Indirect Land Use Change Effects of Biofuel Mandates: Insights from a CGE Approach*

Preliminary draft -- please do not quote

April 15, 2010

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* Paper submitted for presentation at the Thirteenth Annual Conference on Global Economic Analysis, Bangkok, Thailand, 9-11 June 2010

1 Introduction

The last decade has seen the development of biofuel programs in many countries. These programs initially benefited from vast support since bioenergy is supposed to kill several birds with one stone: reduce CO2 emissions, reduce foreign-oil dependencies and support farm income. However, that optimistic consensus has waned with the progress of research and as the initial impacts of biofuel mandates are realized. In addition to the economic costs of such distortive policies, for the taxpayers and the consumers (including poor food consumers), the environmental costs have significantly added to the ensuing debate.

Although other quantitative methods have contributed to the overall analysis of biofuel programs, computable general equilibrium (CGE) models, especially the global CGEs, are regarded as the most appealing tool since it is the only tool that can capture all inter-sectoral and inter-regional linkages at the same time. It provides key insights on the fuel versus food versus feed versus forest debate by describing the different substitution and extension effects that can take place. Unfortunately, such a tool requires a large amount of data, parameters and modeling assumptions that can undermine the credibility of the results for policymakers and make CGE models look like the Colossus with feet of clay.

This paper aims to discuss the concept of the indirect land use change (ILUC) and its measurement using the the MIRAGE-Biofuel CGE model. Using the most recent modeling approach and available data, we assess the ILUC effects of the main biofuels mandates and discuss the robustness of these computations under alternative assumptions, as well as the relevance of the ILUC approach. Indeed, we aim to answer two questions: Is the ILUC notion relevant for policy making? Could we trust CGE estimates to compute this ILUC?

Building on the initial work of Bouet, Dimaranan and Valin (2009), the MIRAGE-Biofuel model has been extended to incorporate more disaggregated sectors (e.g. different vegetal oils), different technologies for a same product (ethanol) and the co-products (differentiated by feedstock). Due to the key role of productivity gains in the overall assessment of ILUC effects, the modeling of fertilizers has been improved, relying on more original functional forms. The introduction of co-products has also led to a careful analysis of the interaction between the crop and the livestock sectors. We have modified the modeling of animal feed demand, the possibility of yield increase in the livestock sector and the capacity for the livestock sector to choose between intensive versus extensive growth. The latter effect is crucial to see how the evolution of livestock activities will determine the demand for pasture land and for total land use.

The dataset has been updated and improved. Starting from the GTAP 7.0 release, 12 new sectors and 16 products are introduced using FAO data and biofuels specialized datasets. In addition, the model is calibrated to reproduce the 2008 existing trade, production and consumption pattern for biofuels in the main markets.

In this framework, we discuss the notion of ILUC and quantify the ILUC coefficients of biofuel mandates in the EU. In addition to the overall effects of the mandates and the average ILUC (per energy unit) discussed in existing literature, we compute marginal ILUC (for the last energy unit). We disentangle the relations between average and marginal ILUC and discuss their relevance for policy makers and study theevolution of the marginal ILUC over time in our dynamic setting and for different levels of mandate ambition. Due to our degree of disaggregation, we also analyse the marginal ILUC coefficient by crop (8 commodities). This approach allows us to show that using an average coefficient (over time, quantity and crops) as frequently used in the literature can be very misleading.

However, the measurement of the ILUC effects using a CGE model remains a challenging exercise, in particular if the final outcome (the coefficient values) are to be used for policy formulation. Researchers and policy makers should be aware of the large degree of uncertainty involved. In this study, we investigate the consequences of three families of uncertainties: policy uncertainties (ambition/extension of biofuel mandates, trade policies), parameter uncertainties (elasticity of substitution across lands and products) and modeling uncertainties (functional forms, market closures). Based on these investigations, we draw recommendations for future research, caution in using existing results but also policy recommendations for side policies that can solve policy/behavioral uncertainties.

Finally, since we assume that the ILUC effects of biofuel policies have to be considered in the decision process, should we not extend the concept to other policy assessments? Are the potential ILUC impacts of the current biofuel mandates worse than other global policies such as global trade liberalization in the agricultural sector? To answer this question, we compare the economic and ILUC effects of the biofuel policies to those of global trade liberalization (without biofuel mandates).

The recent modifications made to the MIRAGE model to allow the modeling of the interactions between biofuels development, crop and livestock markets, and direct and indirect land use changes are discussed in the next section of the paper. Section 3 provides an assessment of the ILUC effects of the EU biofuels policies. Sensitivity analyses are discussed in Section 4. A discussion of appropriateness of accounting for ILUC policy assessments in given in Section 5 and concluding remarks are given in Section 6.

2 Modeling Biofuels in MIRAGE: New Developments

The MIRAGE model[1], a computable general equilibrium model originally developed at CEPII for trade policy analysis, was extensively modified at IFPRI[2] in order to address the potential economic and environmental impact of biofuels policies. The key adaptations to the standard model are the integration of two main biofuels sectors (ethanol and biodiesel) and biofuel feedstock sectors, improved modeling of the energy sector, the modeling of co-products and the modeling of fertilizer use. The land use module which includes the decomposition of land into different land uses, and the quantification of the environmental impact of direct and indirect land use change (ILUC), was introduced in the model at the Agro-Ecological Zone (AEZ) level, allowing for infra-national modeling. The latter feature is particularly valuable for large countries where production patterns and land availability are quite heterogeneous. The overall architecture of the model has been modified to allow for various sensitivity analyses, as well as for the computation of marginal ILUC under specific assumptions. Data enhancements, model modifications, and the land use module are discussed in this section of the report.

2.1 Modified Global Biofuels Data Base

The MIRAGE model relies on the Global Trade Analysis Project (GTAP) database for global, economy-wide data. The GTAP database combines domestic input-output matrices which provide details on the intersectoral linkages within each region, and international datasets on macroeconomic aggregates, bilateral trade, protection, and energy. We started from the latest available database, GTAP 7, which describes global economic activity for the 2004 reference year in an aggregation of 113 regions and 57 sectors (Narayanan and Walmsley, 2008). The database was then modified to accommodate the sectoral changes made to the MIRAGE model.

Twenty-three new sectors were carved out of the GTAP sector aggregates -- the liquid biofuels sectors (an ethanol sector with four feed-stock specific sectors, and a biodiesel sector), major feedstock sectors (maize, rapeseed, soybeans, sunflower, palm fruit and the related oils), co- and by-

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[1] The MIRAGE (Modeling International Relationships in Applied General Equilibrium) model was developed at the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII). Documentation of the standard model is available in Bchir et al. (2002) and Decreux and Valin (2007).

[2] The development of the model for this study was undertaken by a joint team of IFPRI researchers and visiting fellow under a larger research framework including Hugo Valin (land use, biofuel mandate, co-products), Antoine Bouet (energy representation) and David Laborde (value chain, trade).

products of distilling and crushing activities, the fertilizer sector, and the transport fuels sector. For the last two sectors, we split the existing GTAP sectors with the aid of the SplitCom software.[3]

However, after several tests, we found that limitations of the SplitCom software and the initial data lead to very unsatisfactory results in our splitting of several feedstock crops, vegetable oils, and biofuel sectors. We therefore developed an original and specific procedure aiming at providing a database that is consistent in both values and quantities:

1. Agricultural production value and volume are targeted to match FAO statistics. A world price matrix for homogenous commodities was constructed in order to be consistent with international price distortions (transportation costs, tariffs, and export taxes or subsidies);
2. Production technology for new crops is inherited from the parent GTAP sector and the new sectors are deducted from the parent ones;
3. Vegetal oil sectors are built with a bottom-up approach based on crushing equations. Value and volume of both oils and meals are consistent with the prices matrix, the physical yields, and the inputs quantity;
4. Biofuels sectors are built with a bottom-up approach to respect the production costs, input requirements, production volume, and for the different type of ethanols, the different by-products. Finally, rates of profits are computed based on the difference between production costs, subsidies and output prices;
5. For steps 2, 3 and 4, the value of inputs is deducted from the relevant sectors (Other Food, Vegetal Oils, Chemical products, Fuel) in the original SAM, allowing resources and uses to be extracted from different sectors if needed (mapping n to n).
6. At each stage, consumption data are adjusted to be consistent with production and trade flows.

It is important to emphasize that this procedure, even if time consuming and delicate to operate with so many new sectors, was crucial and differs from a more simplistic approach used in the literature until now. Indeed, each step allows addressing several issues. For instance, step 1 allows us to have a more realistic level of production than using the GTAP database that performs production targeting only for OECD countries, with some flaws, and therefore has an outdated agricultural production structure for many countries. Building a consistent dataset in value and volume – thanks to the price

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[3] SplitCom, a Windows program developed by J. Mark Horridge of the Center for Policy Studies, Monash University, Australia, is specifically designed for introducing new sectors in the GTAP database by splitting existing sectors into two or three sectors. Users are required to supply as much available data on consumption, production technology, trade, and taxes either in US dollar values or as shares information for use in splitting an existing sector. The software allows for each GTAP sector to be split one at a time, each time creating a balanced and consistent database that is suitable for CGE analysis.

matrix – is also critical. Targeting only in value often generates inconsistencies in the physical linkage that thereby leads to erroneous assessments (e.g. wrong yields for extracting vegetal oil). Even more important is the role of initial prices, and price distortions, in a modeling framework using CES and CET functions. Indeed, economic models rely on optimality conditions and, in our case, as in all the CGE literature, our modeling approach leads to equalization of the marginal rate of substitution (CES case) to relative prices. It means that the physical conversion ratio is bound to the relative prices. Wrong initial prices, or incorrect price normalization, will lead to convert X units of good i (e.g. imported ethanol) in Y units of good j (e.g. domestic produced ethanol). In the case of a homogenous good, we need to have an initial price ratio equal to one and to ensure with a high elasticity of substitution that this ratio will remain close to one. Otherwise, misleading results appear, e.g. one ton of palm oil will replace only half a ton of sunflower oil, one ton of imported ethanol can replace 1.5 tons of domestic ethanol, etc. This mechanism may be neglected in many CGE exercises where the level of aggregation easily explains the imperfect substitution. In the case of this study, however, we found it imperative to directly address this challenge since we deal with a high level of sector disaggregation, a high level of substitution (among ethanols produced from different feedstocks, among vegetal oils, or among imported and domestic production), and with the critical role of physical linkages, from the crop areas to the energy content of different fuels and meals.

Finally, a flexible procedure is needed (see 5) since some of our new sectors can be constructed from among several sectors in GTAP. SplitCom allows only a 1-to-n disaggregation which is rather restrictive for the more complex configuration that we face with the data. For instance, Brazilian ethanol trade data falls under the beverages and tobacco sector while its production is classified under the chemical products sector. For the vegetal oils, we face similar issues since the value of the oil is in the “Vegetable Oil” sector but the value of the oil meals are generally under in the food products sector.

2.2 MIRAGE-Biofuels Model

Extensive model modifications were done to adapt the MIRAGE trade policy focused CGE model for an assessment of the trade and environmental impact of biofuels policies. Some of the changes were already introduced by Bouet et al.(2008) and Valin et al.(2008). This section presents the model revisions and innovations made in the areas of energy modeling, modeling of the biofuel sectors, fertilizer modeling, the modeling of co-products of ethanol and biodiesel production, and the description of fertilizer use.

2.2.1 Energy Modeling

Most significant of these model modifications is the modeling of the energy sector to introduce energy products, including biofuels, as components of value-added in the production process. Following a survey of energy modeling approaches, the MIRAGE model was modified following a top-down approach, similar to the approach taken with the GTAP-E model (Burniaux and Truong, 2002) wherein energy demand is derived from the modeling of macroeconomic activity. However, beyond what is in the GTAP-E model, the MIRAGE model was revised to include a better representation of agricultural production processes to better capture the potential impact of biofuels development on agricultural production. The possibility of either intensive or extensive production of crops and livestock was introduced in the model. The characterization of demand for energy in non-agricultural sectors, particularly the elasticity of substitution between different energy sources, was also modified. Details about the energy modeling developed for this study are in Bouet et al. (2010).

In addition to the extensive modifications made to address the shortcomings of the MIRAGE global trade model in characterizing the energy sector, modifications were also made in the MIRAGE demand function for final consumption. The Linear Expenditure System - Constant Elasticity of Substitution (LES-CES), which captures non-homothetic behaviour in response to changes in income, was improved through the introduction of new calibration to USDA income and price elasticities (Seale et al., 2003). For China and India, some complementary information was sourced from FAPRI. The LES-CES demand structure was further modified to allow for a separate characterization of demand for fuel relative to demand for other goods. A new CES level is introduced to allow for the lower elasticity of fuel demand to prices.

The sector sub-utility function used in MIRAGE is a nesting of four CES functions. In this study, Armington elasticities are drawn from the GTAP 7 database and are assumed to be the same across regions. But a high value of Armington elasticity, i.e. 10, is assumed for all homogenous sectors (single crops, single vegetal oils, ethanol). For biodiesel, we assume the same elasticity as that for other fossil fuels.

2.2.2 Modeling of the Biofuel Sectors

The biodiesel and ethanol sectors are modeled in slightly different ways. Biodiesel production, which does not produce by-products, uses four kind of vegetal oils (palm oil, soybean oil, sunflower oil and rapeseed oil) as primary inputs. These are combined with other inputs (mainly chemicals and energy) and value-added (capital and labour). Intermediate consumption are modeled using a CES nested structure with high substitutable (elasticity of substitution equals to 8) assumed among the vegetal oils. The initial dataset and the calibration of the model were set to allow for an initial marginal rate of substitution equal to 1 (e.g. one ton of rapeseed oil may be replaced by one ton of palm oil). The feedstock aggregate is then combined with a bundle comprised of the other components of intermediate consumption assuming complementarity (with elasticity of substitution equal to 0.001). As the only output of this sector, biodiesel can be exported or consumed locally. The share of the different vegetal oils is given by initial data but evolve endogenously through the CES aggregate. However, in this framework, a country that does not produce biodiesel initially will never produce biodiesel and if a biodiesel sector in one country does not initially use a type of vegetal oil as feedstock, it will never switch to such feedstock. For the ethanol sector, we first model four subsectors, each using only one of the following as specific feedstock -- wheat, sugar cane, sugar beet, or maize. This main input is combined with other production inputs and value-added assuming complementarity. Each subsector produces a specific by-product (DDGS with different properties and prices), except for the sugarcane-based ethanol sector, as well as the main output ethanol. These different types of ethanol are blended into one homogenous good that is exported or consumed locally. In addition, we allow for Central America and Caribbean regions the possibility to use imported ethanol for Brazil as an input into their own ethanol production sector.[4] Each type of DDGS is also directly traded or consumed by local livestock industries. It is important to emphasize that no other DDGS production is modeled outside of the production of ethanol. It means that the size of DDGS market is more restricted in the model than in the real world and will be totally dependent on the evolution of the ethanol production sectors. It is quite different from the production of meals wherein the vegetal oil production process itself generates oilcakes. Since the biodiesel sector is a limited destination for the overall vegetal oil sectors, the effects of biodiesel policies are much more limited on these markets.

2.2.3 Fertilizer Modeling

Fertilizers are explicitly introduced in the global database and MIRAGE model to capture potential crop production intensification, using more fertilizers, in response to increased demand for biofuel feedstock crops. The characterization of the crop production response to prices resulting from increased bioenergy demand is particularly important. Through improved modeling of fertilizers and its impact on crop yield, we introduce a better representation of yield response to economic incentives while taking into account biophysical constraints and saturation effects. The degree of

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[4] The consumption of other inputs are corrected from the share of imported ethanol used in the processing of domestic ethanol under the assumption that transformation of processing of imported ethanol is performed at a low cost. However, only the existence of tariff preferences on the US and EU markets justify these indirect exports from Brazil.

crop intensification depends on the relative price between land and fertilizers. In this context, crop yields in the model increase through three channels:

- Exogenous technical progress (see baseline section);
- Endogenous "factor" based intensification: land is combined with more labor and capital;
- Endogenous "fertilizers" (intermediate consumption) based intensification, the mechanism described above.

The model does not include endogenous technical progress based on private or public research and development expenditures in response to relative price changes. However, the increase of capital and labor by unit of land (effect *ii*) plays a similar role.

2.3 Land Use Module

To capture the interactions between biofuels production and land use change, we introduce a decomposition of land use and land use change dynamics. Land resources are differentiated between different agro-environmental zones (AEZ). The possibility of extension in total land supply to take into account the role of marginal land is also introduced. The modeling of land use change captures both the substitution effect involved in changing the existing land allocation to different crops and economic uses, and the expansion effect of using more arable land for cultivation. Detailed documentation of the land use module including data on AEZs and land use change modeling are available in Annex I. Land extension takes place at the AEZ level allowing capturing different behaviour across different regions of large countries (e.g. Brazil).

To determine in which biotope cropland occurs, we follow the marginal land extension coefficients computed by Winrock International for the US EPA, wherein the extent of land use change over the period 2001 to 2004 was determined using remote sensing analysis. For Brazil, these coefficients are defined at the AEZ level to capture that deforestation occurs in specific regions. This feature is particularly important since sectoral distribution will lead to different deforestation behaviour: for instance, soya crops are closer to the deforestation frontier than sugar cane plantations. Although the historical trends for land use change are followed in the baseline, changes in land use allocation in the scenarios come from the endogenous response to prices through the substitution effects. Therefore, historical land use changes do not affect the distribution of land under economic use across their alternative uses (cropland, pasture, managed forest).

We also introduce a mechanism for expansion or retraction of pasture land in response to changes in demand for cattle. Alternative assumptions regarding the links between demand for cattle and for pastureland and for the possibility of intensification are accommodated in the revised modeling of land use expansion.

2.4 GHG Emissions and Marginal ILUC Measurement

A critical component of this study is the assessment of the of balance in CO2 emissions between (a) direct emission savings induced by the production and use of biofuels and (b) possible increases in emissions as a result of indirect land use changes (ILUC) induced by biofuels production.

Direct emissions savings for each region, are calculated primarily using the typical direct emission coefficients for various production pathways as specified in the EU Renewable Energy Directive. Additional sources were used for the relevant emissions coefficients data for other regions (EPA, 2009). We also perform sensitivity analysis on these values. The values of these coefficients are critical to the determination of direct emission savings and the net emissions effects of biofuels. We do not model each production pathway separately in the model but calculate an average composition of the biofuels production sector. Data on that composition remain sparse however; consequently the current average composition of production capacity in the industry remains uncertain as well. Moreover, there are major uncertainties with regard to (a) the future weight of each of these production pathways in total production and (b) the possibility for substitution between different pathways to comply with the sustainability criteria defined in the RED. As a result, major uncertainties remain regarding the direct emission savings in the biofuels industry.

We use the consumption approach to allocate direct emission savings: the emission credit is given to the country that consumes the biofuel, not to the producer country. In this we follow the RED directive even though this may appear to be in contradiction with the UNFCCC and Kyoto Protocol emission accounting rules that allocate credits for reductions to the producer country.

In calculating the GHG emissions from indirect land use change, we considered emissions from: (a) converting forest to other types of land, (b) emissions associated with the cultivation of new land and (c) below-ground carbon stocks of grasslands and meadows. We rely on IPCC coefficients for these different ecosystems. We also include two different treatments. For the EU, the carbon stock of forest is limited to 50% of the value for a mature forest. It is considered that no primary forest will be affected by the land extension in the EU and only the recently afforested areas will be impacted.

For Indonesia and Malaysia, we include in addition to the carbon stocks (above and below ground), the emissions from peatlands converted to palm tree plantations. We assume a marginal coefficient of extension of palm tree plantations on peatlands of 10% for Malaysia and 27% for Indonesia, based on statistics provided by Wetlands International[5]. We use two sets of emissions coefficients for peatlands, from IPCC – AFOLU and from Couwenberg (2009), since the literature displays a wide

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[5] http://wetlands.org/.

range of coefficients (from 5 to 40 tonnes of CO2 by hectare). Recent trends emphasize the underestimation of past values.

We compute the overall effect of the mandate using average ILUC, as well as marginal ILUC (the effect of an additional unit of biofuels). The two notions differ from each other due to the non-linearity of marginal ILUC in the model.[6] We estimate the marginal ILUC effects for each feedstock, measured in tons of CO2 emissions per metric ton and per Giga Joule of biofuel, resulting from a marginal extra demand of 10^6 GJ, i.e. around 0.1% of the consumption level at this stage, applied to the EU mandate level. Further details are provided in Annex II.

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[6] The distinction between the concept of average (mean) and marginal ILUC is discussed in Tipper et al. (2009).

3 Assessing the ILUC Effects of Biofuel Policies

We first provide a a description of the baseline scenarios, the alternative trade policy scenarios, and the sensitivity analyses conducted on some parameters used in the model. The baseline scenario provides a characterization of growth of the global economy up to 2020 but without the biofuels policy scenarios of interest in the study. We then introduce the EU biofuels mandate as a policy scenario and examine the resulting changes compared to the baseline scenario. We also introduce alternative trade policy scenarios around this EU biofuels mandate scenario impact. Moreover, since the values of some parameters used in the model are uncertain, sensitivity analyses are performed by simulating the policy scenarios using alternative values of key parameters.

Even if the database has been developed at a detailed level (57 sectors and 35 regions), it is not practical to run the scenarios at this highly detailed level due to the much larger size of this model (now twice the number of equations/variables than the normal MIRAGE model) and the modeling of land extension at the detailed AEZ level. Focusing on the sectors and regions of interest in this study on biofuels and agricultural production and trade from an EU point of view, we limit the size of our aggregation to the main players (11 regions) and 43 sectors. Details are provided in Table 1 and 2. The sectoral disaggregation covers agricultural feedstock crops and processing sectors, energy sectors and other sectors that also use agricultural inputs.

3.1 Baseline Scenario

It is important to emphasize that the underlying GTAP database is first updated from the 2004 data reference year to 2008 through a simulation that uses external macroeconomic variables (GDP, population, labor force) over that period, as well as by targeting observed biofuel production and consumption data for 2008. Endogenous variables (mandate) are used to reach these levels. After 2009, we let the model evolve freely in the baseline except for the macroeconomic variables and oil prices that are still targeted.

Table 1 Regional Aggregation

Region	Description
Brazil	Brazil
CAMCarib	Central America and Caribbean countries
China	China
CIS	CIS countries (inc. Ukraine)
EU27	European Union (27 members)
IndoMalay	Indonesia and Malaysia
LAC	Other Latin America countries (inc. Argentina)
RoOECD	Rest of OECD (inc. Canada & Australia)
RoW	Rest of the World
SSA	Sub Saharan Africa

USA	United States of America

Table 2. Sectoral Aggregation

Sector	Description	Sector	Description	Sector	Description
Rice	Rice	**SoybnOil**	Soy Oil	**EthanolW**	Ethanol - Wheat
Wheat	Wheat	**SunOil**	Sunflower Oil	**Biodiesel**	Biodiesel
Maize	Maize	**OthFood**	Other Food sectors	**Manuf**	Other Manufacturing activities
PalmFruit	Palm Fruit	**MeatDairy**	Meat and Dairy products	**WoodPaper**	Wood and Paper
Rapeseed	Rapeseed	**Sugar**	Sugar	**Fuel**	Fuel
Soybeans	Soybeans	**Forestry**	Forestry	**PetrNoFuel**	Petroleum products, except fuel
Sunflower	Sunflower	**Fishing**	Fishing	**Fertiliz**	Fertilizers
OthOilSds	Other oilseeds	**Coal**	Coal	**ElecGas**	Electricity and Gas
VegFruits	Vegetable & Fruits	**Oil**	Oil	**Construction**	Construction
OthCrop	Other crops	**Gas**	Gas	**PrivServ**	Private services
Sugar_cb	Sugar beet or cane	**OthMin**	Other minerals	**RoadTrans**	Road Transportation
Cattle	Cattle	**Ethanol**	Ethanol - Main sector	**AirSeaTran**	Air & Sea transportation
OthAnim	Other animals (inc. hogs and poultry)	**EthanolC**	Ethanol - Sugar Cane	**PubServ**	Public services
PalmOil	Palm Oil	**EthanolB**	Ethanol - Sugar Beet		
RpSdOil	Rapeseed Oil	**EthanolM**	Ethanol - Maize		

The baseline scenario reflects recent International Energy Agency forecasts (2008) with oil prices reaching $120 a barrel in 2030 current prices. Economic growth projections, now taking into account the effects of the economic crisis, have also been updated with projections data from the World Economic Outlook (April 2009) of the International Monetary Fund. In this context, EU consumption of energy for road transportation is estimated to reach 316 Mtoe in 2020. This figure is in line with the latest projections of DG ENER. However, this number may appear too high when new EU policies aimed a reducing energy consumption are taken into account.

The average total factor productivity (TFP) in the economy is computed endogenously to reach the real GDP target in the baseline. In agriculture, we introduce country and sector specific TFP rates based on estimates from Ludena et al. (2006). It is important to note that no exogenous growth in palm tree yield is assumed due to the lack of data at our disposal. Therefore, compared to other crops, palm oil tends to suffer from a disadvantage in the baseline. Yields in the palm fruit sector can only increase through an endogenous process (intensification). We do not assume changes in the yield of the crushing, distilling and biofuel production activities.

It is important to note that these projections assume very low exogenous productivity increases in EU agriculture, both when comparing agriculture to other sectors in the EU and also comparing EU agriculture to its main competitors (up to +5% only for main crops in the EU whereas yields increase by more than 30% in Brazil). This assumption is based on Ludena et al. (2006) but leads to losses of competitiveness of EU agriculture in the baseline and will have adverse consequences on endogenous yield growth. Indeed, since agricultural sectors are below EU average in terms of productivity growth, capital will tend avoid these sectors as expected returns are higher in other sectors. Less capital accumulation leads to low yield increases through factor intensification.

The baseline scenario leaves the trade policies that were in place by end 2008 unchanged. The Economic Partnership Agreements (EPAs) between the EU and the ACP countries, negotiated in 2008, are implemented either as ratified interim agreements or a complete EPA (e.g. with CARICOM), depending on the status of the agreement. Negotiations on trade agreements that were not finalized by end 2008 are not included: the Doha Development Agenda, an EU-ASEAN agreement and an EU-Ukraine agreement.

The baseline scenario includes the full ad-valorem equivalent (AVE around 48%) of the prevailing EU MFN duty on EU bioethanol imports from countries that do not benefit from bilateral or unilateral (GSP) preferential schemes. In reality, this is likely to be an overestimate of the effective AVE. Significant quantities of bioethanol are imported under temporary suspensions of duties and, in the form of denatured ethanol, as chemical products for which a lower duty applies. In the absence of a specific EU tariff line for bioethanol, there are no trade statistics available that permit us to estimate the effective trade-weighted tariff on bioethanol.

Another critical trade policy measure that we incorporate in the baseline scenario are the anti-dumping duties that the EU imposed on US exports of biodiesel in March 2009. Over the last few years, the US has emerged as the major biodiesel exporter to the EU (with more than 80% of market share among all exporters), supplying about 19% of the EU domestic market for biodiesel. However, due to the tax credit given to the US blenders, and the *splash'n dash* practice, the EU initiated anti-dumping measures and countervailing duties in March 2009. This contingent protection has reduced US biodiesel exports to the EU to negligible quantities. Allegedly, some of these US exports may now have been replaced partially by exports from Indonesia and Malaysia and Argentina and growing trade flows from Canada.[7] In the model, the bulk of the adjustment to the antidumping duty is achieved through increased EU biodiesel production (from EU domestic and imported feedstocks).

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[7] These flows can be re-exported US production and in some cases, double splash'n go has been detected (tax credit in the US then in Canada).

For the EU, we implement two policy elements in the baseline: the sugar reform market and the end of the land set-aside policy. These two assumptions have overall limited effects in the baseline. First, we remove the land set-aside constraint by 2008 (full use of EU land). The main effect is to lead to a fall in EU yields from 2007 to 2020 by an average of 10 percent. This result is quite strong and is translated into a proportional fall in land prices. Indeed, we force EU farmers to use all set-aside land (10% of the overall croplands in our baseline) when overall demand for crops will not change during the same period. Therefore, EU production will not change when the harvested area will increase by 10% and yield decreases. Since the relative price between land and fertilizers determines the use of fertilizers in this model, another yield-depressing effect appears: lower land prices reduce intensification behaviour and yield. The effects are differentiated between crops depending on existing tensions on markets during the period in the baseline: stronger for crops with low demand (other crops -15%), weaker for crops with high demand (-5%). The combination of this with our assumptions on EU agricultural productivity leads to a decline in EU yields in the baseline. This is a crude modelling solution for land set-aside that needs to be improved. Forcing farmers to use all the land set-aside has a strong mechanical effect. In reality, it appears that these lands have lower yields than average and that only a share of it has been used in 2008, even during crop price surges. Second, since we do not explicitly model the existing sugar policy tool, we mimic the sugar market reform by reducing the EU MFN tariff to reproduce the price decrease. Overall, the EU sugar production decrease by 5% between 2008 and 2020 when the world production increases by 47%. The effects of the reform are slightly absorbed by the ethanol industry since the sugar-beet ethanol industry is the most resilient in the baseline (see next paragraph for the evolution of the biofuels sector in the baseline).

No additional EU bioenergy mandate is implemented in the baseline. The status-quo is assumed to prevail until 2020, with biofuel blending levels not exceeding the 3.3% level in 2008. The previous EU target of 5.75% blending is not implemented. We do this to capture the impact of the EU mandate against a baseline where biofuel use remains at the 2008 blending levels (3.3%). It implies that EU consumption reach 9.75 Mtoe in 2020 with a 90% share for biodiesel. At the same time, production increases by 22% while imports fall by 68% with the exclusion of the US from the market. Interestingly, EU production of bioethanol falls by 20% under the pressure of foreign competitors (Brazil). Indeed it appears that the EU has no dynamic comparative advantage in this sector, contrary to biodiesel.

This result is quite strong and has several explanations. First, the relative price of cereals compared to sugar cane/sugar beet increases. This is due mainly to the evolution of world demand and the role of cereals in cattle feeding but also demand from agribusiness sectors (flours etc.). This price gap leads to a loss of competitiveness of EU ethanol (except for sugar beet). Second, as discussed previously, EU yields will progress – exogenously and endogenously - very slowly compared to Brazil. In addition, the land constraint is tighter in the EU than in Brazil. We have also a clear dichotomy between EU and Brazil agricultural supplies since in the former land is scarce and intensification already high, when in the latter both extensive and intensive growth appear to be very easy. This undermines the overall competitiveness of EU ethanol. Last, we have a CGE effect: with the loss of competitiveness of the EU ethanol sector, capital accumulation will slow, other sectors being more attractive, and the ethanol sectors will shrink in the EU.

Since there are already strong political commitments in place in these countries, we implement the US and Brazilian biofuel targets in the baseline. The US mandate will lead to the consumption of 40 Mtoe of ethanol by 2020. The US production of ethanol will increase by 128% in twelve years while the US biodiesel sectors will expand by 193% (but will represent only 12% of the ethanol sector). With the Brazilian blending target fixed at 24.4% over the period, its ethanol production rises by 139%. We also include a 5% mandate for Indonesia, Malaysia, Rest of OECD and China. This assumption is aimed to maintain a minimal consumption target in these countries in the baseline and in the scenarios. It is important to take other countries' bioenergy consumption targets into account since they affect the amount of foreign feedstock and biofuels production that the EU will be able to import and thus the future domestic production in the EU.

As described previously, oil prices follow trends proposed by IEA in the recent World Energy Outlook with an oil price stable at $83.8 a barrel by 2010 and increasing slowly up to $96.4 in 2015, and $109 in 2020 (values are given in 2004 constant dollars). Oil production is forecast to experience constraints with an increase of only 32% on the period 2010-2020. Demand for all crops increases only marginally (+27% in world production) over the same period. The highest increases in demand are for palm fruit (60%) and for sugar cane, sugar beet and soybeans sectors (+47%). Demand for cereals faces limited increases (about 20% for both wheat and maize). These figures are above the FAO-Aglink projections and are mainly driven by a relatively inelastic demand for agricultural products by other sectors (services, agri-business, chemistry) and are intrinsic to the CGE exercise. This forecast is based on the assumption that no major changes occur in the diet of the world population. Given these forecasted changes, cropland expansion is expected to be 1 Mios of km2 between 2008 and 2020 (+9% for crops), with substantial expansion in Brazil (+36%) and Africa (+22%). In Europe, the cropland surface will increase by 5% between 2008 and 2020.

3.2 Central and Alternative Trade Policy Scenarios

Against this baseline scenario, we evaluate the impact of three different trade policy scenarios. In the central scenario, we introduce a biofuels policy shock that assumes that the EU will consume 17.76 Mtoe of bioethanol and biodiesel by 2020 in order to achieve the mandate target of 10% renewable energy in road transport fuels. This figure is taken from an intermediate biofuels demand scenario by DG ENER, based on the PRIMES model, that combines various renewable energy sources, including second generation biofuels and increased use of electric cars powered by renewable electricity. Furthermore, the model uses a target ratio for 2020 of 55% ethanol and 45% biodiesel, based on DG AGRI projections.[8]

However, the current baseline does not include new projections for total road transport fuel consumption in the EU in 2020, taking into account new EU energy and emission policy initiatives. For this reason, we stick to the existing PRIMES figure of 316 Mtoe by 2020, and derive a biofuels incorporation ratio of 5.6%[9]. As a result, the denominator of that ratio is probably too high. We do however test the sensitivity of the outcomes for other values of this ratio. The mandate target is achieved in the model by mandatory regulation (explicit biofuels mix constraints build into the supply of road transport fuels) and not by means of explicit subsidies or tax credits.

Our two trade policy scenarios are:

MEU_BAU: Implementation of the EU biofuels mandate of achieving 5.6% consumption of ethanol and of biodiesel in 2020 under a Business as Usual trade policy assumption - this scenario seeks to achieve the EU policy objective of at least 5.6% biofuels consumption in transport fuels in 2020 by imposing that bio/fossil fuel mix on all fuels sold in the EU. In that case, the consumer bears most of the cost of any fuel price increases at the pump. It is compared to the baseline situation where no mandate is implemented. The mandate is implemented progressively and in a linear fashion from 2010 to 2020. It is applied on each type of biofuel and no blending over 5.6% is allowed for biofuels in either gasoline or diesel. No changes in trade policies are considered.

MEU_FT: Implementation of the EU biofuels mandate of achieving 5.6% consumption of ethanol and of biodiesel in 2020 with the assumption of full, multilateral, trade liberalization in biofuels - in this

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[8] "Impact Assessment of the Renewable Energy Roadmap - March 2007", DG AGRI, AGRI G-2/WM D(2007). These targets are still very close to the latest estimates of the JRC ISPRA. The ratio of bioethanol to biodiesel is largely determined by the car fleet composition. Diesel cars cannot use petrol, and vice versa. We assume that the fleet composition is exogenous to the model and not influenced by EU biofuels policies.

[9] Note that this estimated 5.6% target for biofuels in 2020 is actually below the previous target of 5.75% for 2012. It implies only a small increase of X percentage points compared to the actual situation in 2008.

scenario, the same objectiveis reached through a more market-based approach, by lowering the consumer price of biofuels in order to stimulate consumption. This is achieved by the full liberalization of biofuels sectors. Contingent protection on US biodiesel remains.

Two important points regarding the trade policy scenarios have to be emphasized. First, the size of the mandate is not excessive since it will require an increase in EU demand of biofuels by 70% and an 8% increase of world production/consumption of biofuels. The limited size of the shock explains the magnitude of our results in the next section. Due to the potential non-linearity in our analytical framework, this policy design will also explain the relatively low per unit cost (CO2 and economic inefficiency) of such a mandate. Second, the initial ad valorem equivalent (AVE) MFN tariff on EU imports that we use, about 50%, appears to be an upper bound to more recent estimates (25%-30%).[10] Combined with the high Armington trade elasticity assumed for this product to represent a more homogeneous good, the effects of trade liberalization will be very strong, and may be overestimated.

We evaluate the effects of these policy scenarios on several key elements - biofuel production, biofuel imports, crop production, agricultural value-added, variation of land use by sector, variation of total land use, variation of the intensification index for cultivation ($ of fertilizer used by ha), direct emissions reduction related to biofuels, and indirect emissions related to indirect land use change effect.

3.3 Production and Trade Impact of Trade Scenarios

Table 3 illustrates the impact of the various scenarios on biofuel production. The two first columns in Table 3 provide the level of ethanol production in 2008 and in 2020 in the baseline (without policy shocks – column Ref). The next columns give the level and variation of production in 2020 implied by the two scenarios with variation being a comparison with the baseline. The same table organization is kept throughout all the report unless indicated otherwise.

The mandate scenarios and trade liberalization scenario have very contrasting effects on biofuel production in the European Union. In 2020 ethanol production increases by 157% in the EU under an EU mandate scenario, while the competition coming from increased imports in a trade liberalization scenario would mean a decrease by -48% in case of full liberalization scenario. The removal of tariffs on ethanol would be followed by a surge in European imports of this product (they are multiplied by 6.8 by 2020 – see Table 4) under trade liberalization scenario. As previously mentioned, since the

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[10] Please note that the estimation of the EU AVE on ethanol is complicated by two main difficulties: (i) identification of the relevant unit value on imports, and (2) identification of the tariff line actually used by Member States to import ethanol for biofuel production.

baseline tariff may be overestimated (by a factor of 1.5), the effects of trade liberalization simulated here may also be overstated.

Table 3 Level and variation of biofuels production (Mio toe and %)

		REF	MEU_BAU		MEU_FT	
		Lev	Lev	Var	Lev	Var
Biodiesel	**Brazil**	0.36	0.37	*1.81%*	0.37	*2.92%*
Biodiesel	**China**	0.23	0.23	*-0.72%*	0.23	*-0.76%*
Biodiesel	**EU27**	8.15	9.04	*10.92%*	9.07	*11.27%*
Biodiesel	**IndoMalay**	3.58	3.65	*2.06%*	3.65	*2.07%*
Biodiesel	**LAC**	0.45	0.48	*5.91%*	0.48	*6.10%*
Biodiesel	**RoOECD**	3.24	3.24	*-0.01%*	3.24	*0.12%*
Biodiesel	**USA**	3.46	3.45	*-0.18%*	3.46	*-0.03%*
Biodiesel	**World**	19.46	20.45	*5.08%*	20.49	*5.30%*
Ethanol	**Brazil**	28.51	32.78	*14.97%*	34.36	*20.50%*
Ethanol	**CAMCarib**	7.25	7.45	*2.64%*	7.19	*-0.89%*
Ethanol	**China**	10.81	10.83	*0.18%*	10.83	*0.16%*
Ethanol	**EU27**	0.84	2.17	*156.89%*	0.44	*-48.23%*
Ethanol	**LAC**	0.69	0.69	*0.95%*	0.70	*2.21%*
Ethanol	**RoOECD**	5.66	5.78	*2.03%*	5.84	*3.03%*
Ethanol	**RoW**	1.51	1.50	*-0.54%*	1.50	*-0.49%*
Ethanol	**USA**	29.10	29.57	*1.64%*	29.72	*2.14%*
Ethanol	**World**	84.38	90.77	*7.58%*	90.57	*7.34%*

Source: Authors' calculations

As can be expected, the European mandate increases overseas production of ethanol by less than when it is coupled with trade liberalization. The greatest impact are seen in the two largest producers, the US and Brazil. In particular, Brazilian ethanol production is increased by 5.8 Mios toe (+20%)in 2020 under the trade liberalization scenario, while it is increased by +4.3 Mios toe (15%) under a European mandate. Effects on US production are more limited US (+2.14% with trade liberalization). US exports to the EU do not increase significantly (they remain a tiny fraction of the market) but they need to replace displaced Brazil exports. However, the free trade scenario leads to a strong preference erosion for the Central America and Caribbean region (-83%).

These policy scenarios have significant impact on crop production, particularly on feedstocks needed for the production of ethanol and biodiesel. This is particularly true for rapeseed and sugar cane-sugar beet. For example, while the production of sugar cane-sugar beet is increased under the MEU_BAU scenario (+3.8% in 2020 with +9.7% for Brazil –sugar cane and +9.3% for the EU –sugar beet), this increase is much more significant in the case of trade liberalization (+4.9% under the MEU_FT scenario with +15% for Brazil –sugar cane, and a decrease of -2.4% for the EU –sugar beet).

Table 4. Level and Variation of EU Biofuel Imports, by Origin (Mio toe and %) by 2020

		REF	MEU_BAU		MEU_FT	
		Lev	Lev	Var	Lev	Var
Biodiesel	**Brazil**	0.00	0.00	*6.21%*	0.00	*5.49%*
Biodiesel	**China**	0.00	0.00	*14.45%*	0.00	*14.59%*
Biodiesel	**IndoMalay**	0.44	0.51	*15.29%*	0.51	*15.46%*
Biodiesel	**LAC**	0.19	0.22	*15.69%*	0.22	*16.04%*
Biodiesel	**RoOECD**	0.00	0.00	*12.92%*	0.00	*82.07%*
Biodiesel	**USA**	0.00	0.00	*11.78%*	0.00	*12.10%*
Biodiesel	**World**	0.64	0.74	*15.40%*	0.74	*15.79%*
Ethanol	**Brazil**	0.92	5.53	*502.82%*	7.56	*724.32%*
Ethanol	**CAMCarib**	0.04	0.27	*517.35%*	0.01	*-83.48%*
Ethanol	**USA**	0.00	0.01	*546.96%*	0.00	*111.89%*
Ethanol	**World**	0.96	5.82	*503.58%*	7.57	*685.98%*

Source: Authors' calculations

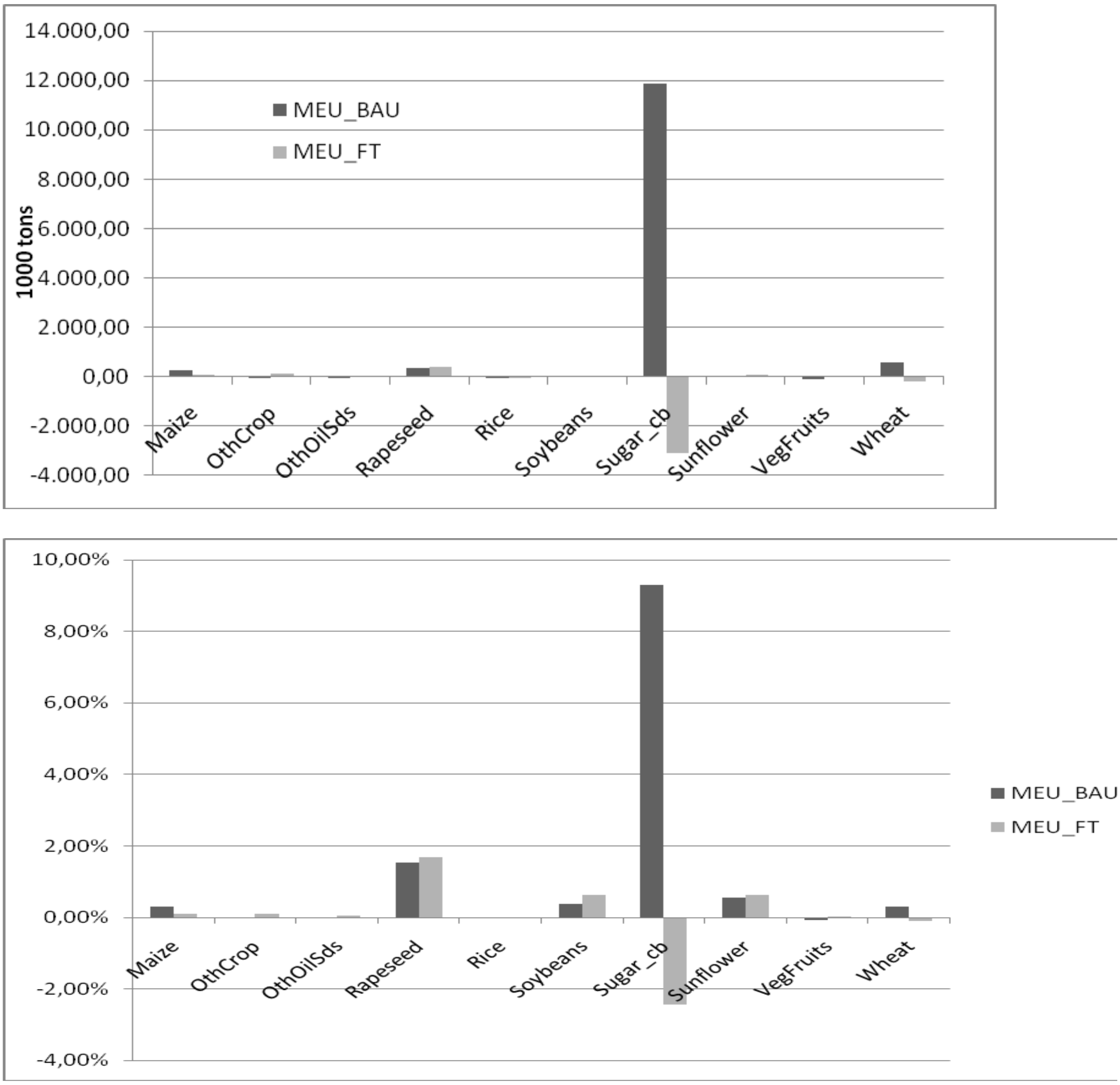
Table 5. Main Changes in Crop Production (non EU27) in 2020, 1000t

Crops	Region	REF	MEU_BAU		MEU_FT	
		Lev	Lev	Var	Lev	Var
Sugar_cb	**Brazil**	913385	1001556.15	9.65%	1045492.08	14.46%
Rapeseed	**CIS**	571	583.00	2.06%	583.42	2.13%
PalmFruit	**Brazil**	3117	3196.06	2.53%	3181.86	2.07%
Rapeseed	**Brazil**	151	153.15	1.59%	152.85	1.39%
Rapeseed	**SSA**	108	108.87	1.10%	108.89	1.12%
Sunflower	**Brazil**	153	155.23	1.24%	154.91	1.03%
Rapeseed	**RoOECD**	13848	13969.92	0.88%	13975.74	0.92%
Soybeans	**RoOECD**	3999	4020.98	0.54%	4025.62	0.66%
Sunflower	**USA**	2142	2155.86	0.64%	2156.20	0.65%
Soybeans	**CIS**	1129	1134.41	0.46%	1135.71	0.58%
Soybeans	**LAC**	77981	78349.47	0.47%	78428.70	0.57%
Sunflower	**LAC**	5883	5916.54	0.57%	5916.34	0.57%
Rapeseed	**LAC**	141	142.09	0.52%	142.10	0.53%
OthCrop	**Brazil**	9090	9034.08	-0.61%	9002.90	-0.96%
Wheat	**IndoMalay**	1	0.55	-5.92%	0.55	-6.81%

Source: Authors' calculations

These policy scenarios have a substantial impact on the European production of agricultural crops (Figure 4). As a result of the development of ethanol and biodiesel, the European production of crops used in these processes of production is increased in 2020: rapeseeds, sugar beet, wheat, maize, soybeans and sunflower. The production of various agricultural crops competes for common scarce productive resources (like land). On the one hand, the production of agricultural commodities for non-food purposes can have negative consequences on other agricultural commodities through increased price of this common resource (although limited by the presence of co-products in the analysis). On the other hand, demand for food is inelastic and there should be some substitution effects in demand that could positively affect the production of other agricultural crops. Production of other crops (rice, vegetable and fruit) can be negatively affected but the phenomenon is limited.

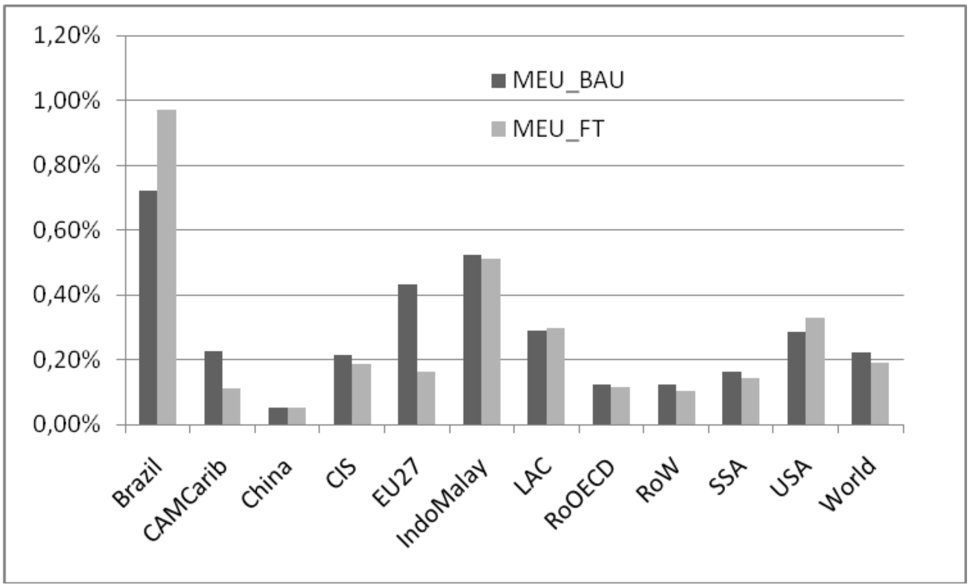
Figure 1 Variation of EU Crop Production - 2020 - (volume and percentage)



Source: Authors' calculations

Figure 5 illustrates how agricultural value-added could be affected by these different scenarios. The potential impact of both policies on agricultural value-added is positive in almost all countries/regions throughout the world, in particular in the three countries/regions shown on Figure 5: Brazil, Indonesia and Malaysia, the EU and the US. These policies create more activity in the agricultural sector and the impact is worldwide. While the mandate is more positive for European agricultural value-added than for Brazil and the US, the impact is larger for the US and Brazil.

Figure 2 Variation of agricultural value-added in 2020 (%)



Source: Authors' calculations

These gains in agricultural value-added have to be compared with the cost to consumers (consumers are negatively affected in the EU) in order to derive a net economic benefit/loss. This is done through the calculation of welfare effects of European policies not only for the EU but also for other countries/regions as shown in Table 6. The two policies have minimal effects on other countries/regions welfare, except for Brazil which benefits from significant improvement in their terms of trade thanks to their exporting status of oilseeds for biodiesel and sugar cane. As far as the European Union is concerned both policies are neutral: in that sense the increase in agricultural added value observed on Figure 5, is offset by negative impact of both policies on consumers' surplus and public receipts.

As mentioned earlier the production of biofuels also produces several by-products for which there is current or potential demand: Dried Distillers Grains with Solubles (DDGS) obtained from the production of ethanol and which is used as animal feed, and oilcakes (animal feeds) from biodiesel production. When accounting for by-products, biofuels development should lead to less pressure on food markets and in particular on markets for animals feeds. The increased availability of these by-products should have beneficial side effects in other areas of agriculture. A biofuel mandate could potentially lead to a positive impact on livestock production in terms of reduced prices for animal feed.

Table 6. Real Income Impact of European Biofuel Policies, 2020 (Variation / Baseline)

	REF	MEU_BAU		MEU_FT	
	Lev	**Lev**	**Var**	**Lev**	**Var**
Brazil	856	857	*0.06%*	857	*0.08%*
CAMCarib	444	444	*-0.01%*	444	*-0.02%*
China	4593	4592	*0.00%*	4592	*-0.01%*
CIS	1093	1091	*-0.18%*	1091	*-0.17%*
EU27	15182	15184	*0.01%*	15182	*0.00%*
IndoMalay	564	564	*-0.02%*	564	*-0.03%*
LAC	1605	1604	*-0.05%*	1604	*-0.06%*
RoOECD	8590	8589	*-0.01%*	8588	*-0.01%*
RoW	5639	5633	*-0.11%*	5633	*-0.11%*
SSA	912	911	*-0.12%*	911	*-0.12%*
USA	15219	15218	*0.00%*	15218	*-0.01%*
World	54697	54687	*-0.02%*	54684	*-0.02%*

Source: Authors' calculations

The model used in this analysis includes by-products and illustrates how the development of biofuels production can clearly contribute to the consumption of biofuels by-products in cattle and "other animal" sectors. Price of meals will decrease by 0.9% to 1%, with the strongest reduction in rapeseed cakes. In the DDGS market, the expansion in supply will lead to more substantial price changes (as much as -45% for beet pulp in Europe) in the scenario without trade liberalization. This strong result is related to the strong bias of the mandate towards ethanol production and the fact that the initial DDGS market is very small. Since DDGS in the EU only goes to the domestic market in our model, and since new trade flows cannot be generated in our framework, all the initial DDGS production is linked to biofuel ethanol plants.[11] At the opposite end, when trade liberalization is implemented, EU ethanol production, as well as co-products production, is sharply reduced. Since sugarcane ethanol is not associated with a by-product in our model, the market is depleted and prices go up. With weak substitution effects, the meal prices will decrease less (changes reduced by one-tenth).

The augmentation of consumption of co-products is driven by more availability of DDGS and oilcakes, of which prices are reduced thanks to the EU mandate. As illustrated in Figure 3, this is beneficial for the value-added in livestock sectors particularly in the European Union where the reduction of prices of these intermediate commodities are more significant than elsewhere: the value-added in the cattle sector will increase by almost 0.08% while the one for the "Other Animals" sector will be augmented by 0.07%. The results are also positive for value-added in the same sectors of the US. Globally the value-added in the cattle sector throughout the world is augment by 0.04% (0.03% as far

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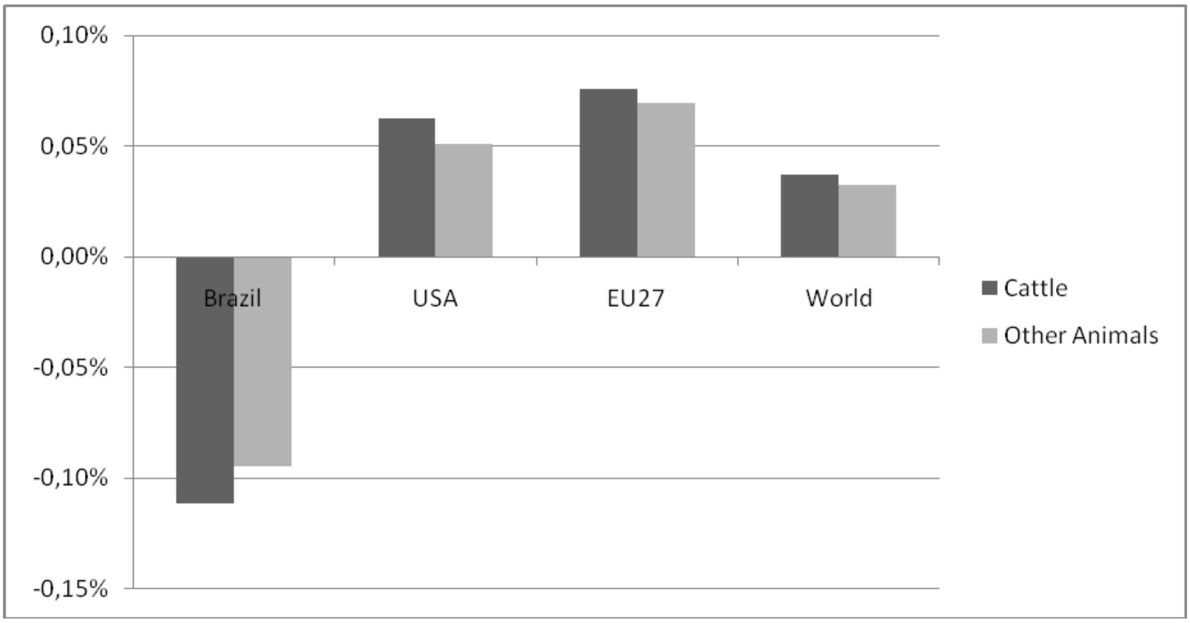
[11] It will be interesting to change the elasticity of substitution between DDGS and other energy feed to see if the strong results remain.

as the “Other animal” sector is concerned). In Brazil, on the other hand, the livestock sector will suffer from land competition with the different crops (-0.07% of pasture land, see Table 7) and a rising price of soya and other feedstocks .

Figure 3 Variation of value-added in livestock sectors in 2020 (%) – MEU_BAU scenario

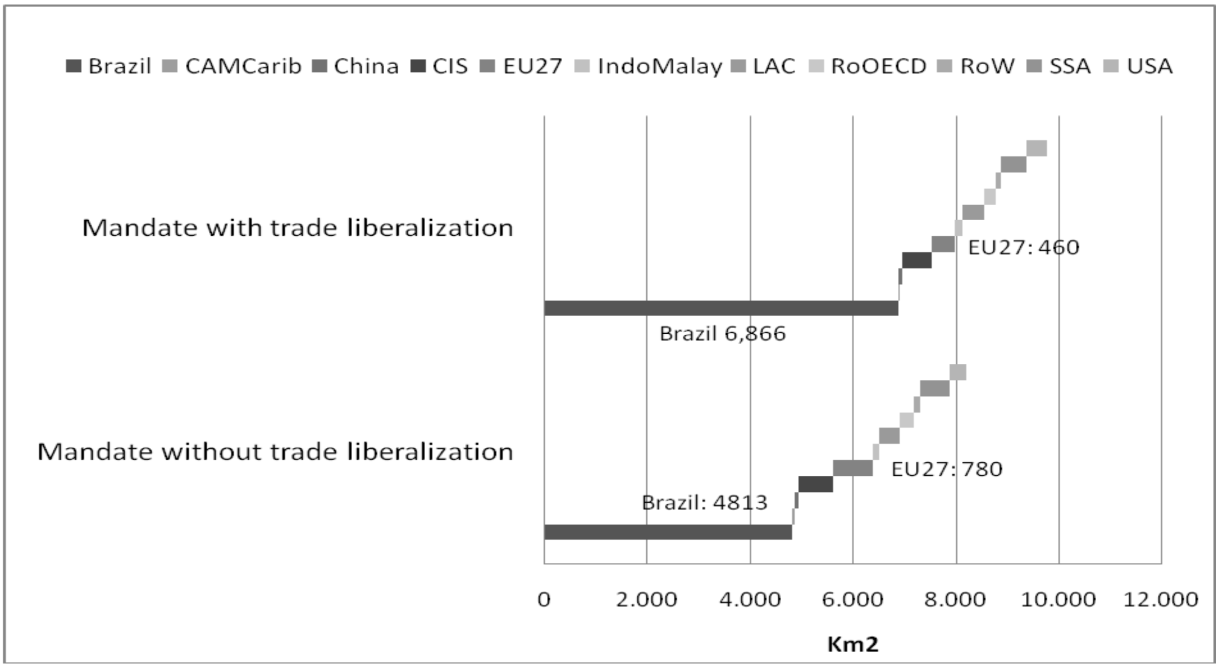


Source: Authors’ calculations

3.4 Land Use Effects

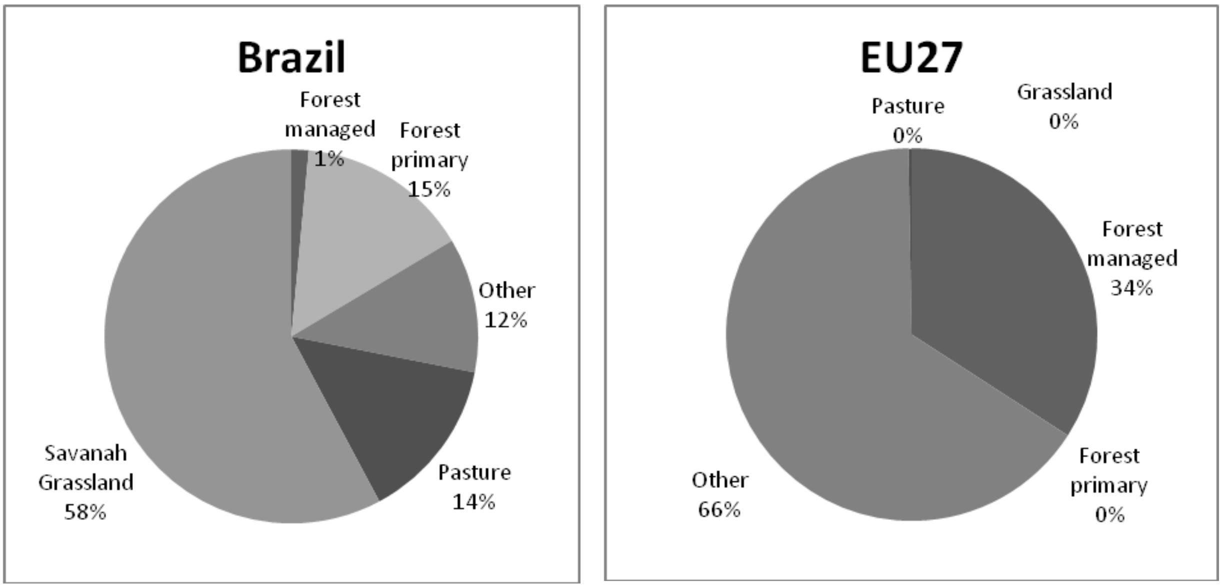
Changes in crop production, particularly due to the increased demand for feedstock crops used as inputs in biofuels, will have different implications on the expected patterns of land use under the mandates and trade liberalization scenarios. Table 7 indicates the variation in land use by type of land which could be expected from these policy scenarios. The amount of cropland is significantly affected in Brazil (+0.54% without trade liberalization, +0.77% with trade liberalization, see Figure 7). This result is due to the combination of the demand for ethanol (sugar cane) and oilseeds (soya) and the high elasticity of land extension for this country. However, due to the AEZ level modeling of land extension, it appears that primary forest are not the main source (see Figure 8 and Table 7) of new land for sugar cane production but Savannah/Grassland (South East of Brazil). The other regions that are mostly affected are the EU, the CIS region, the rest of Latin America and Indonesia-Malaysia. However, since land extension is more difficult in these regions (lower elasticity of land extension), the effect is limited. Globally the mandate increases cropland use by 0.07% in 2020 and by 0.08% under the trade liberalization scenario, with slightly more encroachment into areas reserved for forest. The land use changes under the two policy scenarios have implications on CO2 emissions.

Figure 4 Cropland Extension by Region, 2020, Km2



Source: Authors' calculations

Figure 5 Source of Cropland Extension by Type of Land



Source: Authors' calculations

An interesting question which is related to the expansion of cropland is the relative decomposition of production increase between yield changes and extensive land use. Table 8 provides such a decomposition at the world level for each crop. For instance, in the pure mandate case, the world increase of 0.91% of rapeseed production is achieved by increasing land by 0.54% and by increased use of new capital and labour per Ha (0.34%); intensification of fertilizer used plays only a minor role. At the other hand, we see that for wheat the production increase is achieved completely by intensification, through increased use of fertilizers and through factor intensification.

Table 7. **Variation of Total Land Used (thousands of km²)**

		2020	2020	2020	2020	2020
		REF	**MEU_BAU**		**MEU_FT**	
		Lev	**Lev**	**Var**	**Lev**	**Var**
Cropland	**Brazil**	888.60	893.41	0.54%	895.46	0.77%
Forest_total	**Brazil**	4391.84	4391.05	-0.02%	4390.78	-0.02%
Pasture	**Brazil**	1371.17	1370.49	-0.05%	1370.21	-0.07%
SavnGrasslnd	**Brazil**	1838.39	1835.61	-0.15%	1834.35	-0.22%
Cropland	**China**	1421.29	1421.37	0.01%	1421.37	0.01%
Forest_total	**China**	2112.52	2112.45	0.00%	2112.45	0.00%
Pasture	**China**	1083.30	1083.30	0.00%	1083.30	0.00%
SavnGrasslnd	**China**	1927.67	1927.67	0.00%	1927.67	0.00%
Cropland	**EU27**	1004.03	1004.81	0.08%	1004.49	0.05%
Forest_total	**EU27**	1449.27	1449.00	-0.02%	1449.11	-0.01%
Pasture	**EU27**	617.18	617.17	0.00%	617.18	0.00%
SavnGrasslnd	**EU27**	205.20	205.20	0.00%	205.20	0.00%
Cropland	**IndoMalay**	344.41	344.55	0.04%	344.55	0.04%
Forest_total	**IndoMalay**	867.13	867.04	-0.01%	867.04	-0.01%
Pasture	**IndoMalay**	34.05	34.02	-0.08%	34.02	-0.08%
SavnGrasslnd	**IndoMalay**	138.54	138.54	0.00%	138.54	0.00%
Cropland	**LAC**	397.51	397.91	0.10%	397.92	0.10%
Forest_total	**LAC**	3294.18	3294.07	0.00%	3294.07	0.00%
Pasture	**LAC**	794.01	794.07	0.01%	794.07	0.01%
SavnGrasslnd	**LAC**	2213.70	2213.70	0.00%	2213.70	0.00%
Cropland	**World**	12425.91	12434.11	0.07%	12435.66	0.08%
Forest_total	**World**	37704.94	37703.17	0.00%	37703.05	0.00%
Pasture	**World**	10870.45	10869.46	-0.01%	10869.26	-0.01%
SavnGrasslnd	**World**	29860.28	29857.50	-0.01%	29856.25	-0.01%

Source: Authors' calculations

Note: The land category "Other" is not displayed on the table.

Table 8 Decomposition of production increase

	MEU_BAU				MEU_FT			
	Yield Factors increase	Yield Fertilis-er	Land use Change	Total Production increase	Yield Factors increase	Yield Fertilis-er	Land use Change	Total Production Increa-se
Rapeseed	0.32%	0.04%	0.54%	0.90%	0.34%	0.02%	0.61%	0.97%
PalmFruit	0.10%		0.21%	0.31%	0.10%		0.20%	0.30%
Maize	0.04%	0.03%	0.01%	0.08%	0.03%	0.03%	-0.01%	0.05%
OthCrop	0.01%	0.00%	0.00%	0.01%	0.02%	0.02%	-0.01%	0.03%
OthOilSds	0.01%	0.01%	-0.03%	-0.01%	0.01%	0.02%	-0.03%	0.00%
Rice	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Soybeans	0.04%	0.06%	0.12%	0.22%	0.05%	0.07%	0.15%	0.27%
Sugar_cb	0.66%	0.54%	2.67%	3.87%	0.62%	0.37%	3.98%	4.97%
Sunflower	0.11%	-0.10%	0.37%	0.38%	0.11%	-0.10%	0.39%	0.40%
VegFruits	0.00%	0.05%	-0.06%	-0.01%	0.00%	0.05%	-0.06%	-0.01%
Wheat	0.06%	0.05%	0.00%	0.11%	0.00%	0.04%	-0.09%	-0.05%

Source: Authors' calculations

3.5 Emissions

As displayed in Table 9, the sum of land use related emissions implied by the European mandate is 107 million tons of CO2 equivalent in 2020 without trade liberalization and 118 million with elimination of MFN duties on biodiesel and ethanol. Even without trade liberalization, most of the emissions effects (between 50% and 60% of world emissions) are concentrated in Brazil where these are driven by demand for sugar and soybeans. However, we see that emissions related to deforestation represent just a share (between half and one third) of Brazilian emissions. Modeling the land extension at the AEZ level shows that forest is less impacted than other biotopes (grassland) due to the extension of sugar protection. Without trade liberalization the EU is the second region in terms of direct emissions (nearly 10.63 Mios tCO2eq). Trade liberalization allows the EU to cut its direct emissions by 40% but the CIS and Brazil will emit much more. Taking peatlands into account plays a minor role in the broad picture (up to 1.1% in the case were largest emissions figures are used). But if we compare these additional figures to the other CO2 emissions of Indonesia and Malaysia, we see that these figures can add 25% to overall emissions of this region, acknowledging the fact that it remains a minor supplier for the EU (less than 10% of EU biodiesel consumption when we add biodiesel imports and palm oil imports) and that the mandate target implies limit increase in biodiesel consumption.

Table 9. Indirect land use emissions related to biofuels in 2020

(Mios tCO2eq - extra emissions are positive values)

	5.6% EU Mandate			**5.6% EU Mandate + Full trade liberalization on biofuels**		
	Forest Biomass change	Organic Carbon in Mineral Soil	Total land use emissions	Forest Biomass change	Organic Carbon in Mineral Soil	Total land use emissions
Brazil	**23.97**	33.33	**57.30**	28.50	46.02	**74.52**
CAMCarib		0.52	**0.52**		0.22	**0.22**
China	**1.57**	0.65	**2.22**	1.43	0.60	**2.03**
CIS	**3.18**	5.08	**8.26**	2.91	4.52	**7.43**
EU27	**3.03**	7.60	**10.63**	1.80	4.50	**6.30**
IndoMalay	**3.39**	1.53	**4.92**	3.38	1.53	**4.90**
LAC	**2.63**	3.58	**6.21**	2.71	3.70	**6.41**
RoOECD	**1.08**	2.47	**3.55**	0.87	2.34	**3.22**
RoW	**1.20**	0.94	**2.14**	0.88	0.71	**1.59**
SSA	**1.49**	4.50	**5.99**	1.36	4.04	**5.41**
USA	**1.88**	2.89	**4.76**	2.24	3.47	**5.71**
World	**43.41**	**63.09**	**107.50**	46.07	71.66	**117.74**

Additional MtCo2 emissions from peatlands	IPCC method	0.17
Values are indentical in both scenarios at 0.01 MtCO2eq	Couwenberg(2009):	1.38

Source: Authors' calculations

As shown in Table 10, the sum of direct emissions reductions[12] generated by the substitution of fossile fuel by biofuels and implied by a European liberalization of trade in ethanol and biodiesel is slightly higher: -21 million tons of CO2 equivalent in 2020 under the trade liberalization scenario instead of-18 Mios. This result is driven by the increased use of sugar cane ethanol that is the most efficient feedstock. The net emissions balance (land use emissions minus direct emission savings) is positive and slightly larger under the liberalization case than under the pure mandate scenario. Even if the liberalization leads to more emissions through indirect land use effects, using efficient imported biofuels delivers a net missions reduction in a 20 year period.

Table 11 displays the carbon balance sheet of the 5.6% mandate under our different scenarios. The upper part of the table displays the total carbon release (from forest biomass and soil contents) due to the change in land use during the 2008-2020 period following the implementation of the mandate. The lower part shows *average* ILUC effect computed with our model equal to the sum of carbon

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[12] Each MJ of fossil fuel is assumed to generate 25gr of carbon, i.e. about 92 gr. of CO2.

release from forest biomass and soil carbon content. All annual coefficients take the stock value of the upper table and divides them by 20 years and divided by the increase in EU consumption of biofuels. The average ILUC computed here is between 17.7 gCO2eq/Mj (no trade liberalization) and 19.5 gCO2eq/Mj (with trade liberalization).The net emission balance on a 20-year period is about -42.82gCO2/MJ if the mandate is not associated with an open trade policy and slightly more under trade liberalization (-46.93 gCO2/MJ). These coefficients are average values since they are based on the full mandate increase (from 3.3% to 5.6%) and takes into consideration all the direct and indirect effects in the CGE framework in terms of income and substitution effects. But they do not include CO2 variations not related directly to the biofuel policies (such as the income effect on the steel industry).

Table 10 Emissions balance. Annualized figures. CO2 Mto2 eq.

	MEU_BAU			MEU_FTA		
	Direct emissions	Land use change	Total emissions	Direct emissions	Land use change	Total emissions
Brazil	-0.05	2.87	**2.82**	-0.06	3.73	**3.67**
CAMCarib	-0.32	0.03	**-0.29**	0.24	0.01	**0.25**
China	-0.02	0.11	**0.09**	-0.02	0.10	**0.08**
CIS	0.00	0.41	**0.41**	0.00	0.37	**0.37**
EU27	-18.36	0.53	**-17.83**	-21.24	0.31	**-20.93**
IndoMalay	-0.01	0.25	**0.24**	-0.01	0.25	**0.24**
LAC	0.01	0.31	**0.32**	0.01	0.32	**0.33**
RoOECD	0.12	0.18	**0.30**	0.21	0.16	**0.37**
RoW	0.02	0.11	**0.13**	0.02	0.08	**0.10**
SSA	0.00	0.30	**0.30**	0.00	0.27	**0.27**
USA	0.45	0.24	**0.69**	0.72	0.29	**1.01**
World	**-18.17**	**5.33**	**-12.84**	**-20.11**	**5.89**	**-14.22**

Source: Authors' calculations
Note: Land use emissions column is based on Table 9 figures divided by 20 (years).
The emissions credit is attributed to the country that consumes the biofuel.
Additional peat lands emissions are not included in this table.

We can also compute the *marginal* ILUC coefficient for each crop. In this case, we investigate the marginal effect of the 5.6% mandate by increasing the demand for biofuel in the EU27 by a marginal amount of 1 million GJ in the 2020 (about 0.1% of the EU consumption level in 2020) situation and allowing the corresponding increase in biofuel (domestic or imported) production to come from one feedstock only. We compute the marginal effect for each feedstock at the end of the mandate in 2020. Table 12 displays the coefficient of emissions from land use changes for the eight feedstocks, for ethanol – without constraint on the feedstocks - and biodiesel. Figures are provided with and without the peatland effects. Concerning the later, we use a simple average of the IPCC and Couwenberg coefficients.

Table 11. Carbon balance sheet

	2020 REF	2020 MEU_BAU	2020 MEU_FT
Total carbon release from forest biomass (MtCO2eq)		43.41	46.07
Total carbon release from organic carbon in mineral soil (MtCO2eq)		63.09	71.66
EU Consumption of biofuel in 2020 (million GJ)	443	743	746
Annual carbon release from forest biomass (gCO2eq/MJ)		7.23	7.61
Annual carbon release from organic carbon in mineral soil (gCO2eq/MJ)		10.50	11.84
Annual direct savings (gCO2/MJ)		-60.55	-66.38
Total emission balance on a 20 years period (gCO2/MJ)		-42.82	-46.93

Source: Authors' calculations

Results show that sugarcane and sugarbeet, with the lowest marginal ILUC, are the most efficient feedstocks in terms of land use under the mandate scenario. The average ethanol coefficients from these two feedstocks are between 16 and 19 gCO2/Mj with a life cycle of 20 years. For wheat and sugar beet, under trade liberalization the ILUC effect increased. Since the EU will always outsource is supply of sugar cane ethanol in Brazil, the trade liberalization scenario has a very limited effect on the sugar cane coefficient.

Concerning biodiesel, even if peat land emissions are considered, palm oil is the most efficient feedstock, although still at a level three times above the emission levels for sugar cane ethanol. Palm oil appears as an efficient feedstock and can compete with crops for two reasons: it produces co-products, even in limited quantity and has a very high oil yield (up to six times the rapeseed yield by hectare). The average biodiesel coefficients (between 54gCO2/Mj and 58gCO2/Mj) are between rapeseed oil and the soybean oil. The latter is the most costly biodiesel in terms of ILUC since the soya market puts a lot of pressure on land extension in Brazil.

Compared to the average ILUC coefficients reported in Table 11, the figures in Table 12 are slightly different. We can provide two explanations. First, we are dealing with marginal coefficients that are expected to be above the average due to the decreasing marginal productivity embedded in the model (see next section). Second, as previously discussed, the mandate is mainly driven by an increased consumption of ethanol. As shown in the production figures, this ethanol will be produced from sugar cane (imports) and sugar beet, the most efficient feedstock in terms of land use.

Table 12 Marginal Indirect Land Use emissions, gCO2/MJ per annum. 20 years life cycle.

	MEU_BAU		MEU_FT	
	Without Peatland effects	**With Peatland effect**	**Without Peatland effect**	**With Peatland effect**
Ethanol	*17.74*	*17.74*	*19.16*	*19.18*
Ethanol SugarBeet	16.07	16.08	65.48	65.47
Ethanol SugarCane	17.78	17.78	18.86	18.86
Ethanol Maize	54.11	54.12	79.10	79.15
Ethanol Wheat	37.26	37.27	16.04	16.12
Biodiesel	*58.67*	*59.78*	*54.69*	*55.76*
Palm Oil	46.40	50.13	44.63	48.31
Rapeseed Oil	53.01	53.68	50.60	51.24
Soybean Oil	74.51	75.40	67.01	67.86
Sunflower Oil	59.87	60.53	56.27	56.89

Source: Authors' calculations
Note:The marginal coefficient is computed in 2020 after the implementation of the 5.6% mandate.

Table 13 Marginal Net Emissions by Feedstock. gCO2/Mj. 20 years life cycle.

	MEU_BAU		MEU_FT	
	Without Peatland effects	**With Peatland effect**	**Without Peatland effect**	**With Peatland effect**
Ethanol	*-49.69*	*-49.68*	*-53.55*	*-53.53*
Ethanol Sugar Beet	-35.86	-35.85	21.84	21.83
Ethanol SugarCane	-53.95	-53.95	-55.53	-55.53
Ethanol Maize	3.64	3.65	62.82	62.87
Ethanol Wheat	-7.00	-6.99	-5.02	-4.95
Biodiesel	*5.95*	*7.06*	*3.63*	*4.70*
Palm Oil	-21.98	-18.25	-22.43	-18.76
Rapeseed Oil	8.76	9.42	7.42	8.06
Soybean Oil	24.07	24.96	18.95	19.80
Sunflower Oil	8.73	9.38	7.74	8.37

Source: Authors' calculations
Note: Negative figures represent an emission reduction, positive values represent an emission increase.

The marginal ILUC effects reported in Table 12 combine with direct emissions reductions to generate the net emissions balance reported in Table 13. Sugar cane, Sugar beet and Wheat ethanol will generate marginal net emissions savings (negative emissions) under both the 5.6% mandate and the trade liberalization scenario, with the strongest effect for Sugar cane. For biodiesel, only palm oil will generate emission savings.[13]

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[13] Under the central assumption here that palm oil direct savings coefficient is 61%.

4 Should we Trust the Results? -- Sensitivity Analysis

Assessing the impact of biofuel policies and the ILUC coefficients – the focus of this study – is quite challenging due to a lot of uncertainties. We can group them into two categories: mandate policy targets and varying parameter settings. We assess the robustness of our central case results by performing sensitivity analysis on these different dimensions.

4.1 Mandate Policy Targets

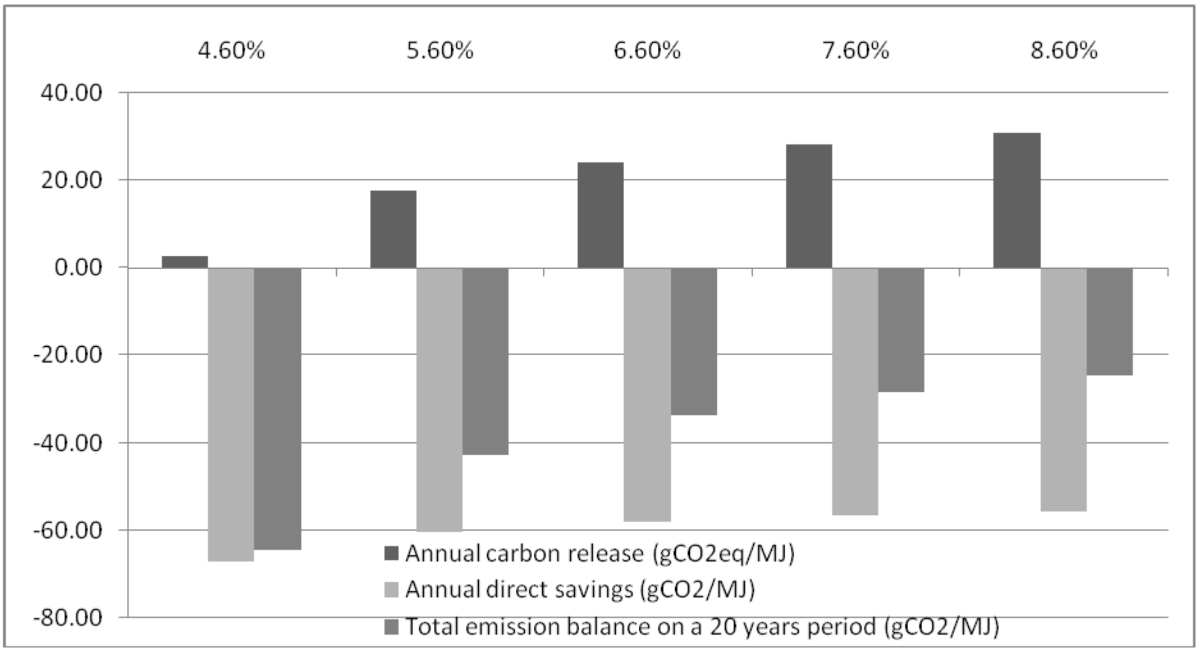
The overall size of the biofuels policies should matter in quantifying the economic and environmental impact of the policy. Due to decreasing marginal productivity, we expect that applying the same marginal change on a low or high level of biofuel demand and supply can play a very different role. The goal of this analysis is to check if (average and marginal) ILUC is constant or increasing with the total demand for biofuels.

Since the overall ambition of the EU mandate is an important question, we compute the average ILUC of the mandate for five levels of mandatory blending in the EU: 4.6%, 5.6%, 6.6%, 7.6% and 8.6%, equivalent to 14.5 Mtoe, 17.8 Mtoe, 20.7 Mtoe, 23.9 Mtoe and 27 Mtoe of biofuels consumption, respectively, for the two main trade scenarios: status quo (**Figure 9**) and trade liberalization (Figure 10).

As expected, the direct emission saving coefficient is reduced as the level of the mandate increases. Greater pressure for biofuel production from a higher target results in increasing use of less efficient feedstock. Similarly, starting with trade liberalization and a low mandate, the EU will import primarily sugar cane ethanol and with the increasing pressure on this feedstock, domestic sources of ethanol will become more attractive and the biofuel mix will become less efficient in terms of direct savings.

Concerning the ILUC emissions, we see a net increase of the adverse effects of the biofuel demands on land use as the level of the mandate increases. A 4.6% mandate could be achieved without noticeable land use impact, however any level above this point starts to generate emissions. Moving from 4.6 to 6.6 % will increase sharply the average emissions to reach 25gCo2/Mj. A 8.6% mandate without trade liberalization will cut by nearly half of the emissions savings under the 4.6% mandate. However, the total emissions balance remains positive for all the level of the mandate considered here.

Figure 6 Indirect land use emissions and direct savings for different mandate levels, No change in trade policy



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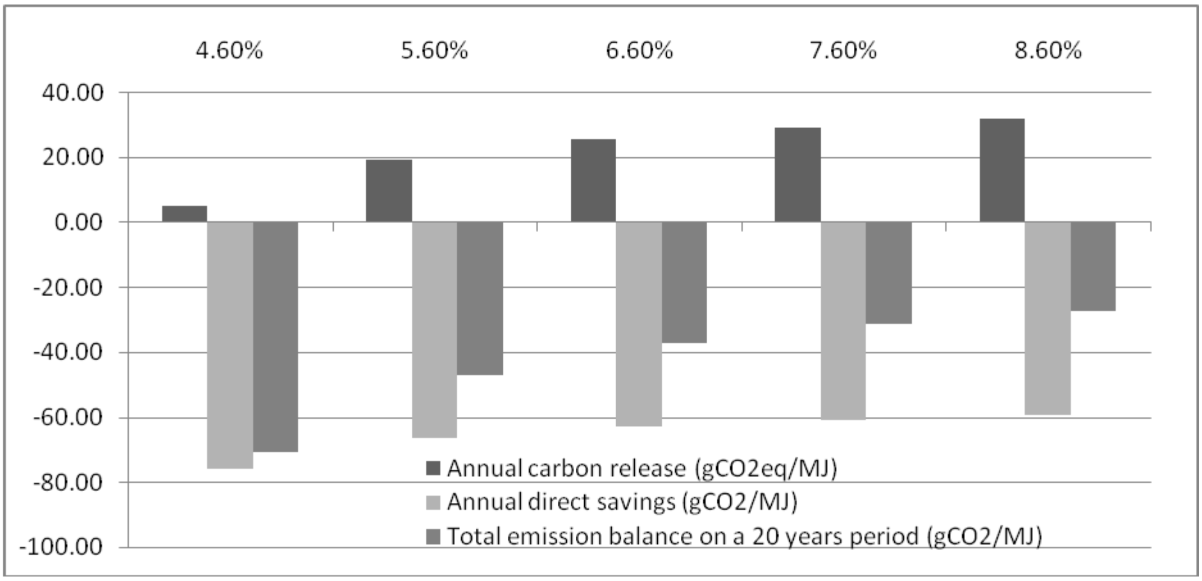
Source: Authors' calculations
Note: Negative figures represent an emission reduction, positive values represent an emission increase.

Figure 7 Indirect land use emissions and direct savings for different mandate levels, Free trade scenario



Source: Authors' calculations
Note: Negative figures represent an emission reduction, positive values represent an emission increase.

A key issue in this research is the question of whether the non-linear ILUC is just a feature of the model or whether it also reflects an underlying reality. First, the evolution of the size of the mandate leads to an evolution in the biofuel mix: no additional biodiesel is needed at 4.6% when about 5Mtoe of biodiesel is required by a 8.6% mandate. Since biodiesel is less emissions friendly, the average effect deteriorates. Second, nonlinearity of the ILUC effect can be expected from the modeling framework. Several mechanisms contribute to this effect:

- The capacity to substitute one type of land for another: it is represented by the concavity of the CET function in the land use module. The marginal productivity of one hectare moving from one sector to another is declining quickly with the low elasticity used. The first unit of land planted to barley can be transformed “easily” to wheat for instance, but this marginal transformation ratio is deteriorating. From the modeling point of view, the CET framework is not totally satisfactory but it remains the mainstream approach in the literature. However, how can we explain in the reality that farmers continue to have diversified productions, even if the price of one commodity dominates the other. Even when the wheat price is high, not all land in Europe is not shifted to wheat. There are many possible reasons for this: desire of diversification from farmers, real differences in land quality for the different crops, short term perception vs long term perception etc. Overall, they will lead to the same consequences: if farmers shift “some” units of land to the expanding crops easily, they will not do it in a linear way. They will stop converting eventually, and if they want to produce more of one crop, they will go for “new” land, while keeping their other production at a certain level. It means that substitution is non linear and that there is more pressure on new land with the increase in magnitude of demand from biofuels. A similar mechanism applies to pasture and forest that is converted to cropland. There is limited substitution (and non linearity due to the CET effect). It represents the fact that (a) pasture and forestry land converted to cropland have decreasing marginal productivity, (b) there are institutional factors that could hinder the conversion of these lands to cropland.
- The rigidity of other sectors to reduce part of their own consumption of feedstocks. The capacity of other sectors, and final consumers, to reduce their consumption level of feedstocks is also non linear (and represented by CES function). If they can initially forego a few units easily (e.g. Palm oil by cosmetic industry), their marginal propensity to do so declines quickly (=their marginal cost to do it increase). In a symmetric way, the absorption capacity for co-products by the livestock sector is disputable. Is it linear or not? In the model, it is not. But it seems also that in the “real” word, people argue about the limit in DDGS, or meals (at least one type of meal) in the animal feed.
- The saturation effect on fertilizers.
- The below-average productivity assumed for new units of land.

Every model is an abstraction of reality but should, at the same time, represent the essential features and behavior of that reality as correctly as possible. The non-linear features in this model are widely used in most biofuels models and indeed in most (agro-)economic models. There is sound economic rationale behind these behavioral assumptions. Abandoning decreasing returns would go against economic logic and common sense. On the other hand, it is difficult to estimate how strong these decreasing returns effects should be. The available empirical evidence is limited and often very different estimates for key parameters are available. There are two options here: extensive sensitivity analysis on key parameters (which we do below) and collecting more robust empirical evidence. The latter is outside the scope of this research project and may take many years to complete.

4.2 Parameter Uncertainties

It is important to underline that the values of some key parameters in the model are still subject to considerable uncertainty. It is therefore important to assess the role of alternative values in determining the robustness of the results.

Land and fertilizer substitution – Due to uncertainty about the values of elasticity of substitution between land and fertilizers, sensitivity analysis (is done by looking at the impact of using twice the land/fertilizer substitution elasticity in the base case.[14] Increasing the elasticity should help the farmers to intensify their production more easily and will limit the pressure for new lands.

Land substitution – Due to uncertainty about the value of the elasticity of land substitution across agricultural production, i.e. how easily land can be shifted from one crop to another, we investigate two cases:

- Elasticity of land substitution between crops are doubled;
- Elasticity of land substitution between crops and pasture are doubled.

In the simulations in this report, we assumed that increased demand for livestock could lead to intensification in some regions, thereby affecting the amount of land that is substituted between the livestock and crop sectors.

Both sensitivity analyses (doubling the elasticity of substitution between crops, and alternatively, the elasticity of substitution between cropland and pasture) have very similar results. Emissions are

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[14] The basic value has been calibrated based on detailed elasticity information extracted from the IMPACT model (Rosegrant et al. 2008)

reduced by 10% on average. Marginal ILUC is reduced by 30% since this parameter plays a key role in defining the marginal productivity profile for the crops.

Land use extension – Due to uncertainty about the value of elasticity of the land extension supply curve, i.e. how new land are converted to agricultural uses when the rental price of land increases, we conduct sensitivity analysis by varying the value of the land extension elasticity. Our main estimates are based on Barr, et al. (2010) for the US and Brazil and on the OECD. Current values assume much more flexibility in Brazil and a land extension elasticity in Brazil that is 5 times higher than in the US or in the EU. We look at two specific scenarios:

- We increase the land extension elasticity in Indonesia and Malaysia to reach the level for Brazil - If we apply Brazil's land extension elasticity to Indonesia and Malaysia, i.e. 0.10 instead of 0.05, the ILUC effects will be stronger in this region. Emissions increase by about 4 millions of CO2eq and the marginal ILUC of palm oil increases by 10%, reaching the same level as for rapeseed oil.
- We reduce by half the land extension elasticity in Brazil (which could be the case if Brazil manages to enforce its preservation program) - If land extension elasticity in Brazil is reduced by half, global ILUC emissions are reduced by one-third and the total emissions balance improves. Brazilian exports to the EU are not significantly affected since land is taken from other sectors and production becomes more intensive.

Other parameters that may be critical to the overall assessment of the emissions effects of the biofuel mandates are: the choice of direct emissions savings and the coefficients of land use

Technology Pathway – In the assessment of the direct GHG emissions from different biofuel feedstocks used by major biofuels producers, we rely on a set of direct emissions coefficients that are sourced from the EU RED Directive, or from the literature. The values are employed in the central scenario. These values, as well as the results of a sensitivity analysis on these values are discussed in Al-Riffai et al. (2010).

It is important to keep in mind that alternative technology pathways are used in an ad-hoc method (per unit coefficient) and do not lead to a modification of the sectoral technology used in the model. We expect that the better the technology (higher reduction coefficients) the better the net CO2 balance effect.

5 ILUC in Policy Assessment (to be completed)

6 Concluding Remarks

The main lesson learned is that ILUC does indeed have an important effect on the environmental sustainability of biofuels. However, the size of the additional EU 2020 mandate, under current assumptions regarding the future evolution of renewable energy use in road transport, is sufficiently small (5.6% of road transport fuels in 2020) and does not threaten the environmental viability of biofuels. If the underlying assumptions should change however, either because the mandated quantities turn out to be higher and/or because the model assumptions and parameters need to be revised, there is a real risk that ILUC could undermine the environmental viability of biofuels. Non-linear effects, in terms of biofuels volumes and behavioural parameters, pose a risk.

At the same time, this biofuels modeling project has demonstrated how the current limits to data availability create significant uncertainty regarding the outcomes predicted by these policy simulations. The model represents a state of the art simulation of the real world, but more data collection work will be required to reduce this margin of uncertainty.

In terms of trade policy, the main result is that biofuels trade liberalization would lead to slightly more ILUC effects through deforestation outside the EU (especially in Brazil). But this is compensated by the use of a more efficient biofuel (sugar cane ethanol) that improves emissions savings and results in animproved CO2 emission balance. At the same time such an effect can take place only if we assume that the share of ethanol in total biofuel consumption can increase drastically from 19% to 45% by 2020.

Effects on food prices will remain limited (maximum +0.5% in Brazil, +0.14% in Europe). Although EU biofuel policy has no significant real income consequences for the EU, some countries may experience small negative effects, particularly oil exporters (-0.11% to -0.18% of real income by 2020) and Sub-saharan Africa (-0.12%) due to the fall in oil prices and rise in food prices, respectively.

Analysis of ILUC by crop indicates that ethanol, and particularly sugar-based ethanol, will generate the highest potential gains in terms of net emissions savings. For biodiesel, palm oil is the efficient feedstock in terms of CO2 emissions, even if peatland emissions are taken into account.

From a methodological point of view, our study confirmed that yield response and land substitution elasticities play a critical role in our assessment. The potential non-linearity of ILUC coefficients was also demonstrated. However, our main conclusions remain robust to the sensitivity analyses performed at this stage. We have also confirmed the importance of having a high quality database with the need of linking the value and the quantity matrix to feed the model with marginal rates of substitution that are relevant. In terms of policy design, taking into account the biofuels mandates in other economies was important to limit the capacity of the EU to absorb foreign production. However, we have limited our analysis to a conservative case (5% mandates for China, Canada, Japan, Australia, New Zealand, Switzerland, Indonesia and Indonesia) and a stronger constraint may lead to higher ILUC impact.

Even more important is the role of the mix between ethanol and biodiesel. Depending on the flexibility allowed for the ratio between the two biofuels, land use effects and trade policy effects can be very different.

Annex I. Modeling Land Use Expansion

The mechanism of land use expansion in the revised MIRAGE is based on theoretical foundation that is supported by the literature on this issue, but at the same time was designed to be simple enough for modeling purposes. The representation explained in this Annex has been introduced in some previous works (Bouet et al., 2007 and Valin et al., 2008). This note explains the mechanism in play in as much detail as possible.

1 –Land Use Substitution

The details of this mechanism has been documented above. What is however important to keep in mind is that a distinction is made between two types of land: managed land, which has an economic return, and unmanaged land which is represented without any economic value.

Managed land includes in the default mode (mode P=0, P standing for "Pasture"):

- Cropland (cultivated land including permanent crops land and set aside land).
- Pastureland
- Managed forest

These different types of land are substitutes for each other. They are represented in the model in the form of economic rental values and the representative land owner can choose to allocate the land-productivity (homogenous to land rent values at initial year and defined as land surface adjusted by a productivity index) between land use with different substitution levels.

When demand for a crop increases, prices for the crop go up, and more land is allocated to this crop. This land is taken from other uses (pasture and managed forest) with respect to the respective prices of these two other categories. In the standard specifications, the price of pasture land is directly affected by the demand for cattle products (beef meat and dairy). Forest prices are affected by the demand for raw wood products. The magnitude of substitution follows the Constant Elasticity of Transformation (CET) specification:

$$\left(\frac{L_1}{L_2}\right) = A * \left(\frac{PL_1}{PL_2}\right)^{\sigma}$$

where L_1 and L_2 are hectares-productivity associated with two different land uses and PL_1 and PL_2 are their respective prices. A is a calibration constant and σ is the elasticity of transformation.

If the elasticity of transformation is high, the possibility for land replacement within managed land will allow for low prices for the increased demand for crops and aggregated cropland price will not increase significantly. But if transformation possibilities inside managed land are smaller (for instance, simultaneous demand for competing products on the land market; a very homogenous use of the managed land; or very small elasticity of transformation), then cropland prices will rise in response to the increased demand. Land use expansion will occur in response to the price increase.

2 - Land Use Extension

The mechanism for land use expansion in each region and each AEZ can be represented with the simple equation below:

$$
\begin{aligned}
LANDEXTZ_{z,r,t} + MANAGED\_LANDZ_{z,r,ini} \\
= MANAGED\_LANDZ_{z,r,t}{}^{Exo} \\
* \left(\left(\frac{P^{Managed\_land}_{z,r,t}}{P^{Managed\_land}_{z,r,Ref}} \right)^{\sigma^{Landext} * \left(\frac{LandZ_{avail} - LANDEXTZ_{z,r,t}}{LandZ_{avail}} \right)} - 1 \right)
\end{aligned}
$$

Where

$LANDEXTZ_{z,r,t}$ *is managed land expansion into unmanaged land in region r and AEZ z: this land is allocated to cropland*

$MANAGED_{LANDZ_{z,r,t}}{}^{Exo}$ *is the exogenous land evolution trend in AEZ z and region r based on historical data*

$P^{Managed_{land}}_{z,r,t}$ *is the average price of managed land for region r and AEZ z,*

$P^{Managed_{land}}_{z,r,Ref}$ *is the reference price of managed land in the baseline for the region r*

$\sigma^{Landext}$ *is an elasticity of land expansion*

$LandZ_{avail}$ *is the area of land available for rain-fed crops in region r and AEZ z and not already in use*

This relation has the following properties:

- In the initial year, $MANAGED\_LANDZ_{ini}$ = $MANAGED\_LANDZ_t^{Exo}$ and therefore LANDEXT = 0
- In dynamic evolution, land expansion corresponds to the exogenous trend based on historical trends.
- Around the initial point, LANDEXTZ is small in the exponent; therefore, land expansion elasticity equals $\sigma^{Landext}$
- When price of cropland increases, LANDEXTZ increases and MANAGED_LAND expands. In this framework, only demand of new land for crops is considered. Therefore, it is the price of cropland that determines the expansion and the associated natural land uptake is attributed to cropland.

- When LANDEXTZ increases, $\frac{LandZ_{avail\square} - LANDEXTZ_t}{LandZ_{avail\square}}$ becomes smaller and the elasticity of land expansion is reduced by this factor. This means that price increases need to be more and more important to allow expansion, reflecting the fact that land expansion becomes harder when as more available land is used up. If this elasticity gets close to zero, land expansion becomes indeed impossible.

Implicitly, this equation defines what other studies have referred to as a “land supply curve”. Land supply curves are often calibrated on physical values (such as productivity displayed in *Figure 17*). However, this does not really increase their robustness because the most significant indicator is the expansion elasticity at the starting point, which depends more on behavioral factors than on biophysical factors (even if biophysical factors can explain a part of the behavior).

In the revised MIRAGE model, the default value for land expansion has been set at the level of substitution value between managed forest and cropland-pasture aggregate in the substitution tree (between 0.05 and 0.1 varying by region). However, sensitivity analyses are critical on account of the uncertainty on this parameter.

3 – A Database on Land Available at the AEZ Level

In order to use a proxy for land available for rain fed crops at the AEZ level, we computed our own estimates by decomposing IIASA databases following the procedure outlined below:

1) Each region is associated with a reference macro region which has similar geophysical characteristics. It is then assumed that available land distribution ratio across LGP will be close.
2) The land distribution ratio of the LGP are distributed across AEZ (it means it is distributed across climatic zones). For this the key of distribution is a geometric mean of cropland and total land.
3) The land distribution ratio obtained are applied to the land available in the country.
4) The land available obtained is compared to land under cultivation at the AEZ x country level. When land available is less than cropland area, three cases are considered:
    a. If the total of land available is less than the total cropland for the aggregate region, then cropland is considered fixed and no expansion will be possible in the region.
    b. If the total of land available – cropland is positive and twice larger for the sum of the positive terms than the sum of the negative terms, then one redistributes the negative terms, i.e. one considers that AEZs where there is less land available than cropland are computation biases. The gap is then redistributed across regions where

land available is higher than cropland. The key used for AEZ distribution is land available – cropland.

    c. If the total of land available – cropland is positive but less than twice larger for the sum of the positive terms than the sum of the negative terms, then one consider that the data available does not allow a correct distribution of available land and no redistribution is done. Land expansion is enabled but only for AEZs where land available – cropland > 0.

5) Once all land available is distributed across AEZ and larger than cropland, a last step is to check that this land_available does not exceed AEZ area of land with soil (i.e. total productive land > land available for crop). For AEZs where this condition is not respected, the extra land available is distributed among other AEZs using the land distribution ratio as a key of distribution.

Therefore, the database obtained respects the following criteria:

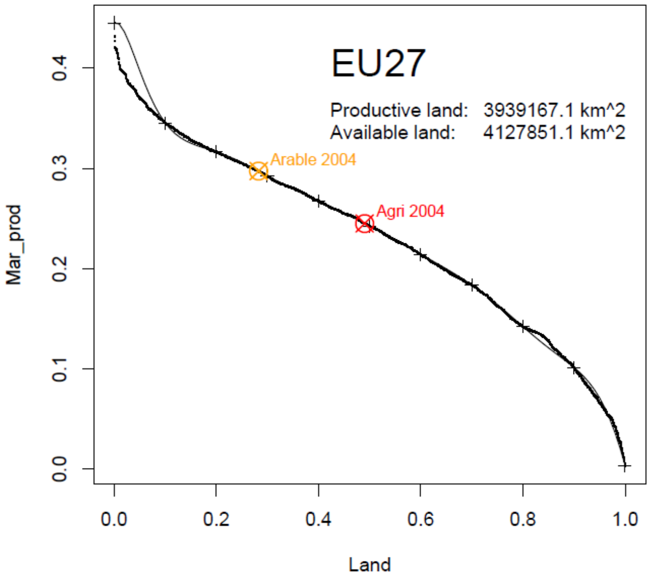
- All land available in regions summed across AEZ matches national data from IIASA on land available for crops;
- In each AEZ, land available is equal or greater than cropland. If equal, no expansion is considered in the AEZ (and no decrease of cropland).
- In each AEZ, land available is less than the total quantity of productive land.
- Available land distribution across AEZ follows the distribution of the macro region mapped with the region considered.

4 - Marginal Productivity of New Land from Expansion

The variable LANDEXTZ is not a land-productivity as in the CET structure. That is why it is necessary to attribute a productivity factor to the new land converted to make it homogenous with the land already in use. A first approach was to multiply the area of land by the marginal productivity of land with respect to mean land productivity. Figure 17 shows the distribution curve that is used in the model in order to compute the marginal yield to apply. An index of average yield for cropland is computed by integrating the curve between the origin and the yellow dot and dividing by the x-axis value of the yellow dot. The marginal yield for expansion is then obtained by dividing the marginal productivity of managed land by the average productivity of cropland (this indicator is referred to as "yield elasticity to land expansion" in the GTAP/CARB study).

However, we have relied on a much simpler approach in the final study. We assume that marginal land productivity in all regions is half the existing average productivity and will not change. This ratio is increased to 75% for Brazil. It is important to keep in mind that this assumption remains strong and recent research seems to show that recent marginal land extension were taking place on land with at least average level yields.

Figure 8. Example of productivity distribution profile for the USA.



Note : Y axis is a relative index of potential productivity for a 0.5 x 0.5 degree grid cell in the IMAGE model. X axis represents the productive land (cultivation potential > 0) and is normalized from 0 to 1. Black dots (thick line) represent the initial data of the distribution, sorted from the highest value to the lowest value, on a 0.5 x 0.5 degree grid cell basis. The thin line represents the interpolation curve defined as an 11th degree polynomial function, and interpolation points are represented with black cross. The yellow circle represents the marginal position of arable land use expansion, under the assumption that the most productive land is used for cropland. The red point represents the marginal position of agricultural land expansion (cropland, pasture and managed forest) under the assumption that the most productive land is used for this category. When managed land expand, we consider that the marginal value to consider is the latter.

5 - Allocation of Land Expansion Between other Uses in the Model

Once land expansion is computed in the model, the difficult task of allocating it between the different types of unmanaged land remains. In the revised MIRAGE model, because we rely primarily on FAO data, only three different types of unmanaged land are distinguished:

- Primary forests
- Savannah and Grassland: this category is mixed with Pastureland into the reference “Meadows and Pastures” under FAO nomenclature. With the Monfreda-Ramankutty-Foley

(2007) database that we use to distinguish the AEZ in managed land, we can disentangle these categories, assuming that Pastureland is associated with an economic use, whereas Grassland and Savannah are not.

- Other land (shrubland, mountains, deserts, urbanized areas).

We then allocate the expansion following a coefficient for each land use type. This coefficient corresponds to the proportion of the land use type which is converted to cropland when 1 ha of cropland expansion occurs.

We use coefficients from the Winrock database (EPA RIA, Feb 2010) for countries for which this data is available. These coefficients are estimated by remote sensing analysis and are supposed to specifically correspond to the effect of cropland expansion. For Brazil, these coefficients are AEZ specific and thus allows us to accurately reproduce the heterogeneity of expansion distribution between AEZs. For other regions, we compute the distribution at the AEZ level with the national distribution keys and we eventually adjust using cross entropy if some land use types are not available in a specific AEZ. Therefore, the national distribution is conserved whatever the specific repartition at the AEZ level.

It should be noted that in some regions managed land expansion can be a managed land retraction. If so, we use the same coefficient to allocate the new land between land use, except for primary forest that cannot be recovered by afforestation in that case. Primary forest is therefore replaced by plantation forest.

6 - Pasture and Managed Forest Retroaction

Representation of cropland expansion into other land uses differ a lot across models depending on the transformation possibilities between cropland, pasture and forest land. In computable general equilibrium models (like GTAP used for CARB), the representation of land rent for cattle and forest is such that demand for these new sectors affects land use. But in many partial equilibrium models that do not represent demand for these types of good, (for instance the FAPRI model used by EPA for countries other than the US[15], AGLINK or other models without representation of cattle land), this feedback effect is not represented. This is an important issue since the effect of the pasture sector on land use can be a large source of uncertainty in results, as long as new demand for cattle is associated with new demand for land (which seems to be the case in some areas of the Brazil deforestation frontier). For example, some income effect in large and poor areas like Africa can have

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[15] The FASOM model used in the EPA assessment of biofuel carbon emissions and compute the ILUC effect represent US cattle and US forest. It can therefore represent the effect of land requirements of these sectors.

a significant land use effect via a drop in demand for meat following an increase in food prices due to biofuels.

In order to test the influence of the retroaction of these sectors to biofuel policies, we considered several variations in the modeling to better control the possible assumptions:

- The first mode (P=0) is the GTAP assumption, where all pasture land is allocated to the production function of cattle. All pasture land is assumed to be used efficiently so that increased demand for cattle products will require an expansion of pasture land. This assumption is clearly not realistic for some regions, where cattle intensification is possible.
- One variant (P=1), which is used in our central scenario, relaxes the P=0 assumption by allowing for cattle intensification using an intensification index. At the present time, this index is computed in a very simple way: it only corresponds to the number of cattle heads (expressed by bovine equivalent, using weight of animals as an indicator of their feed intake) by hectare (see Table 17). This indicator could be refined to take into account the heterogeneity of productivity of grassland, which however cannot be done easily with a non-spatially explicit model. From this index of cattle density, we impose a level above which no intensification is possible. For countries where no intensification is possible, we attribute all pasture to the cattle production function. But for countries where cattle density is below the cap, we attribute only a share of the total pasture, which corresponds to the area on which the cattle would reach the intensification limit value. Because only a share of pastureland is related to production, this design lowers the effect of new demand of cattle.

Table 14 Number of cattle head (bovine eq) per square kilometers for main regions

Region	Cattle head eq per km2
Rest of OECD countries	31
China	53
Rest of World	35
Indonesia & Malaysia	577
South Asia	790
USA	44
Other Latin America countries	60
Brazil	118
Central America and Carribeans	109
EU27	168

Source: FAOSTAT (2009)

- A second variant (P=2) is closer to the assumption in some partial equilibrium models. We assume that intensification is possible for cattle (and also for forest), and we remove these land types from the substitution tree. This means that there is no retroaction from pastureland or from forest land on cropland in the model. Technically, this is done by assuming that these sectors do not remunerate land but instead remunerate a fixed natural resource that is not substitutable with land. Doing so, substitution can only occur within cropland, between crop types. In this design, “managed land” area is reduced to cropland and expansion occurs in more land types than before. It can expand in:
    - Pastureland
    - Managed forest
    - Primary forests
    - Savannah and Grassland
    - Other land (shrubland, mountains, deserts, urbanized areas).

  The share of pastureland and managed land affected by land use demand from cropland is no longer distributed endogenously with respect to demand of cattle and wood but exogenously, using fixed coefficients (more likely, Winrock coefficients).

All these mechanisms allow us to explore the different dimensions of potential impact of biofuel policies on land use change. In turn, computing land use change allows us to compute the associated GHG emissions. However, the detailed description of all these different linkages is done mainly for explanatory purpose because of all uncertainties on the addressed phenomena, as already discussed in the introduction of this annex.

Annex II. Measurement of Marginal Indirect Land Use Change

The indirect land use change effects from the use of different biofuel feedstock to produce an additional 10^6 GJ of biofuels in the EU is computed in terms of CO2 emissions from the equilibrium state reached under the mandate in 2020. Marginal ILUC are computed on a selection of different scenarios for 8 different biofuel feedstock:

- Wheat
- Corn
- Sugar beet
- Sugar cane
- Rapeseed oil
- Soybean oil
- Palm oil
- Sunflower oil

The computation starts from the equilibrium state reached under the mandate in 2020. A small shock of an extra incorporation commitment of 10^6 GJ is applied to the EU mandate of the level selected (4.6%, 5.6%, 6.6%, 7.6%, or 8.6%). For this shock, the level of intermediate consumption of all feedstock, except the one studied, is fixed for biofuel production in all regions. The extra demand of EU for biofuel is consequently met by an extra production of biofuel with this feedstock only. This production can be supplied domestically or come from other regions if some production capacities exist in these other regions. This mechanism is illustrated in Figure 18.

In addition, the demand of regions other than EU for biofuel is maintained constant during the shock to ensure that at constant production volume a country does not divert its exports and domestic oriented production of biofuel, used with other feedstock, to exports to the EU. Similarly, trade in biofuel to non-EU markets are considered unchanged during the marginal shock. Consequently, the supply of biofuels across the world only varies by the extra use of the selected feedstock and this extra production is sent to the EU for incorporation in transportation fuel. This modeling enables the computation of the land use change effects related to the marginal shock on feedstock.

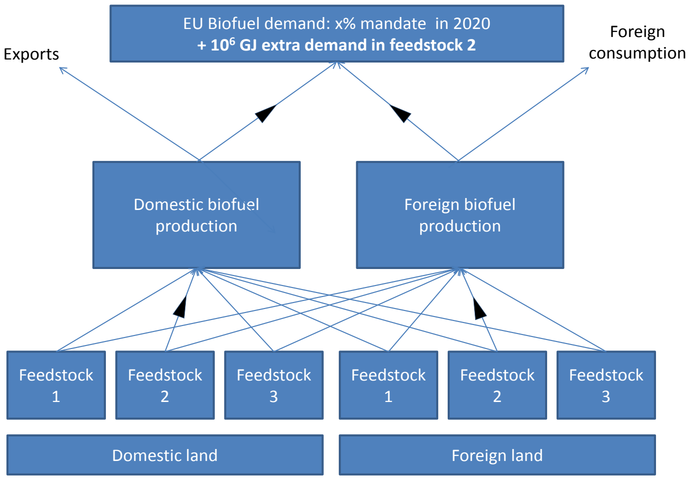

Figure 9 **Modeling of a Marginal ILUC Shock**

Land use change emissions, expressed as gCO2/MJ and gCO2/t of biofuel, are computed from the land use change in the model using IPCC Tier 1 methodology. Two types of emissions are considered:

- Emissions from biomass lost by deforestation: when an area of forest is converted into cropland or grassland, the carbon content above ground and below ground is considered released into the atmosphere. These emissions are accounted for as a stock variation and as an annual loss on a period of amortization of twenty years (no discounting coefficient is applied).
- Emissions from release of carbon in mineral soil: cultivation of new land under several management practices is considered releasing carbon on an annual basis for a period of twenty years. This carbon release is accounted for on an annual basis.

This modeling enables the comparison of the indirect land use effect with direct effects, which can be measured with a detailed description of sector specificities. Land use change effects are also computed by the model. The indicators which are computed are:

1) Feedstock saving per annum - Prod EU (gCO2eq / MJ and kgCO2eq / t)

   *Emissions Prod EU (biofuel) = Production variation (biofuel) * EU Emission factor (biofuel)*

2) Feedstock saving per annum - Conso EU (gCO2eq / MJ and kgCO2eq / t)

   These emissions correspond to savings from the extra world production consumed in the EU. It is therefore computed as:

   Emissions Conso EU (biofuel)

= EU production for domestic demand (biofuel) EU emission factor (biofuel) + Imports (biofuel) * Exporter emission factor (biofuel).*

3) Feedstock saving per annum - Conso World (gCO2eq / MJ and kgCO2eq / t)

   This indicator provides the total carbon savings for the feedstock selected at the world level, as a consequence of the EU increase in demand. It incorporates the values from 3) but also takes into account change in consumption of other countries affected by the EU mandate. It is simply computed as:

   Emissions Conso World (biofuel) = $Sum_{Regions}$ *[Production region (biofuel) * Region emission factor (biofuel)]*

4) Carbon payback time from 2020 (Conso EU)

   Carbon payback time is computed in reference to the second direct emission indicator (2 = Conso EU). This period of time is computed as:

   Carbon payback = Land use change initial emissions (1)

   / Annual emissions savings - Conso EU (3)

The coefficients of direct GHG emissions reduction used for different biofuels feedstock in different regions are given in the next section.

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