuels from renewable energy must be used in US transportation, while Canadian mandates apply for 5% renewable content in gasoline 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 B5¹ in 2010 which are supposed to increase over time to E10+ and B20+, respectively. 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. Also China, Japan and Australia set non-binding targets for biofuel production.

1.2 Effects of biofuel mandates: literature overview

The consequences of biofuel policies on agricultural markets and GHG emissions have been analyzed in numerous papers. The extensive overview of such studies can be found in Rajagopal and Zilberman (2007). As Rajagopal and Zilberman point out, most of these studies focus on simulating the impact of renewable fuel mandate at a national or global level. The majority of these studies analyses the impact of the EU Directive on Renewable Energy (DRE) of 2009 or US Energy Independence and Security Act of 2007 (EISA). The first one implements a minimum binding target of 10% biofuel in transport by 2020. According to the second one, 36 billion gallons of renewables must be used in transport fuel by 2022. Below, we present the global results of biofuel mandates implementation presented in selected studies.

The OECD (2008) assessment of biofuel policies analyses the impact of DRE and EISA using the OECD/FAO AGLINK-COSIMO partial equilibrium model of domestic and international markets for major temperate-zone agricultural commodities. It assumes that next to the first, also a second, generation of biofuel will be produced in the EU and in the US in the simulation period 2013 - 2017. Therefore, it specifies lower targets for the first generation of biofuel than in DRE and EISA. For instance, in the absence of second-generation biofuel, the EU 2020 biofuel share is reduced to 8%, of which 6.67% will to be reached by 2017. Under these assumptions, the OECD projects that DRE and EISA implementation will result in increase of total ethanol production by 17% and total biodiesel production by about 75% average in 2013-2017 compared with the baseline projection where biofuel policies are not considered. However, the first generation of biofuel will be responsible only for about 11% of ethanol and 50% increase of biodiesel production. The additional production of first-generation biofuels results in extra demand for feedstock commodities which pushes up prices for

¹ E# describes the percentage of ethanol in the ethanol-gasoline mixture by volume, e.g., E10 stands for fuels with 90% gasoline 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.

these commodities and creates additional demand for land. The most pronounced world price increases are projected for coarse grains (3%) and for vegetable oils (14%). Global crop area increase associated with the first generation of biofuel production is equal to about 3.6 million hectares (0.4% increase compared with the baseline) from which about 1.1 million hectares (0.12% increase compared with the baseline) results from DRE.

A recent IFPRI study, see Al-Riffai et al. (2010), commissioned by DG Trade of the EU-Commission applies a modified version of a global computable general equilibrium model MIRAGE. It assesses effect of DRE implementation and assumes binding target of 5.6% first generation biofuel used in transport in EU by 2020. According to the simulation results, the DRE causes a global increase of ethanol and biodiesel production by 7.6% and 5.1% compared to the reference scenario. Globally, the biofuel mandate leads to an increase in agricultural land use by 0.03% equivalent to 0.8 million hectares. The calculated emissions balance implied by the European mandate is positive and amounts 13 million tons CO₂ equivalent. Sensitivity analysis carried out under different mandatory blending (from 4.65 to 8.6%) shows that saving GHG emission effect is decreasing when the level of the mandate increases since higher blending target results in more pressure on land and consequently use of less efficient land in the agricultural production.

Both assessments presented above calculate quite small direct and indirect land use effects of EU and US biofuel mandates. In contrast, the study by Banse et al. (2008) utilizing the EURURALIS project methodology, Dehue and Hettinga (2008) report prepared for the Gallagher Review and the Netherlands Environmental Assessment Agency report by Eickhout et al. (2008a) provides much higher estimates of the agricultural land requirements of the EU mandate. Numbers for the respective studies are about 50, 20-30 and 19-31 million ha. At the same time, Banse et al (2008), using CGE model LEITAP, projects similar increase of the biofuel feedstock prices as OECD (2008). Also a study by Mulligan et al. (2010) shows that crop area changes for a marginal change in demand for particular biofuels produced by different models differ significantly.

Why are projections in land use changes so different in different studies? Edwards et al. (2010) analyzed reasons for these differences and point out that “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.” The same factors seems to be the underlying causes of the differences in land use changes as an effect of biofuel mandate implementation in different studies. Another reason for these wide-spread results are differences in the assumptions of available land for agriculture. If one assumes a large amount of potential agricultural land, growing land demand for biofuel crops will neither lead to a significant increase in land price nor to a boost on food prices,. Most studies mentioned above do not consider changes in food consumption resulting from biofuel mandates.

2 Quantitative Approach

This paper explicitly examines the joint effect of obligatory biofuel mandates in the EU, the US, Canada, Brazil, Rest of South America, India, and South-East Asia on land, food production, total GHG balance, trade and prices of agricultural commodities.

2.1 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 characterizing economic linkages

among regions, linked together with individual country input-output databases which account for intersectoral linkages. All monetary values of the data are in \$US millions and the base year for version 6 is 2001. This version of the database divides the world into 88 regions. The database distinguishes 57 sectors in each of the regions. That is, for each of the 88 regions there are input-output tables with 57 sectors that depict the backward and forward linkages amongst activities.

The initial data base was aggregated and adjusted to implement two new sectors – ethanol and biodiesel – representing biofuel policy in the model. These new sectors produce two products each; the main product and byproduct. The ethanol byproduct is Dried Distillers Grains with Solubles (DDGS) and biodiesel byproduct - oilseed meals (BDBP).

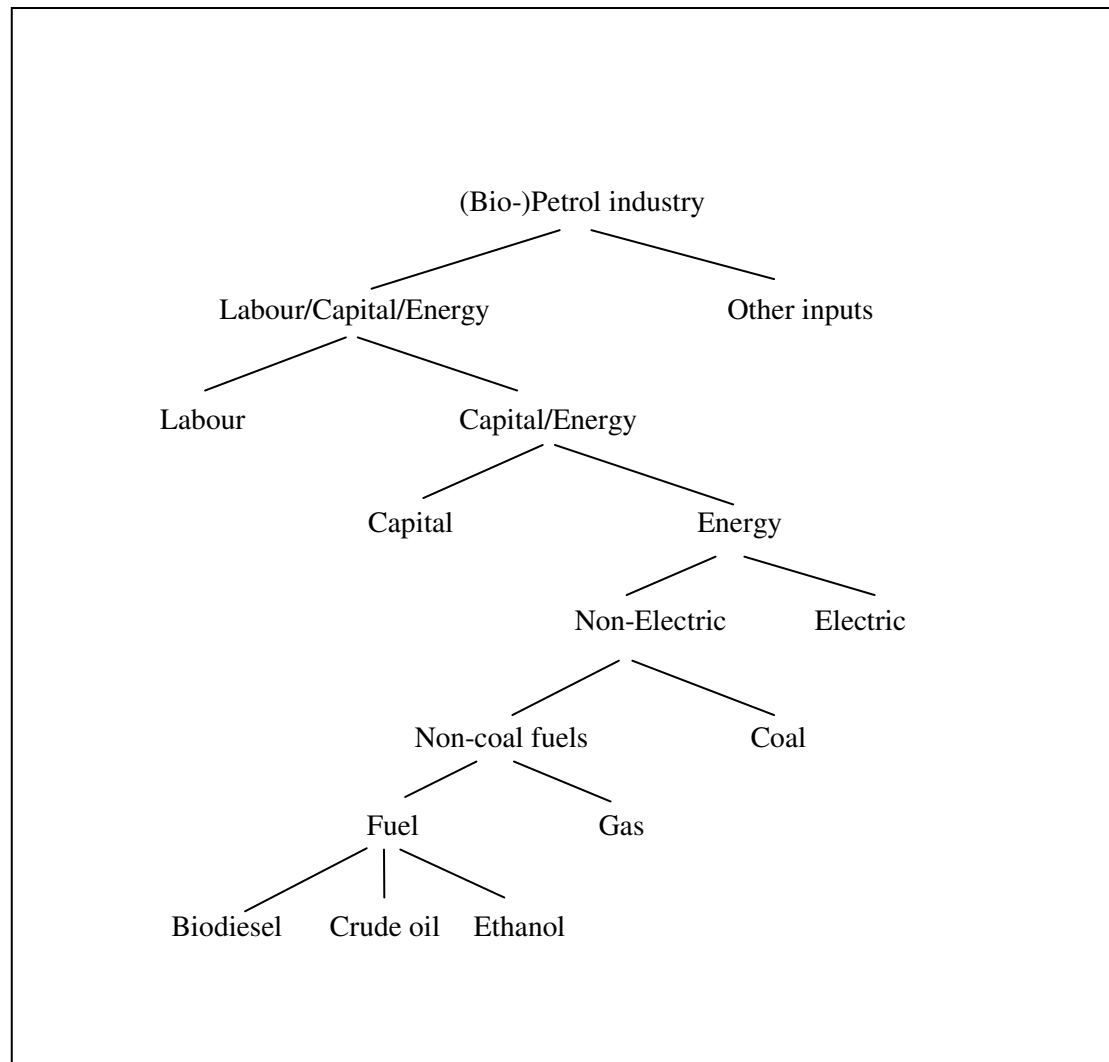
Finally, we distinguish 45 regions, 26 sectors and 28 products. The sectoral aggregation includes, among others, agricultural sectors that use land (e.g., rice, grains, wheat, oilseed, sugar, horticulture, other crops, cattle, pork and poultry, and milk), the petrol sector that demands fossil (crude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

2.2 *LEITAP model*

The economic model is the LEITAP model which is a multi-regional, multi-sectoral, static, applied general equilibrium model based on neo-classical microeconomic theory; see Nowicki et al. (2009) and van Meijl et al. (2006). It is an extended version of the standard GTAP model, Hertel (1997). The core of GTAP and LEITAP models is an input–output model, which links industries in a value added chain from primary goods, over continuously higher stages of intermediate processing, to the final assembling of goods and services for consumption. Extensions incorporated in LEITAP model includes an improved treatment of agricultural sector (like various imperfectly substitutable types of land, the land use allocation structure, land supply function, substitution between various animal feed components), agricultural policy (like production quotas and different land related payments) and biofuel policy (capital-energy substitution, fossil fuel - biofuel substitution). On the consumption side, dynamic CDE expenditure function was implemented which allows for changes in income elasticities when purchasing power parity (PPP)-corrected real GDP per capita changes. In the area of factor markets modeling, the segmentation and imperfect mobility between agriculture and non-agriculture labor and capital was introduced.

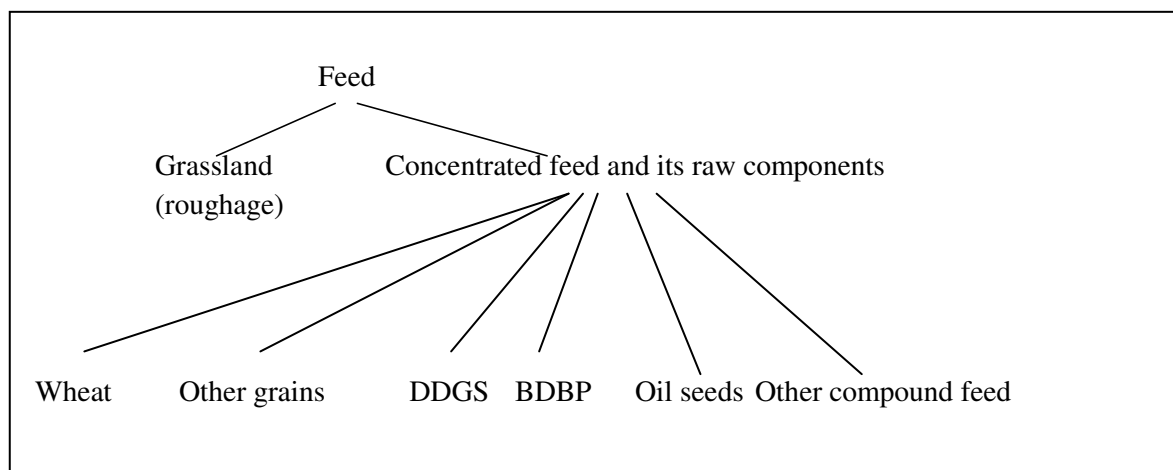
To model biofuel use in the fuel production, we adapt the nested CES function of the GTAP-E model, Burniaux and Truong (2002) and extended it for the petrol sector (Figure 1). To introduce the substitution possibility between crude oil, ethanol and biodiesel, we model different intermediate input nets in the petrol. 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.

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



The feed byproducts of biofuel production (DDGS and BDBP) are demanded only by livestock sectors in LEITAP. This demand is generated through the substitution process in the feed nest in the livestock sector. In order to model substitution between different feed components and feed byproducts of biofuel production, we use 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 level intermediate describes the composition of different types of feed commodities (cereal, oilseeds, byproducts and other compound feed).

Figure 2: The animal feed nested structure



2.3 IMAGE model

IMAGE is an integrated assessment model used for climate change and/or global land use analysis, Alcamo et al. (1994), Alcamo et al. (1999), MNP (2006). Together with LEITAP, IMAGE has been used in several studies, see Nowicki et al. (2006), Rienks (2007), OECD (2008a) to simulate the biophysical consequences of policies based on environmental indicators, e.g., agricultural land use, energy and land-use emissions. The link between LEITAP and IMAGE is established in two ways. First of all, 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, van Meijl et al. (2006). Secondly, the results of LEITAP, i.e., changes in agricultural production (including biofuels) and in the productivity of agriculture, are fed into IMAGE to analyse 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 CO₂-emissions and sequestration. For each grid-cell, seven major carbon pools are distinguished in plants and in the soil, Klein Goldewijk et al. (1994). Besides, other land related emissions like CH₄ from animals and N₂O from fertilizer use, MNP (2006). Feedbacks of emissions on the climate system are taken into account and finally result in changes in productivity of agriculture and natural biomes, Leemans et al. (2002).

3 Scenario results

3.1 Scenario description

The analysis of economic effect of biofuel mandates is based on the combined economic and bio-physical modeling approach, using the general equilibrium model LEITAP and the integrated assessment model IMAGE. The scenario setting is built on a reference scenario (NoBFM) which assumes no mandatory use of biofuel consumption in any part of the world. In addition, we run three different (biofuel-) policy scenario experiments:

- EU & US Biofuel Mandate scenario: EU&US-BFM
- Scenario with mandatory biofuel mandate implemented for all countries: Global Biofuel Mandate scenario Glob-BFM. This scenario covers the following countries Canada, Brazil, Argentina, Colombia, Paraguay, Ecuador South Africa, India, Indonesia, Thailand, Philippines.

- Scenario with mandatory and voluntary biofuel mandate implemented for all countries: Global Biofuel Mandate scenario Glob-BFM&Vol. Here we consider in addition to the Glob-BFM scenario China, Japan and Australia, where ‘voluntary’ blending is implemented as binding targets.

Based on this setting we analyze not only the global biofuel mandate effect but also examine how much the estimated biofuels mandate effect is biased when only the biofuel mandate for the EU and the US is investigated.

3.2 Scenario setup

The scenario is constructed through recursive updating of the database for six consecutive time steps, 2001-04, 2004-07, 2007-10, 2010-13 and 2013-20. The three first periods are distinguished to update the database to 2010 situation by implementing policies introduced in 2001-10 period (European Union enlargement, the Agenda 2000 reform and the 2003 CAP reform), together with the macro-economic development of the world economy. Also, the 2007 EU biofuel shares in transport were targeted.

In the first stage, exogenous GDP targets are met and given the exogenous estimates on factor endowments - skilled labor, capital and natural resources - and population. The procedure implies that an additional country level technological change is endogenously determined within the model, Hertel et al. (2004). In the final stage, this technological change is, in turn, exogenous in the remaining simulation experiments. The sectoral total factor productivities (TFP) are a linear function of country level technological change. Following the Central Planning Bureau, CPB (2003), we assumed different technological development by sector and common trends for relative sectoral TFP growth. CPB assumed that all inputs achieve the same level of technical progress within a sector; i.e., Hicks neutral technical change, see Krugman (2000). We deviate from this approach by using additional information on yields from FAO, see Bruinsma (2003), for land using sectors. For the non-land using sectors we assume Hicks neutral technical change.

The macro-economic development assumption concerning real GDP and population growth are taken from AGMEMOD model database, AGMEMOD Partnership (2008) for EU countries and from USDA (2010) for the rest of the World. Based on stylized facts of long-term economic growth we assume that capital is growing at the same rate as the GDP and employment at the same rate as the population.

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

When the policy is concerned, we assume the continuation of all policies legislated in 2010 throughout the projection period. In particular, this includes agricultural policies as well as policies related to bioenergy. So, we implemented for example, EU Renewable Energy Directive, EU 2003 CAP reform.

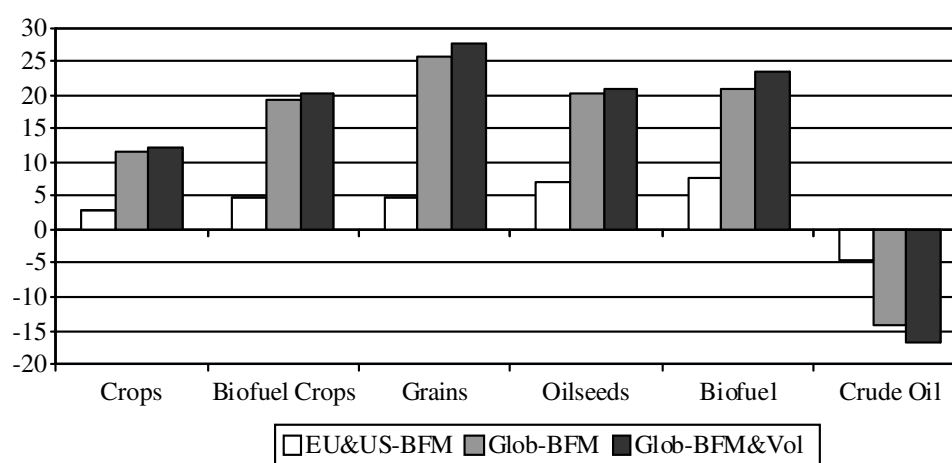
In the biofuel mandate scenarios, we fixed the share of biofuels in fuel used in transportation in 2020. To achieve this policy target, a subsidy on bioenergy inputs in the petrol sector increases endogenously to make bioenergy inputs competitive with crude oil inputs. Since this policy instrument is assumed to be ‘budget-neutral’, these input subsidies are financed by an endogenous user tax on petrol consumption which generates the required funds for the biofuel input subsidies.

The following section will present the results for the reference scenario which does not assume any enforced mandatory blending target. 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 mandatory blending obligations for different countries or regions are altered. All other policy instruments remain unchanged compared to the reference scenario

3.3 Scenario results

As already mentioned in Chapter 1, the global prices of agricultural products tend to increase with enhanced biofuel consumption as a consequence of biofuel policies. This is especially the case for those products which are directly used as biofuel crops. Figure 3 presents the changes in real agricultural prices relative to the reference scenario real NoBFM. Under the EU&US-BFM scenario world prices rise relative to the reference scenario only at a moderate rate. Amongst the crops used for biofuel production the real price of oilseeds shows an increase by 8% above the level under the reference scenario. The impact of biofuel production on world prices becomes even more obvious under the second policy scenario, where all regions with mandatory blending policies implement their target. International grain prices increase by more than 25% relative to the NoBFM scenario.

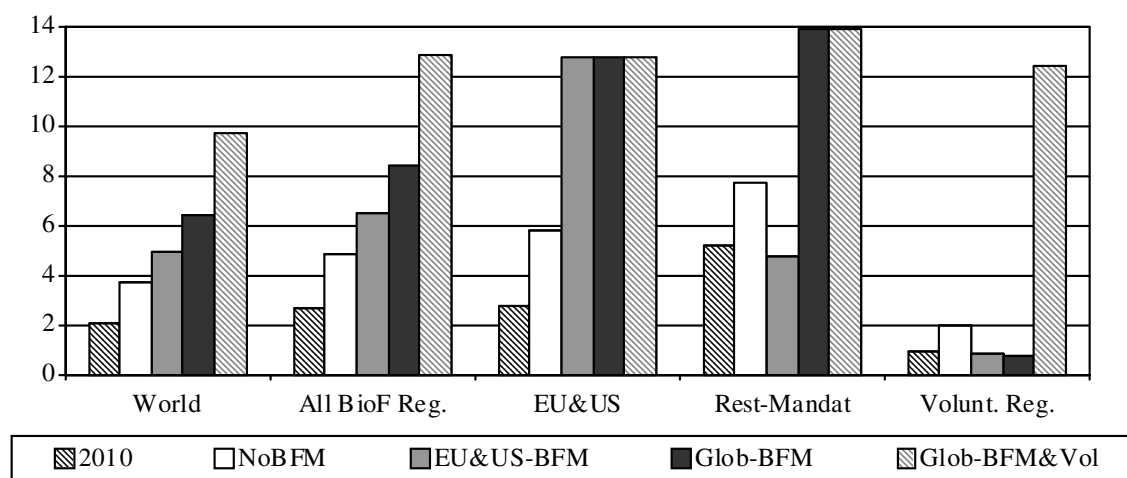
Figure 3: Change in real world prices, in percent, 2020 relative to NoBFM Scenario



Source: Own calculations based on LEITAP.

These results show that at global level ethanol consumption dominates the biofuel sector, while the EU biofuel is more based on bio-diesel. If also the voluntary biofuel policies are taken into account, the increase in biofuel crop and biofuel prices is strongest. The crude oil price declines a little bit due to the introduction of the biofuel directive as demand for crude oil diminishes.

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

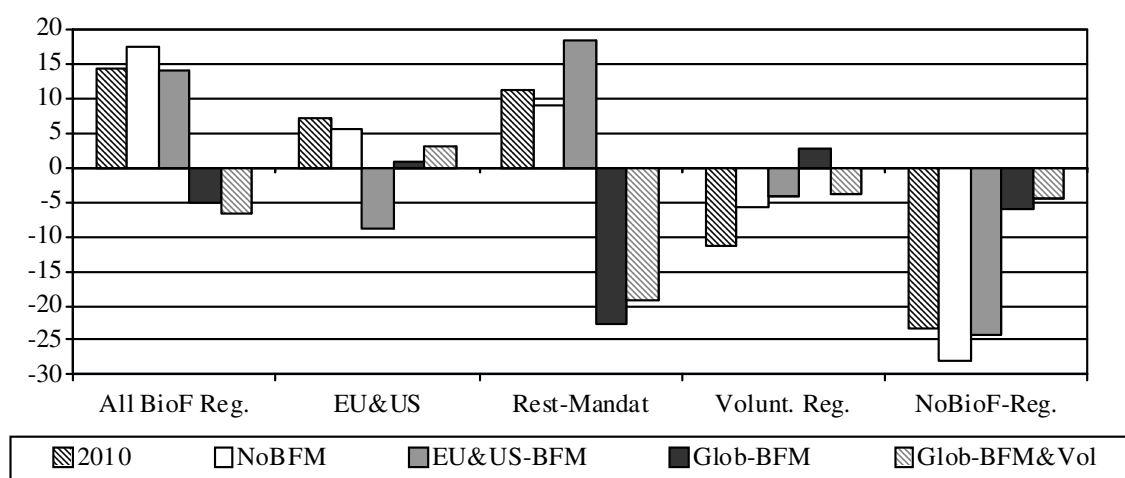
Even without an enforced use of biofuel crops through a mandate, blending of the share of biofuels in fuel consumption for transportation purposes increases. This endogenous increase in biofuel production is due to the fact that the ratio between crude oil price and prices for biofuel crops changes in favor of biofuel crops. Under the reference scenario, biofuel shares increase (Figure 4). The highest initial level of biofuel utilization under the reference situation is 5.2% in the region 'Rest-Mandat.' which includes Brazil. The integrated market of bio-ethanol in Brazil shows a relatively high share of biofuel use in the initial (2010) situation with a share of more than 23%. In this region, the use of biofuel in transportation increases, even without mandatory policies, to a share of 7.7% (+48%). In the EU and the US the endogenous growth of biofuel share leads to biofuel consumption for transportation of 2.8% in 2010 to 5.8% in 2020. These results reveal that without a mandatory blending, the envisaged biofuel targets will be reached in neither the EU nor the US.

With a mandatory blending, the EU and the US reach the required targets and biofuel shares in transportation fuel consumption are 14% in the aggregated EU&US region. However this is at the expense of other countries which do not apply mandatory biofuel policies. Under the EU&US-BFM scenario the share of biofuel use declines in the aggregated region 'Rest-Mandat.' and the 'Volunt. Reg.', see Figure 4. This decline in biofuel production in non-EU-US countries is due to the increase in relative prices between biofuel crops and crude oil. The enhanced demand for biofuel crops in the EU&US region under the EU&US-BFM 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 EU&US region over-compensates the decline in non EU countries, and at a global level, the use of biofuel crops for fuel production increases. A good indicator for this development is the decline in crude oil price under the BFD scenarios compared with reference scenario, see Figure 3. Whether the net-effect – increasing biofuel consumption and

reduced fossil energy utilization - also leads to reduced CO2 emissions will be discussed in Figure 10-12.

Figure 5 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. 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 5: Balance in biofuel crop trade (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.

At the aggregated level total agricultural production increases in the reference and both policy scenarios. In all regions, mandatory blending also leads to a moderate increase in total primary agricultural output, Table 1. Comparing the EU&US-BFM scenario with the reference, the strongest relative increase in agricultural output takes place in the EU and the US itself. Here biofuel crop production increases by almost 19% under the EU&US-BFM scenario. Under the two other biofuel scenario the increase in agricultural production in the EU&US region continues. But also the other regions where mandatory biofuel policies are implemented face an intensification of agricultural production.

Looking at different biofuel crops, Table 1 presents the results for changes in oilseed production which strongly expands under the policy scenarios. Oilseed production in the EU&US region increases by 32% under the EU&US-BFM and 41% in the Glob-BFM&Vol scenario.

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	0.7	1.0	0.8	0.1	0.5
Glob-BFM	1.4	1.2	2.4	0.2	0.5	1.7
Glob-BFM&Vol	1.5	1.3	2.6	0.3	0.6	1.9
Biofuel Crops /1						
EU&US-BFM	6.8	8.9	18.6	4.6	1.3	2.3
Glob-BFM	17.1	18.7	28.6	13.1	13.2	13.8
Glob-BFM&Vol	18.6	20.3	30.7	14.1	15.3	14.9
Grains						
EU&US-BFM	6.6	9.9	20.8	-0.1	-2.9	0.9
Glob-BFM	33.6	37.0	36.9	38.1	35.8	27.5
Glob-BFM&Vol	37.5	41.7	40.9	42.2	42.7	30.2
Oilseeds						
EU&US-BFM	15.5	16.7	31.8	11.9	5.4	9.0
Glob-BFM	19.8	19.8	39.8	13.5	4.9	19.5
Glob-BFM&Vol	20.4	20.4	40.7	13.9	5.4	20.1
Biofuels /2						
EU&US-BFM	74.2	75.9	154.0	-33.1	-56.9	-52.9
Glob-BFM	216.0	219.6	161.2	369.1	-63.1	-57.1
Glob-BFM&Vol	259.0	263.2	163.0	364.0	652.3	-57.8

Remarks: For explanations of the regional aggregation see remarks for Figures 4-5.

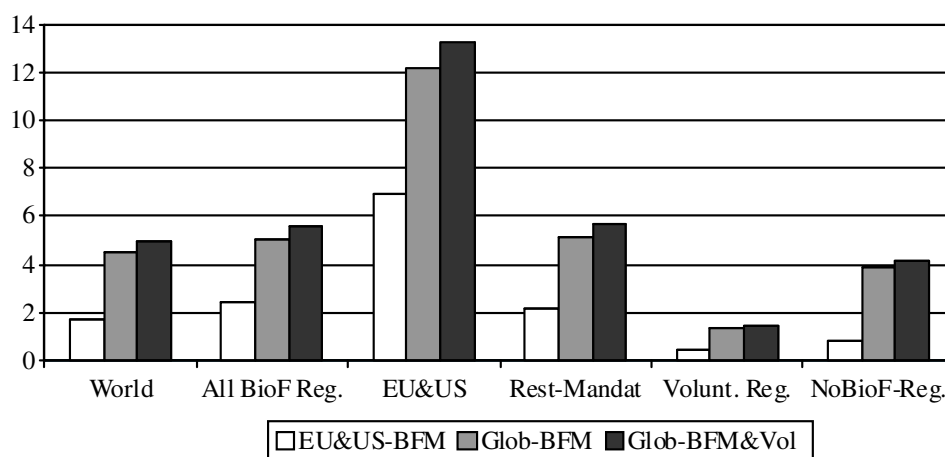
/1: This aggregate summarizes total average production change of sugar beet/cane, cereals and oilseeds.

/2: This aggregate summarizes total average production change of biodiesel und ethanol.

Source: Own calculations based on LEITAP.

These production developments lead to a similar pattern of land use developments (Figure 6). Land use increases in all regions compared with reference and therefore also at the global level if the biofuel targets are implemented by a mandatory blending commitment. In the EU and the US, the slight decline in agricultural land use in the reference scenario almost reverses under the EU&US-BFM scenario. As already seen in previous figures, the main drivers in the expansion of agricultural production and land use are the biofuel policies outside the EU and the US. Under the scenario where mandatory and voluntary biofuel policies are implemented (Glob-BFM&Vol) global land uses for agricultural purposes increase by around 5%. The consequences of this significant expansion of agricultural land use on a global scale also have consequences on GHG emissions and on biodiversity. The impact of increasing land demand driven by an enhanced biofuel production is discussed at the end of this chapter.

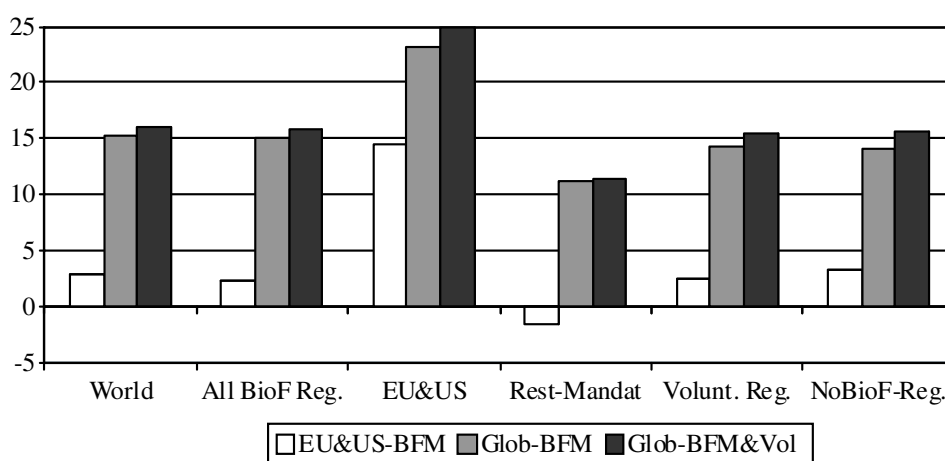
Figure 6: Change in agricultural land use, in %, 2020 relative to NoBFM scenario



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

Due to the increase in land use, prices for agricultural land also increase significantly in all regions (Figure 7). The strong increase in agricultural production in the EU and the US is driven by an increase in land use but also by a more intensive land use in both regions. Therefore, land prices in the EU and the US increase by almost 15% under the EU&US-BFM scenario and by 25% under the Glob-BFM&Vol scenario.

Figure 7: Change in agricultural land prices, in %, 2020 relative to NoBFM scenario



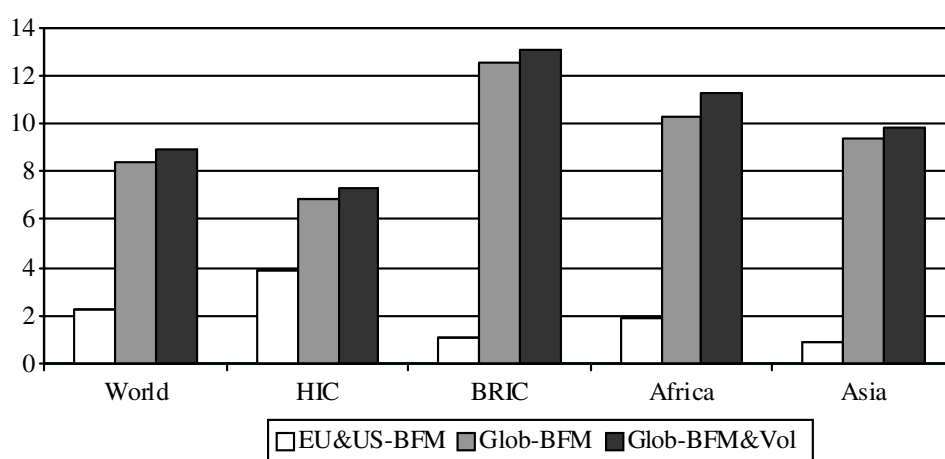
Remarks: For explanations of the regional aggregation see remarks for Figures 4-5.
Source: Own calculations based on LEITAP.

As outlined above, biofuel policies drive up agricultural prices at the world level, Figure 3. The following Figure 8 translates this increase at the global level into changes of agricultural prices in different regions in the world. At the global level agricultural prices increase by only 2.2% under the EU&US-BFM scenario. The strongest impact at global level shows an introduction of other countries' biofuel policies apart from the EU and the US. Under the Glob-BFM&Vol scenario agricultural prices

increase by 8.5%. All regions presented in Figure 8 are affected in a similar way. However, consumers in the BRIC, African and Asian countries are more affected than consumers in high income countries.

This result also indicates that the burden of global biofuel policies is not equally distributed across countries. Countries where consumers spend a higher share of available income on food products are more negatively affected than consumers who can more easily afford increasing food prices. The impact of food consumption is illustrated in Figure 9. Per capita food consumption declines most strongly in African countries. Even if the relative change is small these results show only the change in aggregated per capita consumption across all households. Due to the limitations of the current model version changed in food consumption for different household categories cannot be presented here.

Figure 8: Change in agricultural prices in different regions, in %, 2020 relative to NoBFM scenario

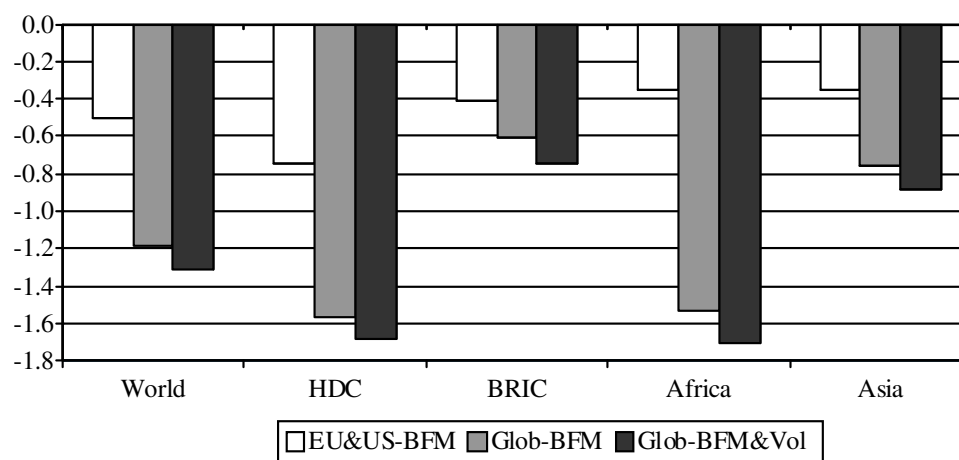


Remarks: HDC = High income countries, BRIC=Brazil, Russia, India, China.

Source: Own calculations based on LEITAP.

As already described above, the combined analysis of an economic model and a land-use model at the grid-cell level also allows for an analysis of changes in the emissions of GHG under different scenarios. The IMAGE model provides results of GHG emissions stemming from various sources, e.g., energy, industry or land use. The following, Figure 10 shows the change in total GHG emission from these three sources. Due to population growth and the increase in total production, the GHG emissions increase under all scenarios between 2010 and 2020. In 2010 more than 69% of the 13.5 Pg CO₂ eq. GHG emissions are related to energy sector. Under the reference scenario total emissions increase by 17.3% (or 2.3 Pg CO₂ eq) between 2010 and 2020. Due to the increase in agricultural land use, the relative share of GHG emission from energy declines to 66.7% and the land use increase contributes to almost 32% to the total increase in GHG emissions under the NoBFM scenario.

Figure 9: Change in per capita food consumption in different regions, in %, 2020 relative to NoBFM scenario

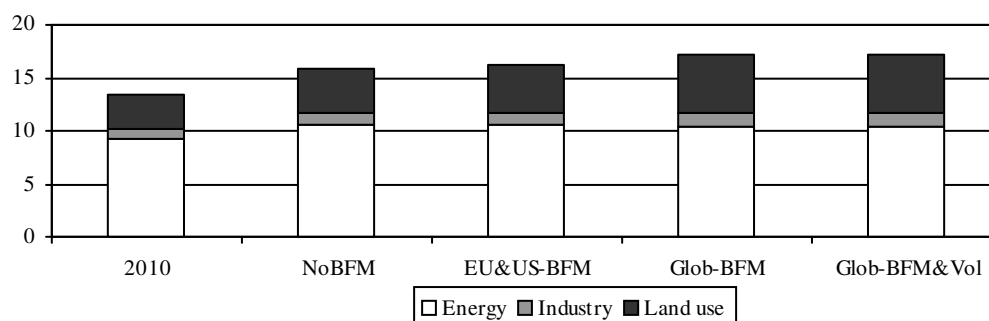


Remarks: For explanations of the regional aggregation see remarks for Figure 8.
Source: Own calculations based on LEITAP.

Under the policy scenarios where biofuel production is increased, significantly driven by mandatory and voluntary blending targets, the GHG emission are even higher compared to the 2020 level under the reference scenario. Due to the reduced fossil energy consumption, the GHG emission from energy declines, and under the Glob-BFM&Vol scenario GHG emissions from energy account only for 60% of all GHG emission. However, the change in land use drives up GHG dramatically. Under the GLOB-BFM&Vol scenario total GHG emissions in 2020 are 8.8% higher compared to the reference level in 2020.

These results show that with enhanced biofuel consumption the net-effects on the GHG emissions are clearly negative and the increases emission of direct and indirect land use changes outweigh the reduced emissions of lower fossil energy consumption.

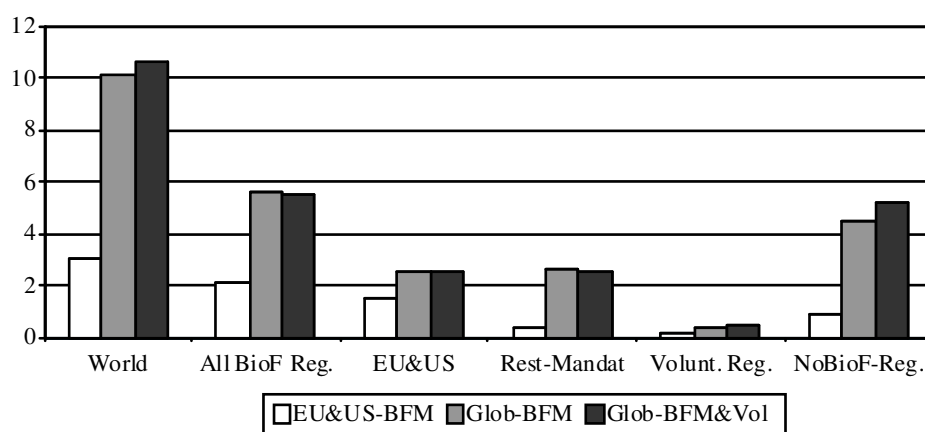
Figure 10: GHG emissions from different origins, in Pg CO₂ eq, 2010 and 2020 for different scenarios



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

Figure 11 and Figure 12 illustrate the increasing GHG emission of increasing use of agricultural land across different regions presented in this analysis. In relative terms the increase in cumulative GHG emissions in the regions implementing mandatory biofuel policies are higher compared to those regions implementing biofuel targets on a voluntary basis.²

Figure 11: Change in cumulative land use GHG emissions, in Pg CO₂ eq, 2020 relative to NoBFM scenario

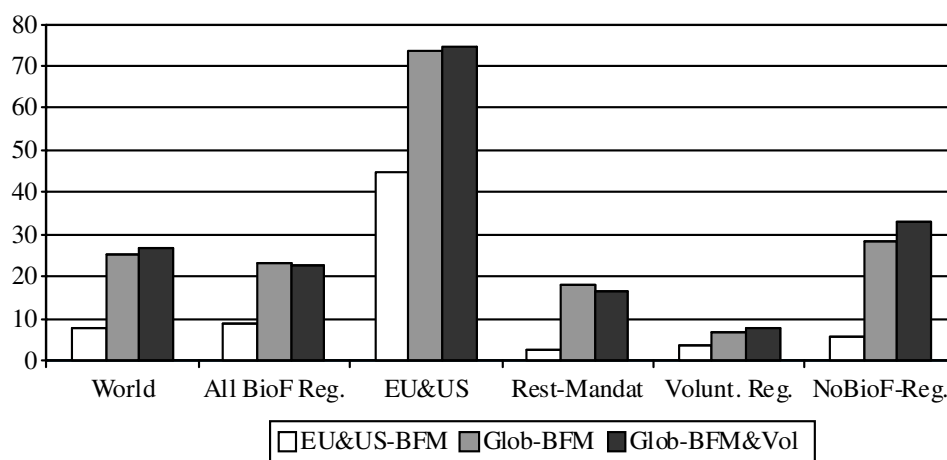


Remarks: For explanations of the regional aggregation see remarks for Figures 4-5.
Source: Own calculations based on IMAGE.

Due to the fact that agricultural production in the NoBioF-Reg is required to fulfill the blending targets with mandatory biofuel policies in those regions, cumulative land use GHG emissions are also increasing in this part of the world. The intensification of land use in the EU and the US contributes also to the significant relative change in GHG emissions, see Figure 12.

² It should be noted, however, that under the Glob-BFM&Vol scenario the 'voluntary' biofuel targets have been implemented as binding targets.

Figure 12: Change in cumulative land use GHG emissions, in %, 2020 relative to NoBFM scenario



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

4 Conclusions

This paper shows the consequences of enhanced biofuel production in those regions and countries of the world which have implemented biofuel policies in terms of voluntary and mandatory blending targets of transportation fuels. The chosen quantitative modeling approach is a based 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. But other countries, such as Brazil, Canada, India, Thailand, Philippines and South Africa, that also introduced mandatory biofuel targets contribute to an even higher extent 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 5%, while production of biofuel crops increases by around 19% indicating a more intensive production of biofuel crops at the global level. Even the strong increase in crop production in countries implementing biofuel policies exceeds domestic supply, and the imports of these biofuel crops from other parts of the world which do not implement biofuel policies are projected to increase significantly.

The results presented here clearly indicate that biofuel policies around the globe contribute to increasing food prices and increasing GHG emissions. Increasing food prices contribute to declining food consumption especially where food expenditure play a predominant role, e.g., in developing countries. The LEITAP model presents final household demand only for an average household. This approach does not allow an illustration of distributive effects of increasing food prices to food consumption for different types of households. Future research will extend to current approach to a multi-household presentation of final demand.

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 dominates. 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 which are only partly compensated by slightly reduced GHG emissions from (fossil) energy production.

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