Global Trade and Environmental Impact Study of the EU Biofuels Mandate

Final Report

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LIST of ACRONYMS and ABBREVIATIONS

AEZ	Agro-Ecological Zone
Btu	British Thermal Unit
CAP	Common Agricultural Policy
CARB	California Air Resource Board
CEPII	Centre d'Etudes Prospectives et d'Informations Internationales
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
CIS	Commonwealth of Independent States
CO2	Carbon Dioxide
DDA	Doha Development Agenda
DDGS	Distillers Dried Grains with Solubles
DG	Directorate General
EC	European Commission
EEA	European Environment Agency
EPA	Economic Partnership Agreement
EPA	(US) Environmental Protection Agency
EU	European Union
FAPRI	Food and Agricultural Policy Research Institute
FAO	Food and Agriculture Organisation of the United Nations
FQD	Fuel Quality Directive
GHG	Greenhouse Gas
GJ	Gigajoule
GTAP	Global Trade Analysis Project
HHV	High Heating Value

IEA	International Energy Agency
IFPRI	International Food Policy Research Institute
ILUC	Indirect Land Use Change
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LCA	Life Cycle Analysis
LES	Linear Expenditure System
LHV	Low Heating Value
MFN	Most Favored Nation
MIRAGE	Modeling International Relationships in Applied General Equilibrium
MJ	Megajoule
MToe	Million Tons of Oil Equivalent
N2O	Nitrous Oxide
OECD	Organisation for Economic Co-operation and Development
PE	Partial Equilibrium
RED	Renewable Energy Directive
RER	Renewable Energy Roadmap
RFS	Renewable Fuels Standard
SAM	Social Accounting Matrix
USA	United States of America

UNIT CONVERSION SYSTEM

Ethanol

1 US gallon = 3.78541178 liter

Corn: 1 bushel = .0254 metric ton

Gasoline: US gallon = 115,000 Btu = 121 MJ = 32 MJ/liter (LHV). HHV = 125,000 Btu/gallon = 132 MJ/gallon = 35 MJ/liter

Metric tonne gasoline = 8.53 barrels = 1356 liter = 43.5 GJ/t (LHV); 47.3 GJ/t (HHV)

Metric tonne ethanol = 7.94 petroleum barrels = 1262 liters

Ethanol energy content (LHV) = 11,500 Btu/lb = 75,700 Btu/gallon = 26.7 GJ/t = 21.1 MJ/liter.

Ethanol density (average) = 0.79 g/ml (= metric tonnes/m3)

Biodiesel

1 m3 de biodiesel = 0,78 tep

Metric tonne biodiesel = 37.8 GJ (33.3 - 35.7 MJ/liter)

Petro-diesel = 130,500 Btu/gallon (34.5 MJ/liter or 42.8 GJ/t)

Petro-diesel density (average) = 0.84 g/ml (= metric tonnes/m3)

Vegetable oil density = 0.89 kg/l

Executive Summary

Global demand for biofuels has risen sharply over the last decade, driven initially by oil price hikes and the need for greater energy security. Support measures were established in many countries in recognition of the potential of biofuel development in reducing dependence on fossil fuels, increasing farm revenues, and generating less environmental damage through lower greenhouse gas (GHG) emissions compared to non-renewable fuel sources. Over the last three years, however, scepticism about the positive impact of biofuels has escalated as the trade-offs between food, feed, and fuels and their impact on global agricultural markets became more evident, eventually leading to the debate over the extent of the role of biofuels in the 2007-08 food price crisis. Furthermore, several studies have raised serious concerns about the negative environmental impact of the unintended consequences of biofuel production, particularly the indirect land use change (ILUC) impact of releasing more carbon emissions as forests and pristine lands are converted to cropland due to biofuel expansion. This has led to the current debate over whether, and how, the ILUC effects should be accounted for, along with the direct land use change effects, in evaluating the potential impact of biofuel policies.

On 23 April 2009, the European Union adopted the Renewable Energy Directive (RED) which included a 10% target for the use of renewable energy in road transport fuels by 2020. It also established the environmental sustainability criteria that biofuels consumed in the EU have to comply with. This includes a minimum rate of direct GHG emission savings (35% in 2009 and rising over time to 50% in 2017) and restrictions on the types of land that may be converted to production of biofuels feedstock crops. The latter criterion covers direct land use changes only. The revised Fuel Quality Directive (FQD), adopted at the same time as the RED, includes identical sustainability criteria and targets a reduction in lifecycle greenhouse gas emissions from fuels consumed in the EU by 6% by 2020. Moreover, the Parliament and Council asked the Commission to examine the question of indirect land use change (ILUC), including possible measures to avoid this, and report back on this issue by the end of 2010. In that context, the Commission launched four studies to examine ILUC issues, including the present study.

The primary objective of this study is to analyse the impact of possible changes in EU biofuels trade policies on global agricultural production and the environmental performance of the EU biofuel policy as concretised in the RED. The study pays particular attention to the ILUC effects, and the associated emissions, of the main feedstocks used for first-generation biofuels production.

This is the only study, out of the four launched by the Commission, that uses a global computable general equilibrium model (CGE) to estimate the impact of EU biofuels policies, in this case an extensively modified version of the existing MIRAGE model. Primary among major methodological innovations introduced in the model is the new modeling of energy demand which allows for substitutability between different sources of energy, including biofuels. The underlying global Global Trade Analysis Project (GTAP) database has been extended to separately identify ethanol (with four subsectors), biodiesel, five additional feedstock crops sectors, four vegetable oils sectors, fertilizers, and the transport fuel sectors. This extension has been introduced using innovative tools to ensure the consistency in both value and volume for the sectors of interests. The model was also modified to account for the co-products generated in the ethanol and biodiesel production processes and their role as inputs to the livestock sector. Fertilizer modeling was also introduced to allow for substitution with land under intensive or extensive crop production methods. Finally, another major innovation is the introduction of a land use module which allows for substitutability between land classes, classified according to agro-ecological zones (AEZs), and land extension possibilities. We assess the greenhouse gas emissions (focusing on CO2) associated with direct and indirect land use changes as generated by the model for the year 2020, and separately quantify the marginal ILUC for each feedstock crop.

The modelling starts from a baseline scenario that excludes the EU biofuels policies introduced by the RED. In that baseline, EU biofuels consumption is kept stable between 2009 and 2020, at the 2008 level of a 3.3% share in the mix of biofuels and fossil fuels. This baseline scenario incorporates the latest forecasts of energy prices by the IEA, and OECD economic growth. It also maintains the EU anti-dumping levy on biodiesel imports from the US. The baseline takes into account the biofuels mandates in other economies but we have limited this to a conservative case (5% mandates for China, Canada, Japan, Australia, New Zealand, Switzerland, Indonesia and Indonesia).

We then introduce a first-generation land-using biofuels share of 5.6% in the overall EU renewable energy target of 10% for road transport fuels (by 2020) in a central policy scenario, and calculate the impact of this policy measure on agricultural production, trade, incomes and carbon emissions. The 5.6% figure is obtained by deducting the expected share in 2020 of other renewable road transport fuels from the 10% target. We also examine the impact of a change in the EU biofuels trade policy regime, with an elimination of import tariffs, in a full multilateral scenario and in a bilateral scenario (with the MERCOSUR countries only). Finally, sensitivity analyses are conducted to assess the robustness of the model results to alternative assumptions about the size of the EU biofuels policy target and on several parameter settings.

The central policy scenario translates the 5.6% first-generation biofuels mix in road transport fuels in 2020 into an increase in biofuels consumption in the EU by 17.8 Mtoe. The required increase in biodiesel production is mostly domestic in the EU while the increase in bioethanol production is mostly concentrated in Brazil. It implies a considerable increase in EU imports of bioethanol, despite the duties. Brazil's real income increase marginally (+0.06%), and even less so for the EU; all other regions lose marginally. World cropland increases by 0.07%, showing that there is indeed indirect land use change associated with the EU biofuels mandate. Direct emission savings from biofuels are estimated at 18 Mt CO2, additional emissions from ILUC at 5.3 Mt CO2 (mostly in Brazil), resulting in a global net balance of nearly 13 Mt CO2 savings in a 20 years horizon.

The multilateral and the bilateral trade liberalization scenarios show very similar results, primarily because Brazil is the main beneficiary in both scenarios. Trade opening is beneficial for the environment. Elimination of tariffs on biofuels imports, especially for bioethanol, leads to slightly higher ILUC effects because of land extension outside the EU, especially in Brazil. But direct emissions are reduced because production and consumption moves towards a more emission-efficient biofuel (sugar cane ethanol from Brazil). The emissions saving rate is improved and the overall emission balance is positive in terms of CO2 reduction (between 43 and 47 gCO2 saved by MJ of biofuels). This effect is based on the assumption that the share of ethanol in EU biofuel consumption can increase from 19% to the maximum level of 45% by 2020.

The model simulations show that the effect of EU biofuels policies on food prices will remain very limited, with a maximum price change on the food bundle of +0.5% in Brazil and +0.14% in Europe. The EU biofuels policy also has no significant real income consequences for the EU, though some countries may experience a slight decline in real income: -0.11% to -0.18% by 2020 among oil exporters, and -0.12% for Sub-Saharan Africa, due to a decline in fossil oil prices and a rise in food prices, respectively.

Analysis of ILUC effects by crop indicates that ethanol, and particularly sugar-based ethanol, will generate the highest potential gains in terms of net emission savings. For biodiesel, palm oil remains as efficient as rapeseed oil, even if peatland emissions are taken into account. The model also indicates that the ILUC emission coefficients could increase with the size of the EU mandate. Simulations for EU biofuels consumption above 5.6% of road transport fuels show that ILUC emissions can rapidly increase and erode the environmental sustainability of biofuels.

There are important uncertainties with respect to a number of behavioral parameters in the model. Still, the main conclusions of the study remain robust with respect to the sensitivity analyses performed. Yield response and land elasticities play a critical role in the assessment. We have also confirmed the importance of having a high quality database that links the value and the quantity matrix to feed the model with technically relevant marginal rates of substitution. .

We conclude by emphasizing critical areas for further research to improve the evidence base for policy makers.

It is important to investigate the assumptions regarding the 45%/55% ratio between biodiesel and bioethanol that we use in this study (as a function of vehicle fleet composition) since this strongly influences the results. It pushes biofuel demand towards bioethanol, where sugar ethanol provides important net emissions savings and accounts for the strong benefits from trade liberalization..

There is also a critical need to improve the overall quality of data for the EU27 SAM. Considerable effort was spent on correcting some inconsistencies and updating the GTAP7 database. However, the quality of the original EU social accounting matrix in the GTAP7 database is poor. Moving to the latest GTAP7.1 database (released in mid-February 2010) that includes updated EU SAMs could improve the analysis.

Finally, considerable uncertainty remains regarding the impact of the sustainability criteria on biofuels markets. The role of certification and the emergence of differentiation in biofuels, feedstock crops and land prices, based on carbon content and the respect of sustainability criteria, require more empirical research. More research on the situation and likely evolution of the share of different production pathways could reduce uncertainties regarding direct emission savings. It would help to get a better understanding of the actual impact of the sustainability criteria in the EU RED on emissions and the market for biofuels.

1 Introduction

Global demand for biofuels has risen sharply over the last decade, driven initially by oil price hikes and the need for greater energy security. Support measures were established in many countries in recognition of the potential of biofuel development in reducing dependence on fossil fuels, increasing farm revenues, and generating less environmental damage through lower greenhouse gas (GHG) emissions compared to non-renewable fuel sources. Over the last three years, however, scepticism about the positive impact of first-generation biofuels has escalated as the trade-offs between food, feed, and fuels and their impact on global agricultural markets became more evident, eventually leading to the debate over the extent of the role of biofuels in the 2007-08 food price crisis. Furthermore, several studies (e.g. Fargione et al, 2008; Searchinger et al., 2008; RFA, 2008) have raised serious concerns about the negative environmental impact of the unintended consequences of first-generation biofuels that are based on feedstock fit for human food consumption and compete for land use with food crops. The indirect land use change (ILUC) impact of these biofuel feedstocks could release more carbon emissions as forests and pristine lands are converted to cropland due to biofuel expansion. This has led to the current debate over whether, and how, the ILUC effects should be accounted for, along with the direct land use change effects, in evaluating the potential impact of biofuel policies.

The adoption of targets for the use of biofuels in road transport fuels is a key component of the European Union's response to achieving its Kyoto targets of GHG emissions. In 2003 the European Union first set a target of 5.75% biofuels use in all road transport fuels by the end of 2010. The proposal to adopt a 10% target for a combination of first and second generation biofuels use in road transport fuels by 2020 was made in the Renewable Energy Roadmap (CEC, 2006) as part of an overall binding target for renewable energy to represent 20% of the total EU energy mix by the same date. On 23 April 2009, the European Union adopted the Renewable Energy Directive (RED) which includes a 10% binding target for renewable energy use in road transport fuels and also establishes the environmental sustainability criteria for biofuels consumed in the EU (CEC, 2008). A minimum rate of GHG emission savings (35% in 2009 and rising over time to 50% in 2017), rules for calculating GHG impact, and restrictions on land where biofuels may be grown are part of the environmental sustainability scheme that biofuel production must adhere to under the RED. The revised Fuel Quality Directive (FQD), adopted at the same time as the RED, includes identical sustainability criteria and it targets a reduction in lifecycle greenhouse gas emissions from fuels consumed in the EU by 6% by 2020. The adoption of the RED includes a requirement for the Commission to report, by 31 December 2010, on the impact of ILUC on GHG emissions and address ways to minimize that impact.

It is against this background that this study seeks to clarify the interactions between different policy scenarios and their potential impact on global agricultural markets and on the environment, particularly on GHG emissions from direct and indirect land use change.

This study was commissioned by the Directorate General for Trade of the European Commission (DG TRADE). The initial objective was to examine the potential economic and environmental impact of various EU trade policy options with respect to biofuels. However, the model developed for this purpose was also a very useful contribution to the Commission's impact assessment and report on ILUC and to possible Commission proposals on the methodology to deal with ILUC under biofuel production. The objective of the study was thus expanded to analyse the global agricultural production, trade and environmental impact of the EU biofuel policy as concretised in the RED. The study pays particular attention to the ILUC effects of the main biofuel feedstocks.

This quantitative analysis of the global economic and environmental impact of biofuel development is conducted using an extensively modified version of the MIRAGE global computable general equilibrium model (CGE)[1]. Primary among major methodological innovations introduced in the model is the new modeling of energy demand which allows for substitutability between different sources of energy, including biofuels. This is facilitated by the extension of the underlying global Global Trade Analysis Project (GTAP) database which separately identifies ethanol with four subsectors, biodiesel, five additional feedstock crops sectors, four vegetable oils sectors, fertilizers, and the transport fuel sectors. The model was also modified to account for the co-products generated in the ethanol and biodiesel production processes and their role as inputs to the livestock sector. Fertilizer modeling was also introduced to allow for substitution with land under intensive or extensive crop production methods. Finally, another major innovation is the introduction of a land use module which allows for substitution between land classes, classified according to Agro-Ecological Zones (AEZs), and land extension possibilities. We assess the greenhouse gas emissions (focusing on CO2) associated with direct and indirect land use changes as generated by the model for the year 2020, and separately quantify the marginal ILUC for each feedstock crop.

The impact of the EU biofuels policy are assessed under alternative trade policy assumptions: business as usual trade policy; full multilateral trade liberalization in biofuels; and bilateral trade liberalization between the EU and MERCOSUR. These trade policy alternatives are calculated against a baseline scenario which incorporates the latest forecasts of energy prices by the IEA and OECD

[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). Model equations for the extensively modified version developed at IFPRI and used in this study are provided in a separate document as Appendix A.

economic growth. Sensitivity analyses are conducted to assess the robustness of the model results to alternative assumptions about the size of the EU biofuels policy target, and on several parameter settings.

A brief review of previous studies that have quantified the potential economic and environmental impact of biofuel development is provided in the next section of the report. Section 3 includes an overview of the data development and model development involved in the study. More detailed discussions of the various components of the methodology are relegated to annexes. The baseline scenario and alternative trade policy scenarios analyzed in the study, along with the variations considered for sensitivity analyses, are presented in Section 4. Results and discussions are provided in Section 5 and concluding remarks are given in Section 6.

2 Review of Recent Studies

Although it is a relatively new area of study, research on the impact of policies to promote biofuels has been particularly intense in recent years. The growing literature reflects the evolution of issues regarding the impact of biofuel development and support policies on agricultural markets and the environment. Most quantitative assessments focused initially on the impact of biofuels on agricultural markets and its contribution to the food price crisis, but more recent studies have centered on the impact of biofuels on global land use change and greenhouse gas emissions. In this section of the report, we provide a brief survey of recent studies focusing on the quantitative assessments of the impact of biofuel support policies on global trade and the environment, specifically on land use and GHG emissions.

2.1 Impact on Production, Prices, Trade

Much of the early literature on biofuels came out in the mid 2000s and emphasized the potential benefits of biofuels development in reducing dependence of fossil fuels, providing opportunities for agricultural and rural development, and reducing environmental damage due to lower greenhouse gas emissions compared to biofuels. However, concerns about the impact on food security quickly emerged due to the rising competition between biofuel feedstock crops, food crops, and feed crops, thereby giving rise to the debate on food versus fuel.

In their review of early work on the economic, environmental, and policy aspects of biofuels, Rajagopal and Zilberman (2007) found that the current generation of biofuels from food crops is intensive in land, water, energy and chemical inputs. The authors' synthesis of economic studies revealed that most models predict that biofuels development will result in higher food prices, a decline in cereal exports of the United States and European Union, a decline in farm support programs, an increase in rural jobs, and an ambiguous effect on the livestock sector.

The impact of biofuels on food prices became a hotly debated issue during the food price crisis of 2008. Several researchers sought to quantify the impact of biofuel polices on food prices. Studies range from back of the envelope calculations, such as those from the JRC (de Santi, 2008) and the World Bank (Mitchell, 2008) to extensive modeling exercises. In assigning the largest proportion of the blame on biofuels, Mitchell (2008) concluded that higher energy costs and exchange rate changes contributed between 25-30% of the rise in food prices, while the other 70-75% was due to biofuels along with the associated low grain stocks, large land use shifts, speculative activity and export bans. Although results vary, there is broad agreement from these studies that the price increases are due to several factors including but by no means restricted to biofuels (Sheeran, 2008, Von Braun, 2008).

In a partial equilibrium exercise using IFPRI's IMPACT model, Rosegrant (2008) also addressed the question of the extent to which biofuel production contributed to the high food prices in 2008. Based on a comparison of the simulations of market developments between 2000-2007, with and without the sudden increase in biofuel production, Rosegrant estimated that biofuel growth accounted for 30% of the food price increases seen in the period. The level varied from 39% for maize to 21% for rice. A simulation of the future impact of freezing biofuel production at 2007 levels indicated that maize prices are likely to decline by 6% in 2020 and 14% in 2015.

Based on their review of 25 studies, Abbott et al. (2008) identified three broad sets of forces that drove up food prices in 2008, namely: the global changes in production and consumption of key commodities, the depreciation of the dollar, and the growth in the production of biofuels. Even in their follow-up study after the financial crisis, Abbott et al (2009) found that the key drivers of food prices remain the same: crop supply and utilization, the exchange rate and world macroeconomic factors and the agricultural-energy linkage through the biofuels market.

Similarly, in their synthesis of several studies that assessed the impact of biofuels development on current and projected food prices, Gerber et al. (2009) found that although there are considerable differences in the methodology and assumptions, and thus in the projection results, the studies predict some common trends: the EU and US biofuel programs are expected to raise prices of vegetable oils the most with smaller price increases for corn, wheat and soybean and price declines for oilseed meals.

2.2 Modeling Bioenergy

The economic studies that assess the impact of biofuel production are based either on partial equilibrium (PE) or computable general equilibrium (CGE) models. These models explain the relationship between supply, demand, and prices through market clearance using a system of equilibrium equations. In partial equilibrium models, clearance in the market of a specific good or sector is obtained assuming that prices and quantities in other markets remain constant, thus providing better indication of short term response to shocks. PE models often provide a detailed description of the specific sector of interest but do not account for the impact of expansion in that sector on other sectors of the economy. Several examples of partial equilibrium models used in the assessment of the impact of biofuel development include AGLINK/COSIMO, ESIM, FAPRI, and the IMPACT model. Witzke et al. (2008) provide a review of the methodologies in modeling energy crops in agricultural sector PE models.

CGE models determine equilibrium by simultaneously taking into account the linkages between all sectors in the economy. The modeling framework provides an understanding of the impact of biofuels on the overall economy by accounting for all the feedback mechanisms between biofuels and other markets, and by capturing factor market impact. As the Gallagher review (RFA, 2008) points out, CGE models provide a better global assessment, taking linkages in the economy into account and predicting outcomes that are more representative of medium and long term impact. Since the present employs a global CGE model, this section focuses on a review of bioenergy modeling in CGE models.

Kretschmer et al. (2008) classified CGE studies according to three different categories based on the approach used in integrating bioenergy in CGE models. The implicit approach avoids explicit modeling of bioenergy production technology and employs an ad-hoc procedure of determining the quantities of biomass necessary to achieve certain production targets. Classified under this category is the study of the economy-wide effects of replacing petroleum with biomass in the US using (Dixon et al. 2007)USAGE, a dynamic CGE model of the US economy. Banse et el. (2008) also used a implicit approach in introducing biofuels in their extended version of the GTAP-E CGE model. Ethanol is introduced in a 'Fuel' nesting, substituting with vegetable oil, oil, and petroleum products. It is produced only from crop inputs (sugarcane\beet and cereals) thereby capturing only a part of ethanol production technology.

The second category identified by Kretschmer et al. (2008) is the latent technology approach that focuses on production technologies that are existent but not active during the base year of the model but can become active at a later stage. Information on the inputs and costs structures of the different types of biofuels are required in modeling latent technologies. Reilly and Paltsev (2007) and Gurgel, Reilly and Paltsev et al. (2007) employed this approach in looking at the potential land use implications of a global biofuels development focusing on second generation biofuels . Boeters et al. (2008) and Kretschmer et al. (2008) both incorporate the European emissions trading scheme (ETS) in assessing the impact of a 10 percent EU biofuels target.

This study falls under the third category of CGE biofuel studies identified by Kretschmer et al. (2008) which are studies that actually disaggregate the bioenergy production sectors in the social accounting matrix (SAM) of the GTAP database, which provides the underlying structure to global CGE models. Since bioenergy sectors are not explicitly identified in the GTAP database, Taheripour et al. (2007) introduced ethanol (from aggregated coarse grains and sugarcane) and biodiesel from an aggregated oilseeds sector. External data on production, cost structure and trade are used to extract these bioenergy sectors from existing food processing sectors in the 2001 GTAP 6 database. Bioenergy is modeled through an extended version of the GTAP-E model (Burniaux and Truong, 2002). The applications of this approach include Birur, Hertel, and Tyner (2008) looking at the impact of biofuels production on the global agricultural market; Hertel, Tyner, and Birur (2008) looking at the impact of both US and EU biofuel support policies; and Taheripour et al. (2008) which compares the impact of adding by-products to the results of Hertel et al (2008).

In a recent study, Britz and Hertel (2009) linked the European CAPRI PE model with the GTAP CGE model to look at the impact of the EU biofuels directive on global markets and on the environment. Starting from a modified GTAP model that includes a 'parsimonious summary' of the regional supply models of CAPRI, the authors then take the resulting equilibrium price changes from the global model and apply them to the supply models of CAPRI to obtain highly disaggregated results in terms of changes in farming practice and their impact in the EU.

The production of biofuels results in several by-products which have potential or existing markets. Producing ethanol from corn results in a by-product – Dried Distillers Grains with Solubles (DDGS) which is used as animal feed. Its sale represents 16% of ethanol revenues in the US (Hertel et al., 2008). Biodiesel production from vegetable oil produces seed meals which can be used as animal feed. Farrell et al. (2006) pointed out the importance of integrating by-products in assessments of the energy balance of biofuels. In particular they found that studies which didn't take by-products into account concluded that biofuels had a negative energy balance because they failed to take account of the energy use which the by-products offset.

The increased availability of by-products also have beneficial side effects in other areas of agriculture. The Commission's impact assessment of the biofuels mandate pointed out the positive impact on livestock production in terms of reduced prices for animal feed, with soymeal prices predicted to fall by 25% and rapemeal by 40% by 2020 (CEC, 2007). In a CGE assessment of the impact of including biofuel by-products, Taheripour et al. (2008) also found significant differences in feedstock output and prices depending on whether the existence of by-products is taken into account. In terms on the land use impact of accounting for by-products, Kampman et al (2008) estimated that incorporating by-products into the calculations for land requirements of biofuels reduced the land demand by 10-25%. Croezen and Brouwer (2008) found that scenarios which include 2G biofuels resulted in substantial reductions of almost half in the amount of avoided land use. It is clear that the integration of by-products is key to properly estimating changes in prices and land use, as well as energy balance.

2.3 Land Use Modeling

Although extensive research and literature exists about local drivers of land use changes concerning deforestation processes, arable land conversion, pasture expansion, and the associated methodological challenges and development of land-use indicators, the boom in biofuel production is a recent phenomenon and as such has not yet been included as a factor driving land-use change (Gnansounou and Panichelli , 2008).

It is clear however, that increased demand for biofuels will have impact on the demand for land and will result in potentially significant land use changes. The increased demand for land for biofuels is estimated to be lower than the increased demand for land for food, however estimates vary. Based on their review of the literature, Kampman et al. (2008) estimated that land for food and feed will expand between 200-500 Mha by 2020, whereas increased demand for biofuels could result in total demand of between 73-276 Mha (up from 13.8 Mha today). Eickhout et al. (2008) estimated the land requirements of the EU's mandate alone as being between 20-30 Mha. There are high levels of uncertainty in these estimates as much depends on development of demand, but also on the extent to which high yield crops (such as sugar cane) are used, the share of second generation biofuels (land demand is 30-40% less in scenarios with 2G biofuels) and on crop yield. The FAO reported estimates of the difference between the land required for different sources of first generation biofuels if they were to replace 25% of global transport needs. This varies from 17% of available land (estimated at 2.5 bn ha) if the source were sugar cane to 200% for soybean (FAO, 2008a).

Many CGE models use the constant elasticity of transformation (CET) approach to capture the conversion of land to other uses due to the expansion of bioenergy production. Under the CET, different types of land can be transformed to other uses with the ease of transformation determined by the elasticity of transformation. Using the WorldScan CGE model to assess the impact of the 10% EU biofuels target, Boeters et al. (2008) used the CET framework to allow for transformation of different types of arable land use. The authors assess the sensitivity of the elasticity value of the CET by allowing for lower and higher-end values of 0.5 and 15, respectively, aside from the default value of 2. They found that their results for arable land rents and economic welfare are quite robust to the value to the CET.

Banse et al. (2008) also used the CET approach but employed a 3-level CET nesting structure that allows for different degrees of land use transformation across types of land use. The third level nest distinguishes between land in wheat, coarse grains, and oilseeds. This aggregate is distinguished from land in sugar and pasture in the second level nest. Together, as Field Crops\Pasture, they are distinguished from Horticulture and Other Crops at the top-level nest. The authors also introduced a land supply curve which allows for endogenous processes of land conversion and land abandonment.

In their analysis of the impact of implementing biofuels mandate on a global scale, the authors found that compared to a reference scenario of trade liberalization, the EU's land use falls by less under both an EU and global biofuel scenario. All other key regions expand land use under a global biofuels scenario, in particular Central and South America which increases agricultural land use by almost 10 percentage points compared to the reference scenario. The study also shows, however, that the majority of the expansion in land use in most regions is due to the liberalization of trade and other projected changes in the world economy. These are modeled under the reference scenario, where global agricultural land increases by18% compared to 21% under the global biofuels scenario. Although biofuels contributes to greater land cultivation it is not, therefore, projected to be the major driver.

Birur et al. (2008), Hertel et al. (2008) and Taheripour et al. (2008) also employ the CET approach. These studies use a GTAP-E model adapted to include Agro-Ecological Zones (AEZs). In other words they take account of the fact that land types differ and substitutability is only possible within limited zones. Hertel et al. (2008) find substantial impact on land use from the EU and US mandates. In the US, coarse grains acreage increases by 10% at the expense of other cropland, as well as pasture land and forests. The biggest global impact are however seen as a result of the boom in oilseeds production due to EU demand for biodiesel. Here increases range from 11-16% in Latin America, 14% in SE Asia and Africa and 40% in the EU itself. The model restricts the potential land sources of increased biomass production to pastureland or forests as it does not take into account idle land. This tends to over-estimate the impact. The largest impact are for pastureland in Brazil where the acreage is estimated to reduce by 11%, of which 8% is due to the EU mandate. Reductions in forestry cover are highest for the EU (-7%), Canada (-6%) and Africa (-3%). The model (like that used in this study) does not take account of the potential impact of biofuel by-products which the authors acknowledge to be an important limitation which overestimates the impact of the mandates on corn and livestock markets. Greenhouse Gas Emissions (ILUC)

A major reason behind the adoption of biofuels is based on the assumption that they are a more environmentally friendly fuel source, as the GHG emissions associated with their production and use are lower than those associated with traditional fossil fuels. This assumption is not based on the GHGs impact from the use of biofuels, as the GHGs emitted from burning them are not noticeably different to those of other fuels. There is a reduction in certain pollutants, with a possible increase in others (Worldwatch Institute, 2006). Rather their advantage over fossil fuels is based on the idea that the production of biofuels absorbs CO2 and therefore offsets large percentages of the future emissions from using them.

This assumption is far from being universally accepted. Early estimates from the International Energy Agency indicated that the use of biofuels resulted in net GHG savings – between 20-90% for ethanol from crops (with most crops in the lower levels. The higher figures are for cellulosic ethanol) and around 50% for biodiesel from oilseeds (IEA, 2004).

Although the logic for these figures is intuitively attractive, several researchers have pointed out that such estimates are incomplete as several aspects of the lifecycle and indirect effects of biofuels are not properly taken into account. Even early, positive analysis of biofuels' potential, such as that from the Worldwatch Institute warned that there were limits to its potential benefits. In particular, biofuels that are produced from low yielding crops, or grown on previous forested or grasslands or produced using large inputs of fossil fuel, could easily have a negative GHG balance (Worldwatch Institute, 2006). The fact that biofuel's GHG balance varies widely depending on these factors is increasingly taken into account in analyses.

A recent review conducted by the US Government Accounting Office (US GAO, 2009) found that although there is general consensus on the approach for measuring the direct effects of increased biofuels production, there is disagreement about assumptions and assessment methods for estimating the indirect effects of global land-use change. The twelve scientific studies that the GAO reviewed provided a wide range of estimates on the lifecycle GHG emissions of biofuels relative to fossil fuels: from a 59 percent reduction to a 93% increase in emissions for conventional corn starch ethanol, a 113% reduction to a 50 % increase for cellulosic ethanol, and a 41% to 95% reduction for biodiesel. The differences in assumptions about the agricultural and energy inputs used in biofuel production and how to allocate the energy used in this production to co-products, such as DDGS, primarily explain why large differences in the GHG emission estimates among the studies.

One key issue is that producing biofuels requires energy and the assumptions on where that energy comes from can make a large difference to the calculated relative efficiency of different biofuel sources. Mortimer et al. (2008) note the large difference between the CO2 emissions in the production of corn based ethanol in the US and France (0.108 kg eq/MJ compared to 0.049 kg eq/MJ respectively), which is largely due to the assumption that coal is used for ethanol processing in the US compared to natural gas in France. Biofuels that use plant waste to fuel their processing, such as those based on switchgrass and sugarcane are clearly the most efficient.

In their research for the Gallagher Review, Mortimer et al. (2008) provide estimates of the percentage of GHGs emissions by various sources of biofuels compared to standard fossil fuels. Their results are fairly consistent with other sources in highlighting the relative efficiency of Brazilian sugar cane (which generally uses bagasse as the fuel source) and the relative inefficiency of maize which the study found to be more intensive in GHG emissions than the fuels it seeks to replace.

The above results take into account the 'credit' represented by the by-products of the various processes and the N2O emissions from the soil where the crops are grown. This latter issue is one of the most contentious and difficult to integrate in relation to the biofuels debate. N2O is a greenhouse gas which is far more detrimental to global warming than CO2 (296 times according to Mortimer at al (2008)). For this reason, although emissions are far lower by weight than CO2, they are potentially very damaging.

A key input to the debate on NO2 emissions and biofuels is a paper by Crutzen et al. (2007). This paper claims that the manner in which the UN's Inter-governmental Panel on Climate Change (IPCC) integrates N2O emissions into its assessments underestimates N2O emissions from crops by a factor of 3 to 5. The paper has been criticized and its accuracy called into question. Mortimer et al. (2008) have undertaken an exhaustive review of the paper and conclude that while it raises an important issue '…*it cannot be regarded as resolving the problems and assisting the objective evaluation of biofuels.*' (Mortimer et al, 2008, p. 29). For the moment, as their review makes clear, it is impossible to accurately measure the extent of N2O emissions related to a given biofuel from a given source. For this reason and due to the complexities of seeking to integrate it in the model, this research does not seek to assess the indirect effects, related to land use, of biofuels on GHGs other than CO2. But direct effects related to CO2 and N2O are accounted for as they are incorporated in the coefficients.

The other key issue which has emerged as controversial in recent months is the question of the 'credit' attributable to biofuels from the 'carbon uptake' of the crops used to produce them. A key paper in this debate is that by Searchinger et al. (2008). His main point is that earlier assessments of the carbon impact of biofuels have been biased because they have not taken account of the land use impact. In short they have counted the carbon benefits of using land for biofuels but not the carbon costs – the carbon storage and sequestration which is sacrificed when the land is diverted from its former use (direct GHG effects) or when land is cleared for growing food to replace land which has been diverted into biofuel production (indirect GHG effects). Searchinger et al. (2008) used the Greenhouse gases, Regulated Emission and Energy use in Transportation (GREET) model to calculate the total GHG emissions from various biofuel sources. The model indicates that, without taking into account land use changes, replacing gasoline by corn-based ethanol reduces GHG emissions by 20% by 2015. Once they account for land use change, however, the picture changes significantly and they find that corn based ethanol more than doubles GHG emissions over a 30 year timescale and increases GHGs for 167 years. On the other end of the spectrum, Brazilian sugarcane production is estimated by their model to provide GHG savings of 86%. If this sugarcane production converts only tropical grassland, the payback for GHG emissions would be only 4 years, although this would rise to 45 years if displaced ranches were to convert forest to grazing land.

In their review of the Searchinger paper and the GREET model to assess its applicability to the EU/UK context, Mortimer et al. (2008) concluded that the model is too US specific to be readily useable outside that context. The US Department of Energy has itself issued a rebuke criticizing many aspects of the study, which it considers to also misrepresent the US case, by overestimating corn ethanol production and making several invalid assumptions (DOE, 2008). Nevertheless the key point which Searchinger makes – that land use changes and their impact on GHG emissions are key to assessing the true impact of biofuels - is a valid one which needs to be taken into account in analysis. The Gallagher review acknowledges this, particularly in its recommendation that policies should seek to direct biofuels production towards suitable idle land or appropriate wastes and non-food products.

This recommendation is based on a series of calculations on the net impact of the conversion of various types of land on GHG emissions which concur with the broad conclusions of Searchinger's paper (Mortimer et al., 2008). The analysis finds that, apart from the lowest estimate of ethanol from sugar beet, all current biofuel production on converted UK grasslands would increase GHG emissions, in some cases emitting twice the level of fossil fuels. The figures calculated for biofuels from overseas sources are even worse. Of all sources analysed - oil palm in Malaysia, soy biodiesel in Brazil, maize ethanol in the US and sugar cane ethanol in Brazil - only the latter showed a net saving and the others showed large net losses, topping 30,000% for biodiesel from soy converted from Brazilian rainforest.

The calculation for the impact of using fallow land is slightly different, as it assumes that the N2O emissions which would have been emitted by this land are avoided by its cultivation, thus adding an additional 'credit' to the calculation. The results are generally positive i.e. the production of biofuels in the UK from fallow land is calculated to emit less GHG than fossil fuels, although the percentage varies from 88-55%. The figures are similar for biodiesel and ethanol, although they tend to be lower for the former, especially in the long term and when rotational set-aside land is used.

The JRC report also looked at the issue of land use change and its impact on GHG emissions (de Santi, 2008). They made the point that looking at direct effects alone was probably legitimate when rates of substitution by biofuel were low and most biofuel feedstock could come from set-aside or other unused arable land. However the 10% target means that most of the EU biofuel feedstock will be removed from the world commodity markets either by reduced EU exports or increased EU imports.

They looked at the alternative sources of these extra biofuels and in most cases found significant negative effects. For example using EU permanent grassland would result in an initial emission of carbon which would take 20 to 110 (+/- 50%) years to recover through biofuel production. The carbon losses from drained peat forest, which is used for palm oil production in South East Asia, are so high that if even 2.4% of the EU's biodiesel needs are met directly or indirectly by palm oil grown in peatland all GHG savings from EU biodiesel would be cancelled out. Palm oil is a key alternative to rapeseed for the food industry, so EU imports are likely to increase once the latter is diverted to biofuel production. The calculations in the report indicate that the level of EU imports of palm oil produced on peatland is likely to be considerably higher than 2.4%. Although local regulations could be set in place to avoid such negative indirect effects, the report is dubious about the potential of certification schemes to assure sustainability. The report concludes '*Indirect land use change could potentially release enough greenhouse gas to negate the savings from conventional EU biofuels*.' (De Santi, 2008).

Finally a key question which is frequently ignored in the biofuels debate is whether the use of biomass for biofuels is the most efficient means to use the limited biomass resources at our disposal to reduce GHGs. A recent JRC report pointed out that while the efficiency of fuel burners for heating and electricity is 21 almost as high as that of fossil fuels, the energy efficiency of converting biomass to liquid fuels is only 30-40% (de Santi, 2008). Their cost benefit analysis indicates that the decision to specifically target GHG reductions in the transport sector reduces the benefits that could be achieved in other ways. The European Environment Agency has furthermore expressed concern that diversion of biomass to biofuel will make it difficult for the EU to meet its objectives for renewable energy sources in energy production (EEA, 2004).

A related point is that support for biofuels is a very expensive means of reducing CO2 emissions. The OECD has estimated that policy support to biofuels would cost taxpayers and consumers between $960 and $1 700 per ton of CO2 emissions avoided (OECD, 2008). The exact figures can be debated as they are based on a series of assumptions and indeed are far higher than the figures used in the Commission's impact assessment of the Renewable Energy Directive[5] or even the high end estimates (over €300/ton) referred to in the Economic and Social Committee's report (EESC, 2008). However the fundamental point of the OECD work – that reducing CO2 emissions through measures in support of biofuel production is an expensive option – is a valid one, reiterated both in that report (EESC, 2008) and in the work of the JRC (2007).

3 Data and Methodology

The MIRAGE model[2], a computable general equilibrium model originally developed at CEPII for trade policy analysis, was extensively modified at IFPRI[3] 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. The full set of model equations are provided in a separate document as Appendix A. Data enhancements, model modifications, and the land use module are discussed in this section of the report.

3.1 *Global 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-

[2] Decreux and Valin (2007).

[3] 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.[4]

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

[4] 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.

structure for many countries. Building a consistent dataset in value and volume – thanks to the price 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-ton 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.

The specific data sources, procedures and assumptions made in the construction of each new sector are described in Annex I.

3.2 Global 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). In this section, we first provide a brief description of the standard MIRAGE model. This is followed by the adaptations and innovations made in the areas of energy modeling, the modeling of co-products of ethanol and biodiesel production, and the description of fertilizer use. More detailed explanations of the various modeling changes are provided in the annexes.

3.2.1 Standard MIRAGE Model

The work starts with the MIRAGE model, initially developed at CEPII. This section summarizes the features of the standard version relevant for this study. MIRAGE is a multisector, multiregion Computable General Equilibrium Model for trade policy analysis. The model operates in a sequential dynamic recursive set-up: it is solved for one period, and then all variable values, determined at the end of a period, are used as the initial values of the next one. Macroeconomic data and social accounting matrixes, in particular, come from the GTAP 7 database (see Narayanan, 2008), which describes the world economy in 2004. From the supply side in each sector, the production function is a Leontief function of value-added and intermediate inputs: one output unit needs for its production x percent of an aggregate of productive factors (labor, unskilled and skilled; capital; land and natural resources) and $(1 - x)$ percent of intermediate inputs.[5] The intermediate inputs function is an aggregate CES function of all goods: it means that substitutability exists between two intermediate goods, depending on the relative prices of these goods. This substitutability is constant and at the same level for any pair of intermediate goods. Similarly, in the generic version of the model, value-added is a constant elasticity of substitution (CES) function of unskilled labor, land, natural resources, and of a CES bundle of skilled labor and capital. This nesting allows the modeler to introduce less substitutability between capital and skilled labor than between these two and other factors. In other words, when the relative price of unskilled labor is increased, this factor is replaced by a combination of capital and skilled labor, which are more complementary.[6]

Factor endowments are fully employed. The only factor whose supply is constant is natural resources. Capital supply is modified each year because of depreciation and investment. Growth rates of labor supply are fixed exogenously. Land supply is endogenous; it depends on the real remuneration of land. In some countries land is a scarce factor (for example, Japan and the EU), such

[5] The fixed-proportion assumption for intermediate inputs and primary factor inputs is especially pertinent to developed economies, but for some developing economies that are undergoing dramatic economic growth and structural change, such as China, the substitution between intermediate inputs and primary factor inputs may be significant.

[6] In the generic version, substitution elasticity between unskilled labor, land, natural resources, and the bundle of capital and skilled labor is 1.1, whereas it is only 0.6 between capital and skilled labor. This structure has been modified for the present exercise (see 4.2).

that elasticity of supply is low. In others (such as Argentina, Australia, and Brazil), land is abundant and elasticity is high[7].

Skilled labor is the only factor that is perfectly mobile. Installed capital and natural resources are sector specific. New capital is allocated among sectors according to an investment function. Unskilled labor is imperfectly mobile between agricultural and nonagricultural sectors according to a constant elasticity of transformation (CET) function: unskilled labor's remuneration in agricultural activities is different from that in nonagricultural activities. This factor is distributed between these two series of sectors according to the ratio of remunerations. Land is also imperfectly mobile between agricultural sectors.

In the MIRAGE model there is full employment of labor; more precisely, there is constant aggregate employment in all countries, combined with wage flexibility. It is quite possible to suppose that total aggregate employment is variable and that there is unemployment; but this choice greatly increases the complexity of the model, so that simplifying assumptions have to be made in other areas (such as the number of countries or sectors). This assumption could amplify the benefits of trade liberalization for developing countries (see Diao et al. 2005): in full-employment models, increased demand for labor (from increased activity and exports) leads to higher real wages, such that the origin of comparative advantage is progressively eroded; but in models with unemployment, real wages are constant and exports increase much more.

Capital in a given region, whatever its origin, domestic or foreign, is assumed to be obtained by assembling intermediate inputs according to a specific combination. The capital good is the same whatever the sector. MIRAGE describes imperfect, as well as perfect, competition. In sectors under perfect competition, there is no fixed cost, and price equals marginal cost. Imperfect competition is modeled according to a monopolistic competition framework. It accounts for horizontal product differentiation linked to product variety. Each firm in sectors under imperfect competition produces its own unique variety, with a fixed cost expressed as a fixed quantity of output. According to the Cournot hypothesis, each firm supposes that its decision of production will not affect the production of other firms. Furthermore, the firms do not expect that their decision of production will affect the level of domestic demand (which would be what modelers call a "Ford effect").

The demand side is modeled in each region through a representative agent whose propensity to save is constant. The rest of the national income is used to purchase final consumption. Preferences between sectors are represented by a linear expenditure system–constant elasticity of substitution

[7] This assumption that applies to the standard model is modified in the version of MIRAGE used in this biofuels study.

(LES-CES) function. This implies that consumption has a non-unitary income elasticity; when the consumer's income is augmented by *x* percent, the consumption of each good is not systematically raised by *x* percent, other things being equal.

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. Macroeconomic closure is obtained by assuming that the sum of the balance of goods and services and foreign direct investments (FDIs) is constant and equal to its initial value.

3.2.2 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. Further details about the energy modeling developed for this study are in Annex II.

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. Further details on this energy demand structure modification is provided in Annex III.

3.2.3 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 crop intensification depends on the relative price between land and fertilizers. Further details on the fertilizer modeling are provided in Annex IV.

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.

3.2.4. Modelling of 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 (see Figure 1). 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.[8] 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.

3.2.4 Modeling of Co-products and Livestock Sectors

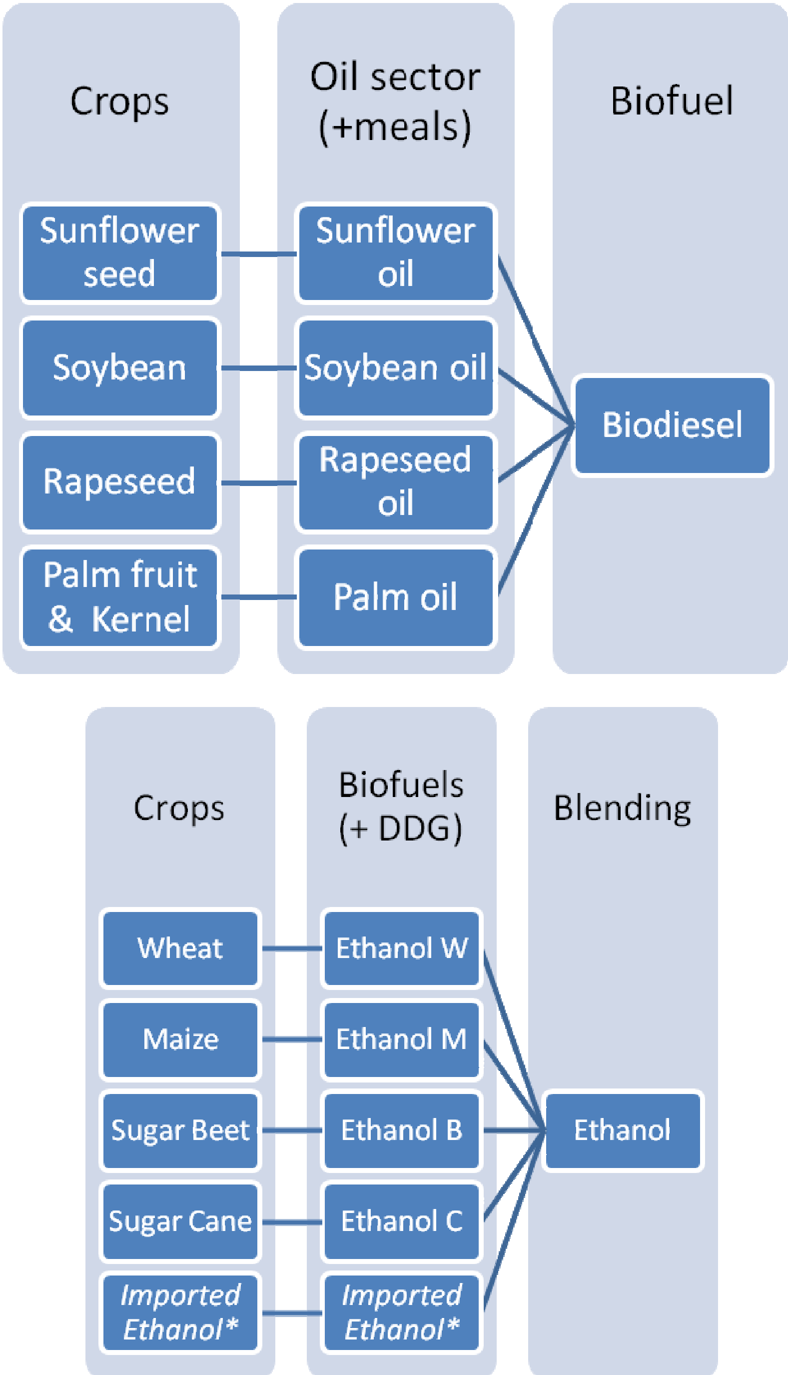
Co-products of the biofuels industry, such as Dried Distillers Grains with Solubles (DDGS), soy meal, and rapeseed meal, are used as substitutes for feedgrains in livestock production. It is therefore recognized that in assessing the impact of biofuels development on agricultural markets, co-products should be taken into account since they could lessen the unfavorable impact of biofuels: they reduce the need of land reallocation/extension to replace the crops displaced from the feed and food sectors to bio-energy production. Biofuel co-products are also recognized for their role in potentially mitigating the land use impact of biofuels as demand for feedgrains are reduced. Kampman et al. (2008) estimated that incorporating by-products into the calculations for land requirements of biofuels reduced land demand by 10-25%.

Accounting for co-products was only recently introduced in CGE assessments of the impact of biofuels development. Taheripour et al. (2008) analysed the impact of including biofuel by-products (DDGS) in an analysis based on the GTAP CGE model. They found significant differences in feedstock output and prices depending on whether the existence of by-products is taken into account. Inclusion of co-products has become a prerequisite to the modeling of biofuel policy impact.

[8] 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.

Significant efforts have been made in the US Environmental Protection Agency and the California Air Resource Board (CARB) assessments of indirect land use impact to take co-products into account at the US level (DDGS from corn ethanol production).

Figure 1 Biofuel Feedstock Schematic



**Only for Central America and Caribbean regions to represent the re-export channel of Brazilian ethanol in the region.*
Note: Other inputs and Value added are not displayed here.

Co-products play a different role in the ethanol and in the biodiesel production pathways. For ethanol, distillers grains and sugar beet pulp are low value materials that are not profitable without the benefits from ethanol sale (the share of ethanol by-products in total production value is below 20%). On the other hand, the production of oilseed meals is at the heart of oilseed market dynamics in biodiesel production. Oil and meals are co-products that can be valued independently and the demand for one of them directly affects the price of the other. This difference in treatment of co-products of ethanol and biodiesel production is reflected in the modeling of co-products introduced in this study. For ethanol, co-products are represented as a fixed proportion of ethanol production, with the shares based on cost shares data for co-products for selected ethanol feedstocks in the USA and EU. For biodiesel, we consider as co-products the oilcakes\meals that are produced in the crushing of oilseeds to produce vegetable oils that are then processed for biodiesel production. We rely on cost share information for oilcakes in the vegetable oil production process. Co-products are then introduced in the model as substitutes for feedgrains in livestock production. Substitution between oilcakes, based on the protein content of the different oilcakes, is first introduced. The composite of oilcakes is then introduced as substitute for animal feed and DDGS as feed inputs to the livestock sector based on their energy content. However, we do not model the co-products of the biodiesel trans-esterification process, i.e. glycerol and similar products that can be used as additives to the feeding process.

With the introduction of co-products in the model, the modeling of livestock production was also significantly modified to allow for intensification through substitution of livestock feed, including ethanol and biodiesel co-products, with land. This is treated using a similar approach to our modeling of crop intensification through substitution of fertilizer for land, and is assessed as an alternative case in the sensitivity analyses. Further details on the modeling of co-products are given in Annex V.

3.3 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 VI. 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 and discussed in Annex VI.

3.4 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 (see in Annex VII). 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 biofuels, 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, the study 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 areas recently concerned by afforestation 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[9]. We use two sets of emissions coefficients for peatlands, from IPCC – AFOLU and from Couwenberg (2009), since the literature displays a wide range of coefficients (from 5 to 40 tonnes of CO2 by hectare). Recent trends emphasize the underestimation of past values.

In this study, 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.[10]

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 VII.

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

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

4 Baseline, Trade Policy Scenarios, and Sensitivity Analysis

This section provides 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.

4.1 Sectoral and Regional Nomenclature

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.

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		

4.2 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.

An exhaustive description of the baseline scenario is provided in the Excel workbook that accompanies this report: *Details_baseline_CentralScenario.xlsx*.

4.2.1 Macroeconomic Trends

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.

4.2.2 Technology

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). (See table B9 of the Baseline Excel workbook for details). We do not assume changes in the yield of the crushing, distilling and biofuel production activities.

It is important to notice 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.

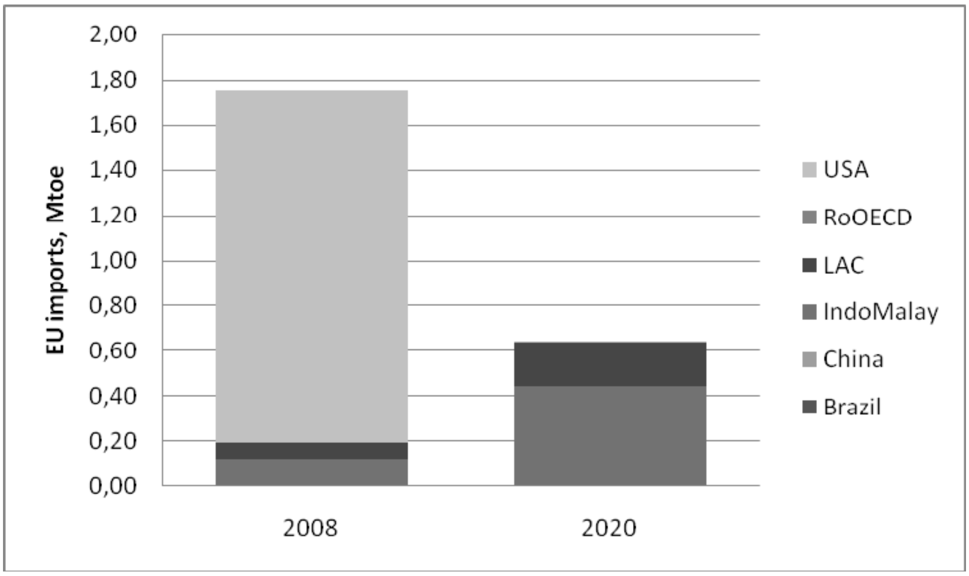
4.2.3 Trade Policy Assumptions

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.[11] In the model, the bulk of the adjustment to the antidumping duty is achieved through increased in EU biodiesel production (based on EU produced and imported feedstocks). Figure 2 shows the change in EU imports in 2008 and 2020.

Figure 2 EU biodiesel imports by source, Mtoe, in the baseline



Source: Authors' calculations

[11] 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).

4.2.4 Agricultural and Agri-Energy Policies

For the EU, we implement two policy elements in the baseline:

i. The sugar reform market;
ii. 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 will be 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 (Section 4.2.2) leads to the decline in EU yields in the baseline. This is a crude modelling solution for land set-aside and it should be improved. In particular, 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).

In the baseline, no additional EU bioenergy mandate is implemented. 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 (see Figure

2). 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.[12] 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.

4.2.5 Other Baseline Evolutions

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

[12] A survey of biofuels policies in the EU, US and Brazil is provided in Annex X.

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.

4.3 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.[13]

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%[14]. 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 (see below 4.4.1)

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.

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[13] "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.

[14] Note that this estimated 5.6% target for biofuels in 2020 is actually below the previous target of 5.75% for 2012. These 5.6% include land-using first-generation biofuels only. Non land-using first generation biofuels such as recycled waste oil and animal fats are not included.

Our 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;
- **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. Contingent protection on US biodiesel remains;
- **MEU_MCS:** Implementation of the EU biofuels mandate of achieving 5.6% consumption of ethanol and of biodiesel in 2020 with the assumption of EU bilateral trade liberalization with MERCOSUR.

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 (see section 5.2.3), 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%).[15] 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.

4.4 Sensitivity Analysis Design

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. A third set of sensitivity analyses regarding modeling assumptions is performed on two issues and reported in relevant annexes: the modeling of fertilizers (Annex IV) and the interaction between pasture and crop lands (Annex VI).

[15] 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.

4.4.1 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 look at different values for the mandate: 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.

4.4.2 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.[16] Increasing the elasticity should help the farmers to intensify their production more easily and will limit the pressure for new lands.

In addition, in Annex IV, we also analyze the consequences of alternative modeling of fertilizers.

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.

The last section of Annex VI provides a discussion of the role of the interaction between croplands and pasture in our modeling and describes three variations on how pasture land area is affected by increased demand for livestock. In the simulations in this report, we use the mode P=1 wherein 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.

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

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;
- We reduce by half the land extension elasticity in Brazil (which could be the case if Brazil manages to enforce its preservation program).

Other parameters that may be critical to te overall assessment of the emissions effects of the biofuel mandates are: the choice of direct emissions savings and the coefficients of land use extensions. Since different set of values are available and are based on different methodological choices, we discuss them in Annex IX.

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 Annex VIII.

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 Results and Discussion

In this section, we present the results of the central scenario along with alternative trade policy scenarios, focusing first on the potential impact on production and trade under these policies and then on the land use and environmental impact in terms of GHG emissions from direct and indirect land use changes. Included in this assessment of environmental impact is the calculation of marginal crop-specific ILUC change, which is an important focus of this study. The final sub-section presents the results of several sensitivity analyses that are designed to assess the robustness of the results to changes in the mandate policy and some parameter values. The full set of results indicators calculated for the scenarios are available in the **Detailed_scenario_results.xlsx.**

5.1 Production and Trade Impact of Trade Scenarios

In this section we examine the impact of two policy scenarios:

First, the European mandate 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 change in trade policies are considered (scenario MEU_BAU).

Second, the trade liberalization scenario consists of reaching the same objective through a more market-based approach, by lowering the consumer price of biofuels in order to stimulate consumption. This is achieved, in a first scenario, by the full liberalization of biofuels sectors (scenario MEU_FT). A second scenario consists in a liberalization of biofuels trade between MERCOSUR countries and the EU (scenario MEU_MCS). We do not present in the report the detailed figures for the EU-Mercosur scenario since it leads to result very similar to the multilateral liberalization.

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.

5.1.1 Biofuel Production and Imports

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.

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

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

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%).

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%*

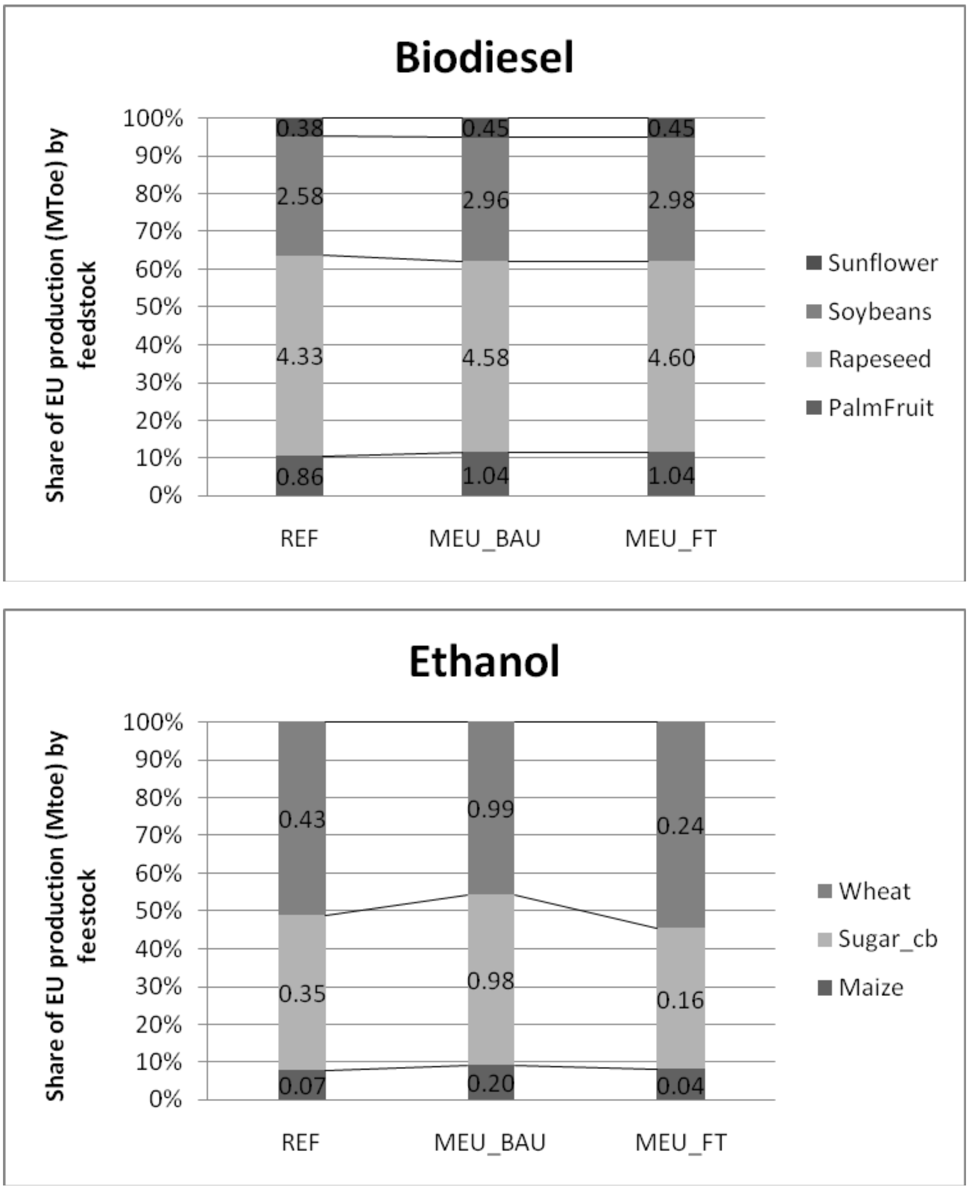
Source: Authors' calculations

Figure 3 shows EU production of biofuels in 2020 broken down by feedstock crops. The ranking among feedstocks by share of productionin 2008 is not modified since the impact of trade liberalization for the biodiesel sector is weak and the effects of the mandate are very limited. We see only a slight expansion of the share of palm oil in EU biodiesel production[17] and a contraction of the share of rapeseed oil. It shows that palm oil is marginally more competitive and with a larger mandate (and a stronger demand of biodiesel), we can expect a larger use of palm oil. This is also true for soya (from 32% to 33%). It is important to keep in mind that with the antidumping and countervailing duties applied in the baseline, the significant share of US soya-based biodiesel was already eliminated in the baseline.

For the ethanol sectors, the evolution of the feedstock structure of EU production is stronger. When the demand for EU ethanol is high (no trade liberalization), most of the production expansion will be based on sugar beet (from 41% to 45% of EU ethanol production). Symmetrically, with trade liberalization, this feedstock will be marginally the most affected (from 41% to 37%).

[17] This is in addition to the increase in biodiesel imports.

Figure 3 Structure of EU Biofuels Production by Feedstock (2020)



Source: Authors' calculations

5.1.2 Agricultural Production

These various 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, see Table 5, and +9.3% for the EU –sugar beet, see Figure 4), 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 5. Main Changes in Crop Production (non EU27) in 2020, 1000t

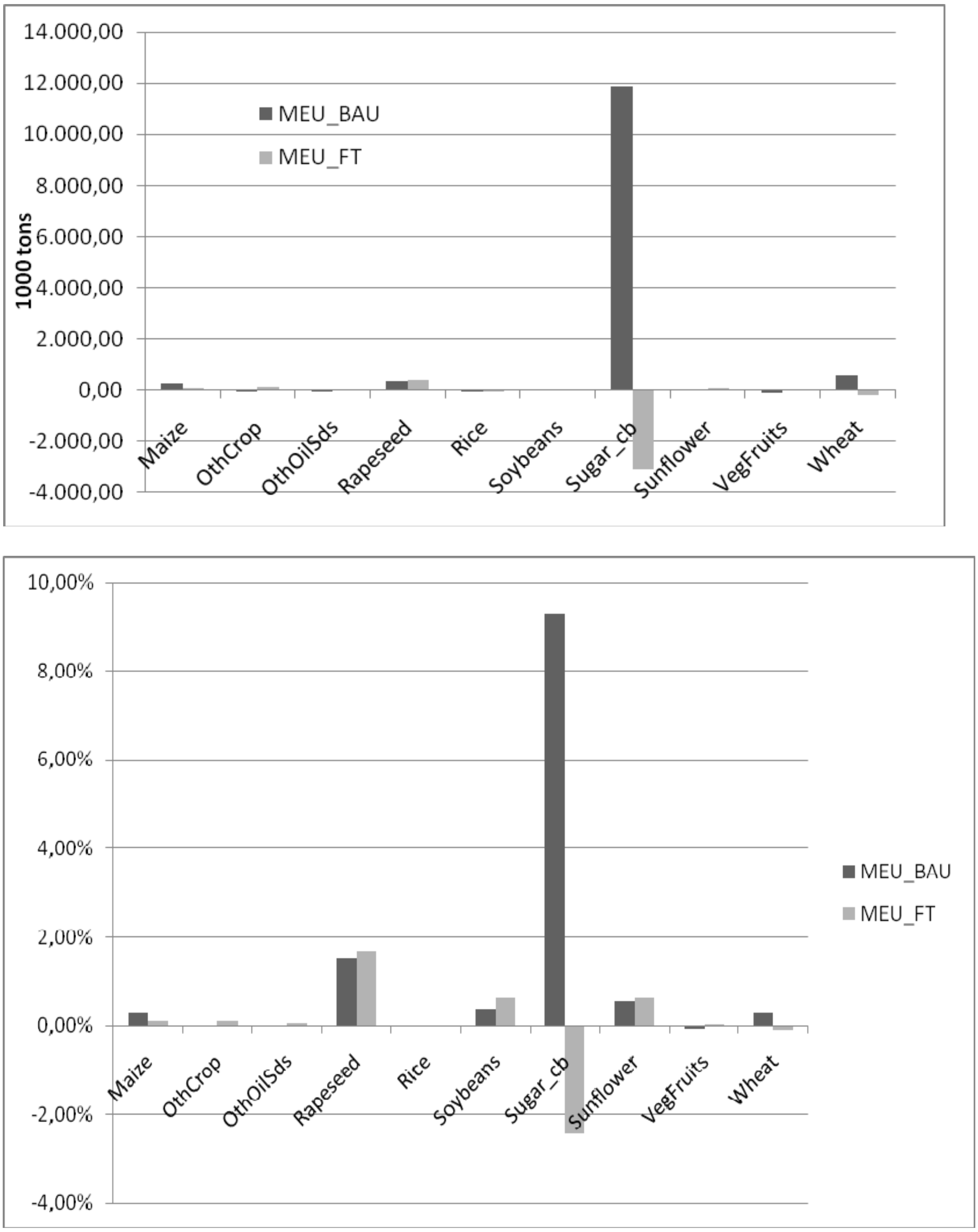
Crops	Region	REF	MEU_BAU		MEU_FT	
		Lev	Lev	Var	Lev	Var
Sugar_cb	**Brazil**	913385	1001556.15	9.65%	1045492.08	14.46%
Rapeseed	**CIS**	571	583.00	2.06%	583.42	2.13%
PalmFruit	**Brazil**	3117	3196.06	2.53%	3181.86	2.07%
Rapeseed	**Brazil**	151	153.15	1.59%	152.85	1.39%
Rapeseed	**SSA**	108	108.87	1.10%	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 (this effect should be limited by the presence of co-products in the analysis). On the other, 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.

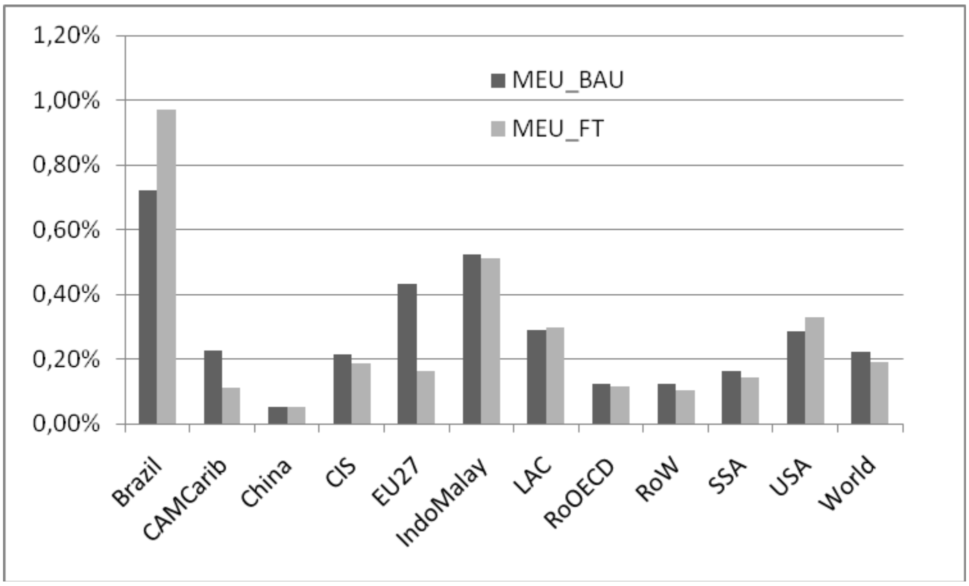
Figure 4 Variation of EU Crop Production - 2020 - (volume and percentage)



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 5 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.

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

5.1.3 Fuel and/or Feed?

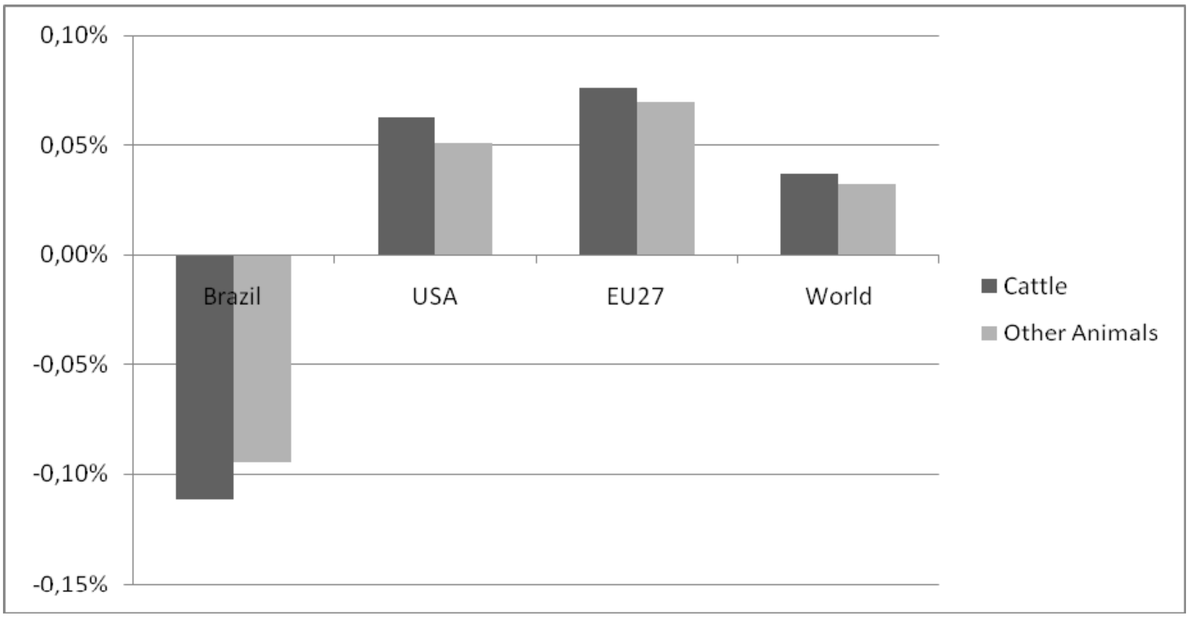
As mentioned earlier the production of biofuels also produces several by-products for which there is current or potential demand: Dried Distillers Grains with Solubles (DDGS) obtained from the production of ethanol and which is used as animal feed, and oilcakes (animal feeds) from biodiesel production. 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.

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.[18] 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 6, 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 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 6 Variation of value-added in livestock sectors in 2020 (%) – MEU_BAU scenario



Source: Authors’ calculations

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

5.2 Land Use Effects

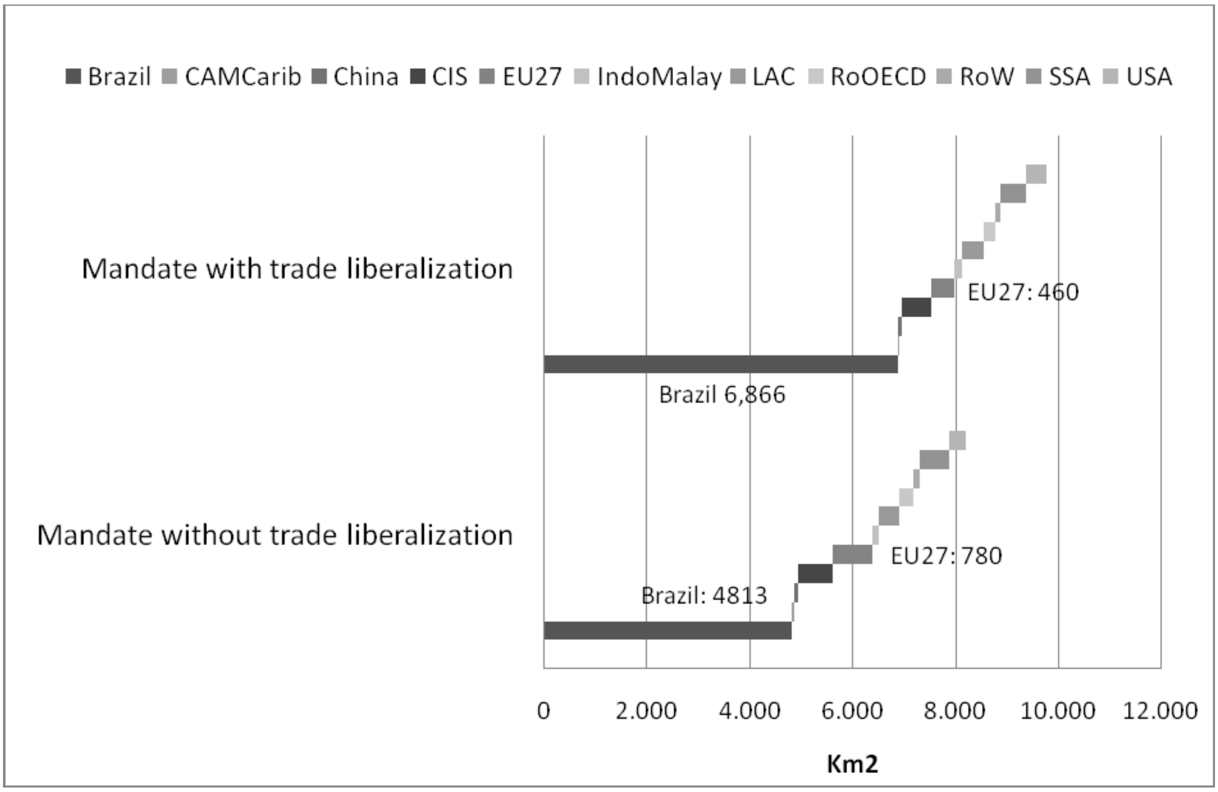
5.2.1 Land use

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.

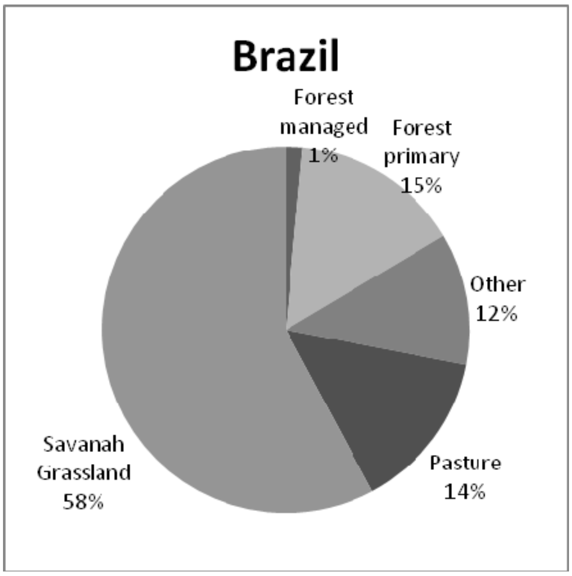
Globally the mandate increases cropland use by 0.07% in 2020 and by 0.08% under the trade liberalization scenario, with slightly more encroachment into areas reserved for forest. The land use changes under the two policy scenarios have implications on CO_2 emissions and these are discussed in the next section.

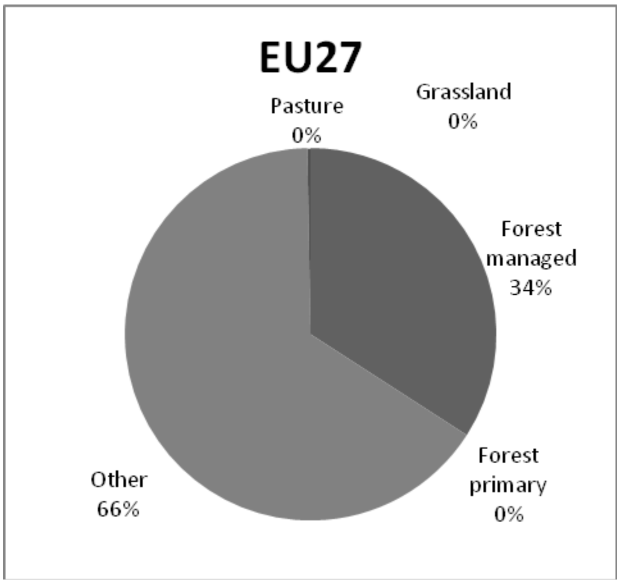
Figure 7 Cropland Extension by Region, 2020, Km2



Source: Authors' calculations

Figure 8 Source of Cropland Extension by Type of Land[19]





Source: Authors' calculations

[19] These results are based on estimates of past behavior on deforestation in Brazil and we do not consider new preservation policies in the central scenario.

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.

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 8 Decomposition of production increase

	MEU_BAU				MEU_FT			
	Yield Factors increase	Yield Fertilis-er	Land use Change	Total Producti on increase	Yield Factors increase	Yield Fertilis-er	Land use Change	Total Producti on 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

5.2.2 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[20] 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.

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

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.

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 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 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

5.2.3 Crop specific ILUC

Applying the method described in Annex VII, 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.

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.

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.

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.

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.[21]

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

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.

5.3 *Sensitivity Analysis*

This section discusses two aspect of the sensitive analysis done in this study:

- The policy target;
- The value of key parameters.

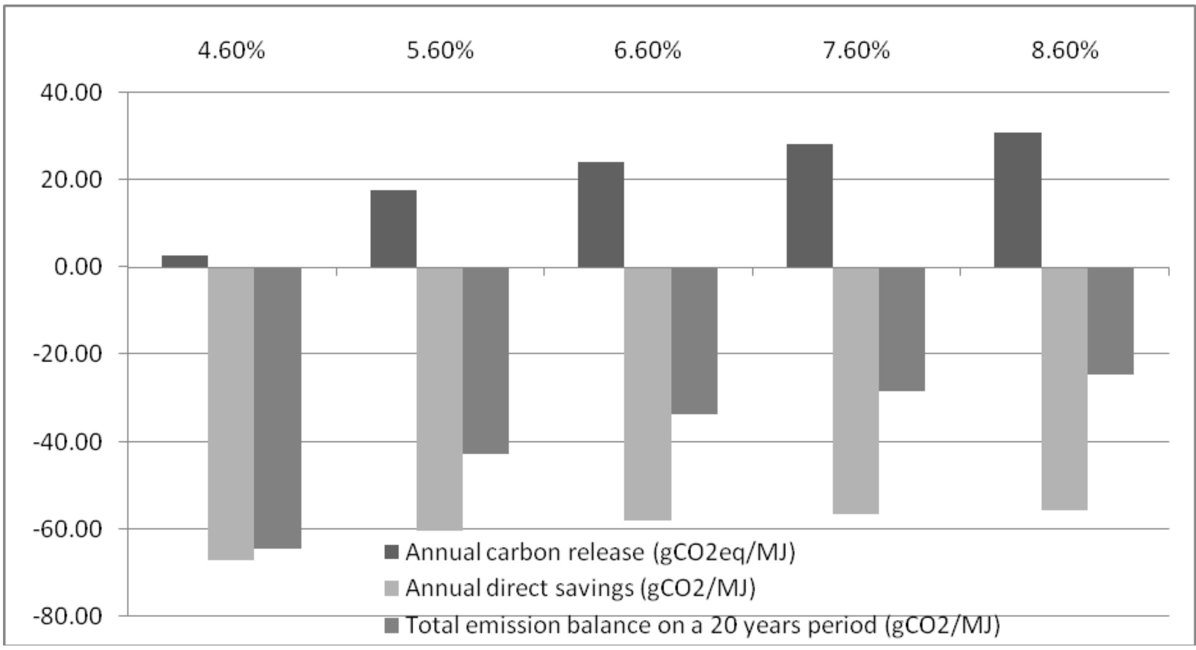
On the later issue, we only study alternative cases but a richer and systematic analysis should be performed in future research.

5.3.1 Alternative Mandate Targets

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% 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.

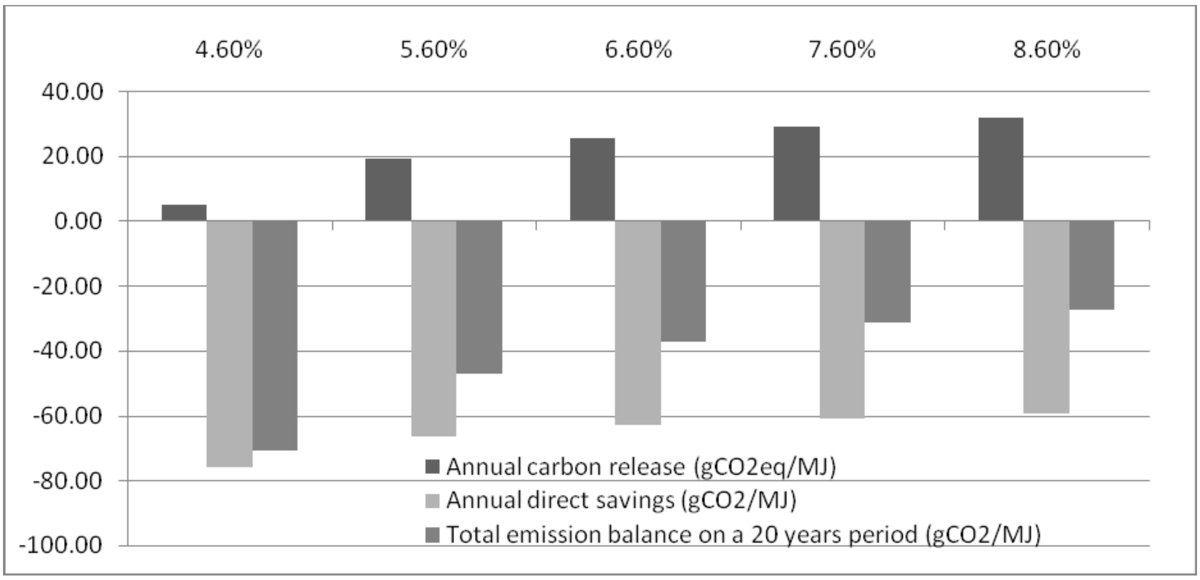
Figure 9 Indirect land use emissions and direct savings for different mandate levels, No change in trade policy



T

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

Figure 10 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.

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.

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.

5.3.2 Land substitution

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 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.

5.3.3 Land extension

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.

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.

6 Concluding Remarks

This section summarizes our main findings and then provides some recommendations for future research.

6.1 Lessons Learned

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.

6.2 Suggestions for Further Research

Based on our analysis, we can underline a few directions for future research.

First, due to strong impact of the non linearity on our results, assessing the relevance of this behavior is critical. On one hand, new modeling approach should be introduced to as an alternative to the CET framework of land reallocation. Modeling explicit conversion costs (fixed costs) will allow explaining the short term low elasticity of substitution existing in the literature and will be compatible with stronger marginal productivity (no yield decrease) in the long run. As biofuel policies are expected to be long term policies, this later approach seems reasonable. At the same time, more econometric work is needed to estimate the behavior of EU farmers in the short and long run, in particular in the context of the more market-oriented CAP. Similarly, assessing the relevance of the assumption on decreasing marginal productivity of new land plays an important role here.

Second, our modeling of land extension at the AEZ level allows for the consideration of different extension coefficients for different regions within a country. With this feature, it will be beneficial to have access to more detailed data for an extended set of countries (beyond Brazil).

Third, different assumptions on the mix between biodiesel and ethanol should be studied.

Fourth, the role of certifications, the emergence of differentiated biofuels, crops and land prices based on their “carbon” contents, and direct savings coefficients, should be studied to understand to which extent minimum requirements in the EU legislation impact the market.

Fifth, the modeling of endogenous yield increases, based on research and development activities may be useful to limit the land use effects.

Sixth, more critical is the need to improve the overall quality of data for the EU27. In this exercise, aside from introducing new sectors in the database, considerable effort was spent in correcting some inconsistencies and upgrading the GTAP7 database. However, the quality of the original social accounting matrix for the EU in the GTAP7 is very weak and some strange intersectoral linkages remain. Moving to the latest GTAP7.1 (recently released in mid-February 2010) that includes updated EU SAMs based on the JRC AgroSams and benefiting from the CAPRI input/outputs information appears to be a strong requirement to provide a accurate analysis for the European Union, particularly in looking at domestic policies.

Seventh, a higher level of geographical disaggregation is needed to gain a better understanding of land use effects, e.g. having Canada and Australia in one region leads to an important loss of information in terms of production allocation and elasticity of supply, but also of the carbon content of different biotopes.

7 ANNEXES

Annex I. Construction of the Global Biofuels Database

External data for 2004 on production, trade, tariffs and processing costs of the new sectors, especially for ethanol and biodiesel, for use in splitting these sectors from GTAP sectors were compiled from published sources, FAO stats and from the BACI databases. The primary feedstock crops used in the production of liquid biofuels in the major producing countries were identified from available literature. The input-output relationships in each biofuels producing country in the GTAP database were then examined to determine the feedstock processing sector from which the new ethanol and biodiesel sectors could be extracted. Since the global database is comprised of national social accounting matrices (SAMs) which are from different years of data, some of which reflect outdated agricultural production relationships, the global database was adjusted using agricultural input-output relationships developed from FAO data[22].

The database has been developed on a mix 2004 and 2007 data to ensure enough maturity in the biofuels sector (especially trade pattern)

Ethanol

Data on ethanol production for 2004 and 2007, in millions of gallons, were obtained from industry statistics provided by the Renewable Fuels Association for annual ethanol production by country.[23] The data covers 33 individual countries plus a sum for “other countries”. Producer costs structure are extracted from OECD (2008) from which data on ethanol processing costs for the major ethanol producers (USA, Brazil, EU) were compiled. Bilateral trade for ethanol byproduct in 2004 and 2007 was obtained from the reconciled BACI trade database which is developed and maintained at CEPII. Depending on the country, the ethanol sector was carved out either from the sugar (SGR) sector, the other food products (OFD) sector, or the chemicals, rubber and plastics (CRP) sector and then aggregated to create one ethanol sector. Ethanol producers were first classified according to the primary feedstock crops used in production. The input-output accounts in the GTAP database were then examined for each ethanol producer to determine which processing sector used a large proportion of the feedstock as intermediate input. This is then the processing sector that is split to create the ethanol sector in that country. For example, a large share of sugarcane production in

[22] The food and agricultural input-output database is documented in Peterson (2008).

[23] See: http://www.ethanolrfa.org/industry/statistics/#EIO citing F.O. Licht. Renewable Fuels Association, Homegrown for the Homeland: Industry Outlook 2005, (Washington, DC: 2005), p. 14.

Brazil goes to an established sugar ethanol processing sector, which is incorporated in GTAP's chemicals, rubber and plastic (CRP) sector in the Brazilian I-O table. Thus CRP is the sector that was split in Brazil to extract the sugar ethanol sector. However, similar analysis indicated that it was the sugar processing (SGR) sector that should be split in other sugar ethanol producing countries in Latin America. Production of grain-based ethanol in the United States, Canada and in the European Union was introduced in the data by splitting the other food products (OFD) sector where wheat and cereal grain processing takes place.

Total consumption of ethanol in each region was computed from the data on production, total exports and total imports. Ethanol was assumed to go directly to final household consumption and not as an intermediate input into production. Production cost data in terms of the share of feedstock, energy and other processing costs were used to construct technology matrices for ethanol. These vary by country depending on the primary feedstock used in production.

In details, each feedstock is the only agricultural inputs of a sub ethanol sectors. Each ethanol sectors will produce ethanol and and a coproduct (DDGS) except the sugar cane sector. They all share the same techonology (intermediate consumptions, labor) except the sugar cane sector that is less energy intensive (cogeneration).

All the sub-ethanol sectors sell their liquid ethanol to a supra ethanol sector that collects the different varieties and provide its output to final consumers, intermediate consumption for the road transportation sector and to export markets.

The international trade of ethanol is classified in the Harmonized System (HS) under HS6 codes 220710 and 220720 which cover undenatured and denatured ethyl alcohol, respectively. Since it is difficult from trade information to know the exact use of ethanol (agrifood, industry or biofuel), we prefer to rely on trade figures from F.O. Litch. Although ethanol production from different feedstocks is introduced by splitting the appropriate food processing sectors (SGR, OFD, CRP), as guided by the input-output relationships for each region, ethanol trade is actually classified under trade of the GTAP beverages and tobacco (B_T) sector. It is the B_T sector that we split to take bilateral ethanol trade and tariff information into account.

Concerning the EU tariff on ethanol, we assume an average ad valorem equivalent of 50%. However, the effective AVE is difficult to compute since tariffs on the two types of ethanol are significantly different and the mix difficult to define. In addition, some Member States are not applying the specific tariffs of 220710 and 220720 but a lower one considering ethanol for biofuel as a non-agricultural, chemical input.

Biodiesel

Data on biodiesel production in the European Union, in million tons, were obtained from published statistics of the European Biodiesel Board.[24] Biodiesel production data for non-EU countries for 2004 was estimated based on 2007 production data for these countries, obtained from F.O. Licht[25], deflated using 2004-2007 biodiesel production average growth rate for the EU. The volume data were converted to US$ millions using 2004 price data. Information on biodiesel processing costs was obtained from the OECD (2006). The international trade of biodiesel is classified in under the HS 3824 position, mainly under 382490. Once again this product includes non fuel-related imports that make difficult any direct use. Therefore, we combine HS6 trade flows from BACI, 8- or 10- digit trade flows from the US and the EU trade data and rescale flows to match F.O. Licht estimates.

The biodiesel industry is created from the CRP sector in GTAP and relevant feedstocks are extracted from the OFD and CRP sectors depending on the initial IO links. The technology of the sector (share costs) is based on OECD (2008) report without any significant difference across countries, except for the nature of the feedstock (type of vegetal oil) used.

Maize

The most important feedstock crops for biofuel production have to be treated separately in the database in order to more accurately assess the impact of biofuels expansion on feedstock production, prices and on land use. Wheat and sugarcane\sugar beet are both separate sectors in the GTAP database. Maize (corn), however, is classified under the GTAP cereal grains sector which include crops that are not used as feedstock in biofuels production. The GTAP cereal grains (GRO) sector was split to create the maize (MAIZ) and other cereal grains (OGRO) sectors. Maize production volume and price data for 2004, as well as production data for other cereals (barley, buckwheat, canary seeds, fonio, millet, mixed grains, oats, and cereal grains, nes) were compiled from FAO Production Statistics.[26] This allowed us to compute the shares of maize production to total cereal grains production in each country. Similarly, bilateral trade data from the BACI trade database for maize and for the GTAP GRO sector allowed us to compute trade shares for maize trade to total GRO trade for each bilateral trade flow. We then used the production shares information and trade shares

[24] Available online at: http://www.ebb-eu. org/stats.php.

[25] As cited in OECD (2008).

[26] Available online at: http://faostat.fao.org/site/567/default.aspx.

information to split the GRO sector into MAIZ and OGRO. We assume that the production technology for MAIZ and OGRO in each country are the same as those used for the original sector, GRO.

Oilseed crops (Palm nut, Rapeseed, Soybeans, Sunflower Seed)

For oilseeds, we compile 2004 production volume and prices data from FAO Production Statistics for the oilseed crops that are significant feedstocks for biodiesel production (palm nut, rapeseed, soybeans, sunflower seed) as well as for other oilseed crops. Bilateral trade data for oilseeds used in biodiesel, as well for the GTAP OSD sector, were obtained from the BACI trade database.

The different oilseeds are extracted from the OSD sector proportionally to their production value. No technology differences are assumed across them. In several cases, the OSD sector in GTAP was too small to accommodate production value estimated based on FAO statistics. In this case, we extract resources from the OCR (other crops) sector.

Vegetable Oils (Palm oil, Rapeseed oil, Soybeans oil , Sunflower Seed Oil)

For vegetable oils, we compile 2004 production volume and prices data from FAO Production Statistics for the vegetable oils that are used for biodiesel production (palm oil, rapeseed oil, soybean oil, sunflower seed oil) as well as for other oilseed crops. Bilateral trade data for oilseeds used in biodiesel, as well for the GTAP OSD sector, were obtained from the BACI trade database. In addition to the oils value, we add the co-products value in each subsector. Each subsector technology is defined on the relevant crushing technology where only one oilseed is used to produce one type of vegetal oil.

Fertilizer

Fertilizers are part of the large CRP sector in GTAP. A separate treatment of fertilizers is necessary to more adequately assess the implications of biofuels expansion on the interactions between fertilizers and land in crop production. The production values for 2004 for nitrogen, phosphate and potash fertilizers were obtained from production and prices data from the FAO Resource Statistics and from published data.[27] Bilateral trade data for fertilizers and for the GTAP CRP sector were obtained from the BACI database. Tariff data were obtained from the 2004 MAcMap database. The fertilizer production values and trade shares information were used to split the CRP sector into FERT and CRPN. We adapt an average production technology for fertilizers based on the detailed US input-

[27] FAO fertilizer production data available online at: http://faostat.fao.org/site/575/default.aspx. Price data obtained were from: http://www.farmdoc.uiuc.edu/manage/newsletters/fefo08_13/fefo08_13.html

output table and we assume that fertilizers are used only as an intermediate input in the crop production sectors.

Transport Fuel

Fuels used for transport are part of GTAP's petroleum and coal sector (P_C). A separate treatment of transport fuels is necessary to provide a better assessment of the likely substitution between transport biofuels and transport fuels from fossil fuels. Data on the value of consumption of fossil fuels[28] was used along with trade data to obtain the value of transport fuel production by country. Bilateral trade data and tariffs for transport fuel were obtained from the BACI and MAcMap databases, respectively. The transport fuel production values and trade shares information were used to split the P_C sector into TP_C and OP_C. We assume that the production technologies for TP_C and OP_C in each country are the same as those for the original sector, P_C. However, we assume that in contrast to OP_C, TP_C is the main fuel product comprising 90 percent of fuels used as intermediate input in the GTAP transport sectors (land, water and air transport) and in final household demand. TP_C and OP_C are equally split as fuel inputs used in the production of all other sectors.

[28] From national fuel consumption data reported in (Metschies) International Fuel Prices 2005, 4th edition, available at: http://www.international-fuel-prices.com.

Annex II. Modeling Energy and Agricultural Processes of Production

The MIRAGE model has been expanded to address its shortcomings in the energy sector and thus better adapt it to the specific needs of the study. It has been undertaken following a literature review. This review reveals the existence of two main approaches to energy modeling in the literature.

The "top-down" approach focuses on the modeling of macroeconomic activity and international trade and derives energy demand from the activity implied by this modeling. Burniaux and Truong (2002) for example develop an energy version of the GTAP model (the GTAP-E model) and use it to study the impact of alternative implementations of the Kyoto Protocol on welfare and terms of trade in eight regions of the world.

A bottom-up approach places a lot of emphasis on the technical description of the energy sector and provides a more realistic and detailed modeling of energy efficiency. It selects the most efficient process of energy production corresponding to a certain level of energy demand. For example the MEGABARE model (ABARE, 1996) makes use of the technology bundle approach which introduces substitutability between different technologies (for example between the electric arc furnace and the basic oxygen furnace in the steel industry) while the use of a specific technology implies a Leontief combination of primary factors and intermediate consumption.

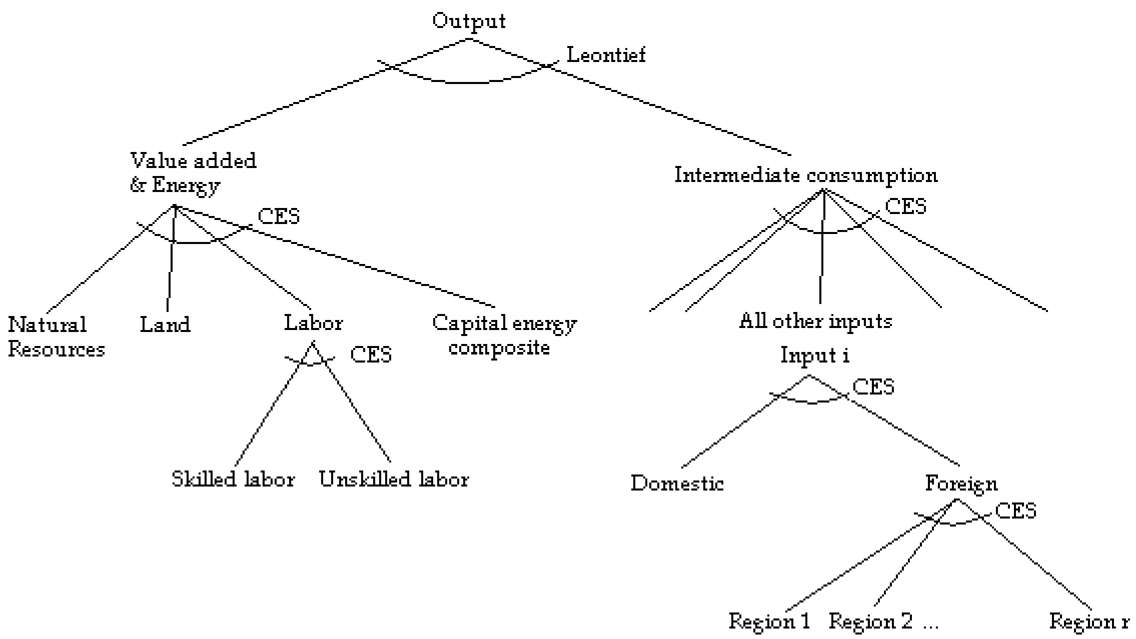
Although this kind of approach is much more difficult to implement on a large scale, it provides very interesting elements. For example the substitutability of capital and energy depends on whether the model is used in a short or long term perspective. Following an energy price increase, in the short term energy and capital are complementary while in the long term a new technology could be adopted which utilizes more capital and less energy. Attention needs to be paid to this aspect. Finally it is possible to envisage combining the two approaches. The CETM model for example (Rutherford et al., 1997) manages to combine the top-down and bottom-up approach. In this model, a partial equilibrium model of the energy sector is developed and linked to a general equilibrium model through energy price and quantity variables.

The bottom-up approach is obviously much more realistic but at the same time it is very demanding in terms of both data and behavioral parameters. In addition, it has been shown that the top-down approach provides a better assessment of economic agents' actual responses to changes in prices. As this project focuses on the potential impact of biofuel mandates on world prices, exports and imports of energy and agricultural commodities and worldwide changes in land use, a top-down approach appears to be much more suitable for the purpose of this study.

The GTAP-E model is a typical example of the top-down approach to modeling (Figure 11). The model introduces complementarity between intermediate consumption and a composite of Value-Added and Energy. It is worth noting that intermediate consumption does not include energy inputs (gas/oil/coal/electricity/petroleum products), although it includes energy feedstock.

The details of the Value-Added and Energy composite are represented in Figure 12Figure 11. This modeling approach has four main advantages. Firstly inside the energy composite, the demands for each source of energy (electricity/coal/gas/oil/petroleum products) can have different degrees of substitutability. In particular demand for gas, oil and petroleum products are relatively substitutable while demand of each of these three energy sources is only moderately substitutable with coal and electricity. Secondly in the standard GTAP model, as well as in the standard MIRAGE model capital is as substitutable with energy as skilled labor due to the inclusion of all energy inputs in the intermediate consumption branch of the nesting. In the GTAP-E model the inclusion of energy inputs in the Value Added branch of the nesting allows for the differentiation of substitutabilities. Thirdly this representation can account for the fact that investment in capital may reduce the demand for energy and that the intensity of this relation can vary by sector.

Figure 11. Structure of production in the GTAP-E model

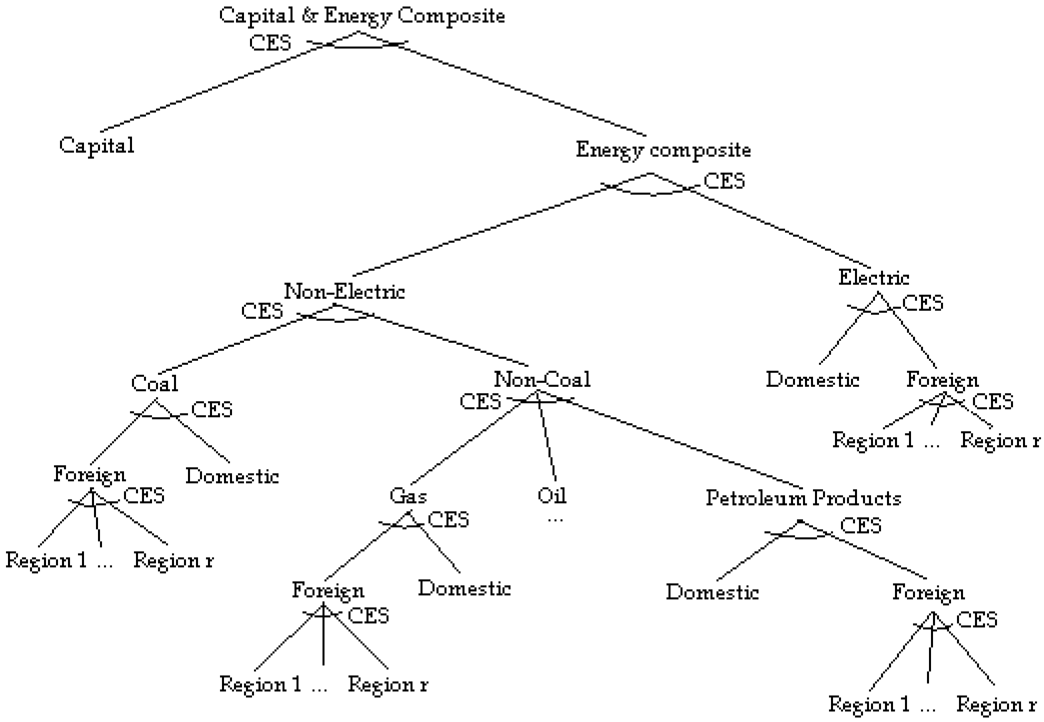


Fourthly this representation of productive process can take into account both a short-term complementarity between capital and energy and a long-term substitutability. Both the GTAP and the MIRAGE models are based on the 'Putty-Clay hypothesis' which holds that old capital is sector-specific while new capital is mobile. Thus following an increase in energy price the substitution between capital and energy is rather limited, as in the short term most of the capital is sector specific. However, in the long run, if the price shock is permanent, the degree of substitution is much larger. Thus the GTAP-E model takes into account both the rigidity in energy use in the short term and its flexibility in the long term. While the GTAP-E model represents a major progression in terms of energy modeling we do think that it is not fully satisfactory in this case, for several reasons.

Firstly a key issue of the debate around the development of a biofuels sector and its impact on food prices and CO2 emissions is what the literature calls the 'indirect land use effect'. In other words because the allocation of land to the production of agricultural feedstock for non-food purpose decreases food supply, it exerts pressure on agricultural prices. This has a tendency to encourage an increase in land supply, either from forest or livestock utilization and this change in itself contributes to increased CO2 emission. One decisive element in this mechanism is how increased agricultural prices translate into increases in land supply. In fact, faced with higher demand farmers can either chose a more extensive production process (increased land supply under a constant yield) or a more intensive production process (increased yield under a constant land supply). The modeling of agricultural processes has to take this mechanism into account. This is the reason why we adopt a new nesting, as illustrated in Figure 13.

In agricultural sectors, the output is a Leontief combination of a "modified Value Added" and a "Modified Intermediate Consumption". We use the term 'modified' as from the Value Added side it incorporates all primary factors, plus the energy products, plus other products like fertilizers and animal feedstock. From the intermediate consumption side it does not incorporate all commodities used as intermediate consumption in the production process. This "Modified Value Added" is a combination of two composites taking into account the traditional MIRAGE assumptions on the elasticity of substitution, which is 1.1 in this case. The first one is a composite of land and either animal feedstock in livestock sectors or fertilizers in crops sectors. It enables the key issue of choice between intensive and extensive production processes to be tackled. The elasticity of substitution for this CES function varies between 0.1 and 2 according to the GTAP database, except for Northern countries for which the default elasticity is fixed to 0.1.

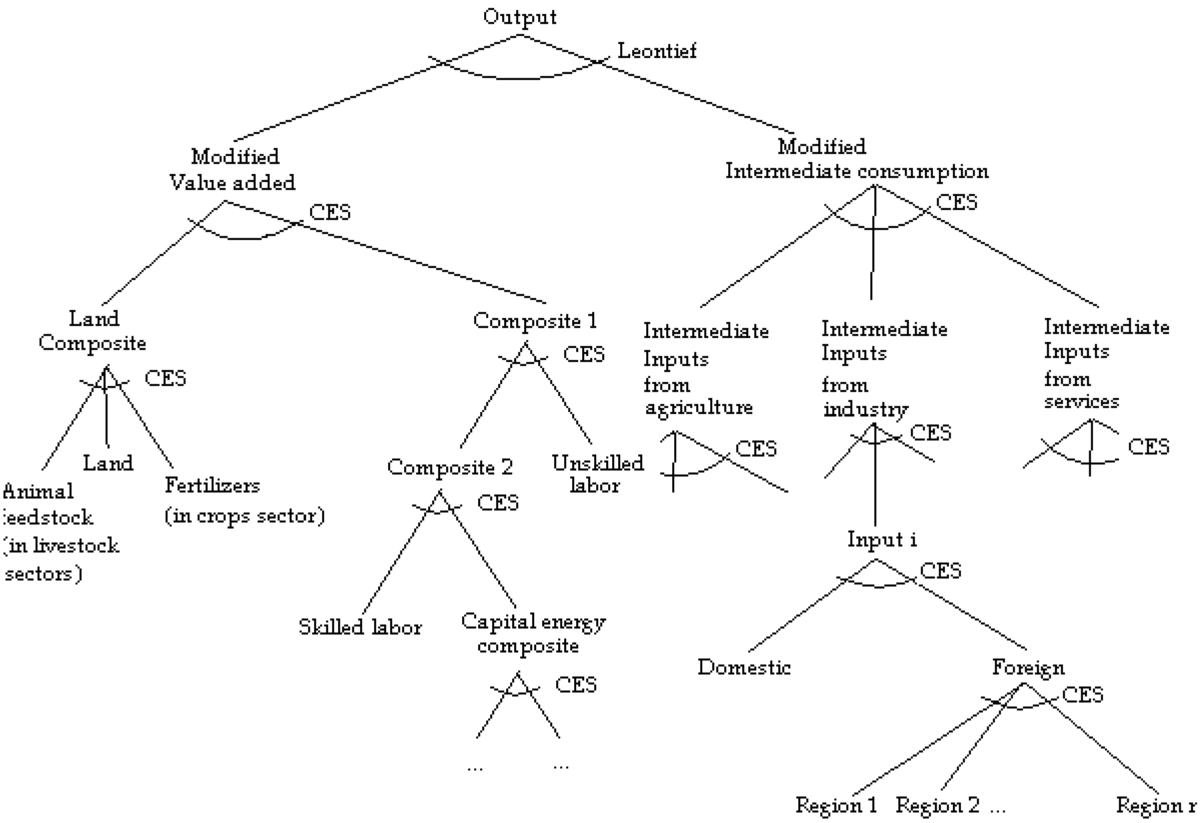
Figure 12. Structure of the Capital & Energy Composite in the GTAP-E model



The other composite is a combination of the standard MIRAGE approach and the GTAP-E approach:

- It incorporates a capital-energy composite according to which investment in capital can reduce the demand for energy;
- As only new capital is mobile, the degree of substitutability between capital and energy is greater in the long term;
- In Figure 13, under the Capital-energy composite we incorporate the nesting illustrated in Figure 12 which incorporates different degrees of substitutability between coal/oil/gas/electricity/petroleum products.
- Skilled labor and the capital-energy composite are rather complementary while both can be substituted for unskilled labor.

Figure 13. Structure of the Production Process in Agricultural Sectors in the Revised MIRAGE Model



The paper by Burniaux and Truong (2002) was the inspiration for the elasticities of substitution of the different CES nesting levels described above. Between energy and electricity, it is set at 1.1, between energy and coal it is 0.5, and between fuel oil and gas it is 1.1. Based on estimates from Okagawa and Ban (2008) - (EUKLEMS estimates), the elasticity of substitution between capital and energy is 0.2 in Industry, 0.3 in services and 0.03 in agriculture.

Finally it is worth noting that a distinctive feature of this new version of MIRAGE is in the grouping of intermediate consumptions into agricultural inputs/ industrial inputs/services inputs. This introduces greater substitutability within sectors, for example substitution is higher between industrial inputs (substitution elasticity of 0.6), than between industrial and services inputs (substitution elasticity of 0.1). At the lowest level of demand for each intermediate, firms can compare prices of domestic and foreign inputs and as far as foreign inputs are concerned, the prices of inputs coming from different regions. In non-agricultural sectors demand for energy exhibits specific features which are incorporated as follows:

- In transportation sectors (Road transport and Air and Sea Transport) the demand for fuel which is a CES composite of fossil fuel, ethanol and biodiesel, is rigidified. The modified Value

Added is a CES composite with very low substitution elasticity (0.1) between the usual composite (unskilled labor and a second composite which is a CES of skilled labor and a capital and energy composite) and fuel which is a CES composite with high elasticity of substitution (1.5) of ethanol, biodiesel and fossil fuel.

- In sectors which produce petroleum products, intermediate consumption of oil has been rigidified. The modified intermediate consumption is a CES composite (with low elasticity, 0.1) of a composite of agricultural commodities, a composite of industrial products, a composite of services and a composite of energy products which is a CES function (with low elasticity) of oil, fuel (composite of ethanol, biodiesel, and fossil fuel with high elasticity, 1.5) and of petroleum products other than fossil fuel. The share of oil in this last composite is by far the biggest one. This implies that when demand for petroleum products increases, demand for oil increases by nearly as much.
- In the gas distribution sector the demand for gas has been rigidified. It has been introduced at the first level under the “modified intermediate consumption” composite, at the same level as agricultural inputs, industrial inputs and services inputs. This CES composite is introduced with a very low elasticity of substitution (0.1).
- In all other industrial sectors we keep the production process illustrated in Figure 4, except that there is no land composite and that fuel is introduced in the intermediate consumption of industrial products.

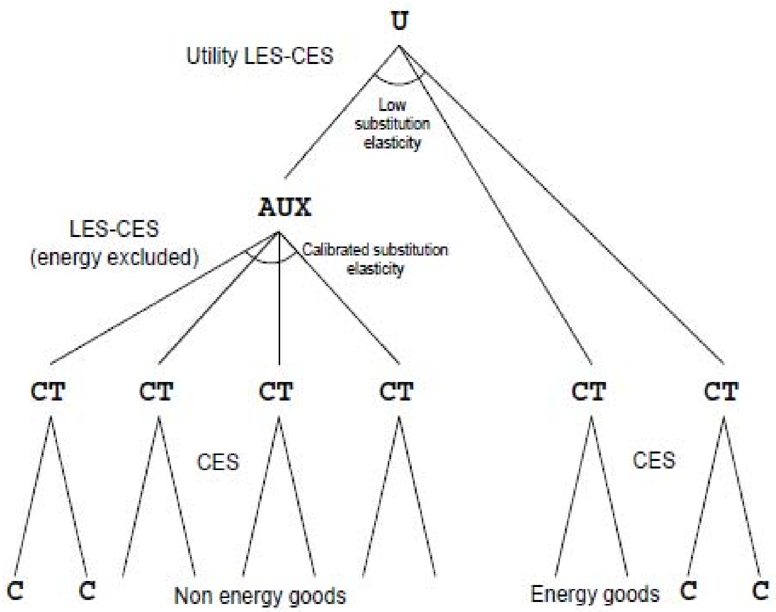
Annex III. Final Consumer Energy Demand

Introduction of a new CES level for energy demand

Because a LES-CES calibration is more efficient for respecting income elasticity values rather than price elasticity ones, it appeared relevant to better set the demand function in order to reflect the low elasticity of energy demand to prices. That is why we introduced a third level in the demand structure by setting an additional LES-CES function at the first level. The overall demand structure, as shown in Figure 14, is therefore:

- A first LES-CES for energy treatment: note that in this first stage, income elasticities for this function will be assumed to be one, i.e. minimum shares will be set to zero, and the function will follow a CES behavior.
- A second LES-CES function for all other goods. This function is calibrated thanks to a specific program that has been adjusted in order to take into account the presence of the first LES-CES.
- A CES function in order to represent highly substitutable goods.

Figure 14. Demand Structure Adapted for Final Energy Consumption



The direct price elasticity of fuel for transportation is calibrated at - 0.45 to reproduce the right evolution of the EU fuel demand for transportation. It corresponds to an intermediate value in the literature.

Annex IV. Fertilizer Modeling

A logistic function for modeling fertilizer effect

Modeling fertilizers is a delicate task since a simple CES assumption cannot be used to represent the impact of fertilizers on crop yield. Indeed, increasing fertilizer use could allow an increase in yields in the short run. However, some saturation can occur and some countries cannot get higher yield through fertilizers because of an already intensive use of them (Kumar and Goh, 2000).

We choose here to represent yield reaction to fertilizer as a logistic function. The most general logistic functional form would be probably the most appropriate to describe how yield reacts because it can be very precisely calibrated on biophysical data. The general form of such a function is the following:

$$yield\,(f) = ymin + \frac{ymax - ymin}{1 + \left(\frac{ymax - ymin}{y_0 - ymin} - 1\right) e^{-a(f)}}$$

where f is the level of fertilizer input per ha, ymin the potential mimimum yield attainable (bottom asymptote), ymax is the maximum yield attainable (top asymptote), y0 is the yield where the maximum efficiency is reached (inflexion point), and a is a parameter giving the maximum efficiency level.

However, in a CGE framework, this representation is quite complex to implement. Indeed, this function is not convex and therefore does not guarantee the uniqueness of a solution. Second, this function is delicate to calibrate because it incorporates many coefficients which require biophysical information that are not available for every region. As a consequence, we decided to use a simplified yield representation of this function. In order to ensure that the convexity is preserved, we assume y0 > ymax-ymin\2. A set of available functions are displayed in Figure 15.

These functions therefore allow for the modeling of different levels of fertilizer saturation, and different levels of response to an increase in fertilizer levels.

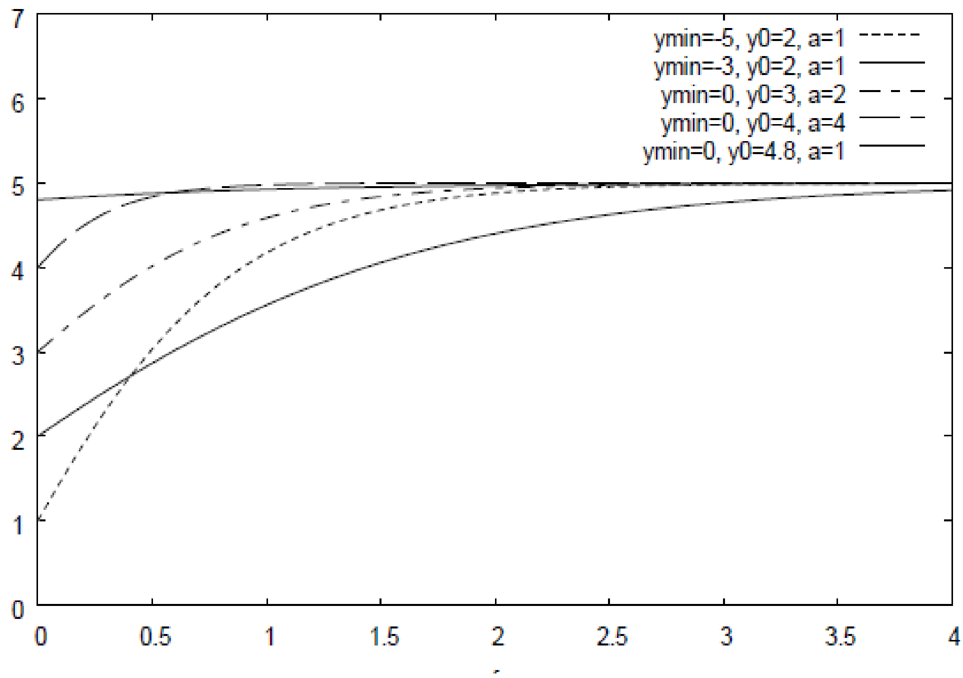


Figure 15. Possible concave yield functional forms (ymax = 5)

Source: Authors' calculations

Detailed parameters of the function are available upon request.

In a comparison of our logistic approach and a more traditional CES function between land and fertilizer wherein the CES elasticity was calibrated to be comparable with the logistic elasticity at the initial point, it appears that the differences are generally minimal (less than 4% on overall ILUC).

Annex V. Modeling of Co-Products of Ethanol and Biodiesel

On the supply side, meals are produced by the vegetal oil sectors and we calibrate quantity and value based on a representative crushing equation for each sector. Yields are assumed to be identical across countries and do not change overtime. They are oilseed specific. No by-products (glycerol) of biodiesel is considered.

For the ethanol sectors, DDGS are introduced for all sectors except the Sugar cane based industry. For the latter, we only assume that bagasse will generate an income of 6% of the production cost but the market is not represented explicitly.

The substitution patterns between the different feeds are different depending on their nutritional content. Oil cakes are appreciated for their protein content (Table 14) and used as a food complement to ordinary rations of cereals and DDGS, for which the caloric content is more relevant. We therefore introduced two substitution degrees, based on different expressions of feed volume:

- Oil cakes: the first level of substitution describes substitution between oil cakes on the basis of their protein content. In order to ensure a consistent substitution, the different values of cakes where converted into protein volume, using the shares displayed inTable 15**Error! Reference source not found.**. The default value for elasticity of substitution used at this level is 5 which implies a very high substitution.

Table 14 Protein Content of Oil Cakes used for the Modeling

Protein content	per ton
Rapeseed cake	38%
Soybean cake	45%
Palm kernel cake	20%
Sunflower cake	39%

Source: Authors' calculations

- Feed, grains and DDGS input: the second level of substitution includes the aggregate of oil cakes in substitution with other types of feed and grains and with DDGS. At this level, all inputs are expressed in their energy content (see Table 15 showing energy content in metabolizable energy, taken from Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Research Council (1982)). For oil cakes, an average energy content is computed from the initial composition of oil cakes for each country and livestock sector.

Table 15 Energy Content of Feed for Livestock - Metabolizable Energy

Feed	Livestock	Mcal/t	Note
Rice	Cattle	2.42	rice bran - ruminant
Rice	OthAnim	2.59	poultry 2.11 - swine 3.07
Wheat	Cattle	3.08	wheat grain - ruminant
Wheat	OthAnim	3.13	poultry 3.02 - swine 3.25
Maize	Cattle	3.03	grain - ruminant
Maize	OthAnim	3.34	poultry 3.38 - swine 3.3
VegFruits	cattle	0.74	potato, tubers, fresh
VegFruits	OthAnim	0.76	poultry 0.71 - swine 0.82
OthCrop	Cattle	2.9	barley, grain - ruminant
OthCrop	OthAnim	2.51	poultry 2.51 - swine 2.91
Rapeseed	Cattle	0.33	fresh, early bloom
Rapeseed	OthAnim	0.29	Derived from meal value
Soybeans	Cattle	0.64	fresh, dough stage
Soybeans	OthAnim	0.54	Derived from meal value
Sunflower	Cattle	1.36	Sunflower, seed meal not hulled - ruminant
Sunflower	OthAnim	1.68	poultry 1.54 swine 1.81
SoybnCake	Cattle	2.94	Soy meal 0.44 - Ruminant
SoybnCake	OthAnim	2.52	Poultry 2.22 - Swine 2.82
RpSdCake	Cattle	2.66	Rapeseed meal prepressed - Ruminant
RpSdCake	OthAnim	2.3	Extrapolated from Rapeseed summer values Poultry 2 - Swine 2.61
PalmKCake	Cattle	3.1	239 kcal / MJ; source: FAO*
PalmKCake	OthAnim	2.5	Extrapolated - should not show in the data
SunflowerCakel	Cattle	2.27	Sunflower meal withou hulls, sol ext - Ruminant
SunflowerCakel	OthAnim	2.36	Poultry 2.08 - Swine 2.65

http://www.fao.org/ag/AGP/agpc/doc/Proceedings/manado/chap25.htm

Annex VI. 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 – Modeling land use expansion: a normative approach

The first important idea is that this representation of land use is based on the principle that an increase in the price of land used for economic activity leads to conversion of new land. Since MIRAGE is an economic model, agents are assumed to follow an optimization behaviour. Therefore, the rationale of agents in the model is completely different from the rationale presented in Fargione et al. (2008) where the assessment is conducted by assuming that a producer arbitrarily plants his\her crops on a new area of land, the type of which remains to be determined. As in the case of most CGE models that rely on neoclassical assumptions, a producer in MIRAGE only reacts to prices and no other rationality constraint is taken into account. Land use conversion is consequently driven by price changes.It is also important to consider that, from the econometric point of view, the relationship between deforestation and cropland expansion is not yet fully understood. These phenomena are quite complex, and most of them depend on the combination of various factors which includes prices and others. Furthermore, due to the lack of robust estimates, field specialists and geographic economists are very reluctant to propose aggregated elasticities of prices variations with respect to land expansion variation. Some scientists also stress that deforestation is impossible to model (most studies about land use expansion concerns deforestation for understandable reasons, but of course, this seems to be applicable to other). Geist and Lambin (2001) provide a very good insight on this complex issue.

With the background given above, , a few assumptions were made for this analysis:

- Strong evidence relying on geographical analysis (even if it does not guarantee any causality linkage), supports the fact that international markets and price incentives affect land use decisions (see Morton et al., 2006 for geographical analysis, Ghimire et al., 2001). And it is straightforward to infer that there is a positive correlation between land expansion and the price level.

- The elasticities of land expansion are usually lower than the elasticities of land use substitution,
- Furthermore, if yield increases are capped and demand is rigid, deforestation will occur to furnish the corresponding supply whatever the value of the elasticity. But we do not know at what price.

However, we do not know the magnitude of the elasticities of land expansion. There are no robust estimates from the econometric literature because of the complexity of the linkage and the highly fragmented data available for land use in deforested regions, the lack of a continuous time series on local prices, and more importantly, land rent, when they exist. More importantly, if we assume for each region such an elasticity, we do not know the variation of this elasticity across regions and we do not know its sensitivity to specific crop prices. For example, how much does deforestation in Indonesia react to price of palm oil in comparison to deforestation in the Amazon with respect to price of beef or soybeans?

One can therefore understand the difficulty of the task of estimating indirect land use change of biofuels. Linking crop price changes to land use changes is a much more complex exercise than the assessment of the contribution of biofuels to the2008 food price crisis (wherein no land expansion is considered since it is a short term phenomena). And yet several quantitative analyses of the food price crisis produced a wide range of estimates. A practical way to address such an issue is as follows:

- We implement in the model with the mechanisms we know, i.e. the positive correlation between prices and land use expansion;
- We base our elasticities on working assumptions, respecting the constraints stated above (lower than substitution elasticities but high enough to support the fact that cropland and other managed land expansion is driven in part by demand for land products)
- We perform sensitivity analysis around these values. Values close to the substitution value will mean that producers are indifferent between expanding their production by replacing their production and using new land. A very low elasticity indicates that the producer will not expand much (protected areas of natural land). A land expansion elasticity higher than the substitution elasticities will mean that there is little competition for managed land because producers can expand at little cost in new areas.
- We choose to adopt a neutral normative assumption concerning elasticities across regions and crops, which means that we assume that each producer, whatever his production type or his region, reacts the same way to a price change.

Even if this approach is weak in terms of support of econometric evidence, it corresponds to the most heuristic representation that we can incorporate in an economic model to represent this complex phenomenon.

2 –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.

3 - Land Use Extension

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

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

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, $\frac{LandZ_{avail} - LANDEXTZ_t}{LandZ_{avail}}$ 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.

4 – 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.

Applied to the aggregation of 10 regions, the distribution is displayed in

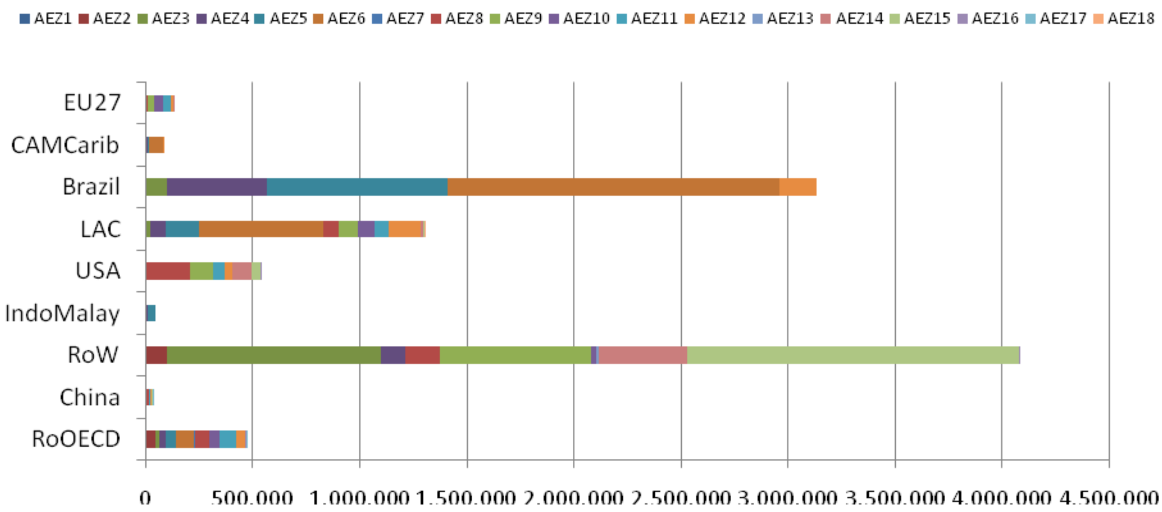
Table 16 and

Figure 16.

Table 16 Share of Land Available for Rainfed Crop Cultivation Computed for the MIRAGE Model (km²)

	RoOECD	China	RoW	IndoMalay	USA	LAC	Brazil	CAMCarib	EU27	World
AEZ1	297		1,077							**1,374**
AEZ2	45,883		97,840			2,227				**145,950**
AEZ3	19,502		998,449			19,659	100,983			**1,138,593**
AEZ4	30,267	16	115,237	12,250		68,796	462,927	11,377		**700,870**
AEZ5	45,407	284		32,734		158,354	848,911	5,285		**1,090,975**
AEZ6	81,214					579,105	1,544,057	67,731		**2,272,107**
AEZ7	5,833	298	1,242							**7,373**
AEZ8	68,838	16,227	157,856		207,758	73,444			8,574	**532,697**
AEZ9		731	709,365		108,956	87,212			33,521	**939,785**
AEZ10	46,740	283	24,478			80,139	2,675		39,079	**193,394**
AEZ11	80,196	6,450			50,422	65,656	608		36,979	**240,311**
AEZ12	42,983	1,827			35,634	150,950	173,797	1,399	13,814	**420,404**
AEZ13	28	104	8,605							**8,737**
AEZ14		2,471	415,007		91,014	8,379			6,103	**522,974**
AEZ15		2,973	1,547,775		42,379	6,221				**1,599,348**
AEZ16	3,215	2,145	1,830		738	4,699				**12,627**
AEZ17	541	323								**864**
AEZ18						1,056				**1,056**
TOTAL	**470,944**	**34,132**	**4,078,761**	**44,984**	**536,901**	**1,305,897**	**3,133,958**	**85,792**	**138,070**	**9,829,439**

Figure 16 Land Available for Rainfed Cultivation in Unmanaged Land Area (in km²)



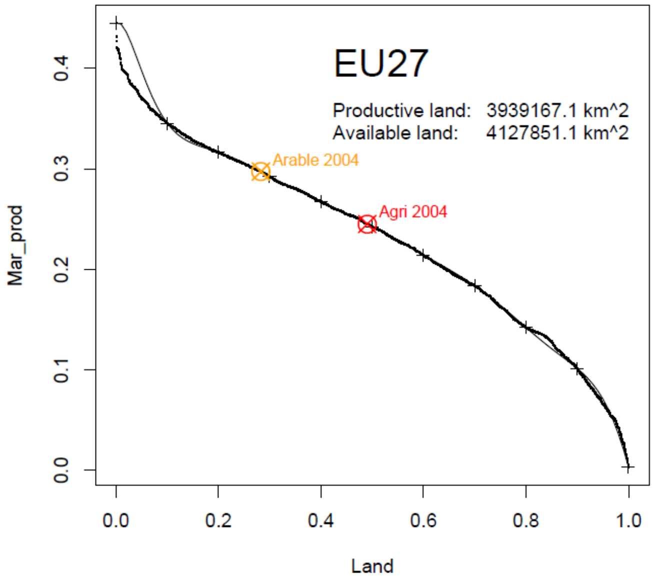
Source: Computed from IIASA databases to obtain AEZ distribution and using symmetric assumptions on the share of available land under managed pasture and forest and the share of land not under management.

5 - 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 17. 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 11^{th} 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.

6 - 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.

7 - 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[29], 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

[29] 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 17 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 VII. 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.

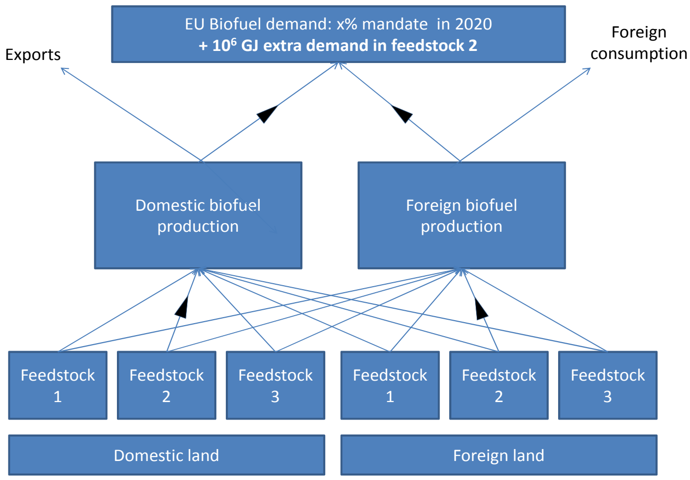


Figure 18 Modeling of a Marginal ILUC Shock

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.

Annex VIII: The Role of Technology Pathway

This study uses coefficients of direct GHG emissions reduction for different biofuels feedstock in different regions, as reported in Table 18. The Set 1 values are employed in the model and the Set 2 values are considered for sensitivity analysis.

These values have no direct impact in our modeling exercise since they are only used in an ad-hoc manner to compute the net emissions effects. They have no influence in the outcome of the simulations. Their choice is highly debatable since they should refer to future technological paths and different methods of estimation of the direct saving effects have been discussed in the literature. We show in this annex the consequences of alternative values on the net emissions computations.

Final users of this research report can easily use alternative values for direct savings and combine them with our ILUC computations to determine final net values to ensure their compatibility with policy targets. An important debate is to determine if we should consider technological pathways that do not match the minimum requirements of the EU legislation. The answer is not straightforward since in each country we can have a mix of heterogeneous production processes with different levels of energy intensity. Even if the EU manages to enforce specific standards for the biofuels sold in its market, substitution can occur: "clean" producers will shift their production to the EU market, and may collect a price premium, and the other producers will supply other markets. Due to this potential substitution effects, the EU demand of high standard biofuels may still lead to the expansion of low energy efficient suppliers, leading to contrasted effects on the environment. However, to which extent this mechanism will take place is unclear. Our model assumes only one average technology in each country. Future research will demonstrate if we see dual markets for biofuels emerge (high standard vs low standard) and how the sector reacts to certification processes, and for the later, if they are enforceable.

Table 18 Reduction of CO2 associated with different feedstock – Values used in calculations

Feedstock	Set 1	Set 2	Source (Set 1)
Wheat (EU)	-45%	-53%	EU Dir (2009)
Wheat (Other)	-32%	-50%	EU Dir (2009)
Maize (EU)	-56%	-56%	EU Dir (2009)
Maize (USA)*	-46%	-69%	EPA (2009)
Maize (Other)**	-29%	-29%	FAO (2008)
Sugar Beet	-61%	-61%	EU Dir (2009)
Sugar Cane	-71%	-71%	EU Dir (2009)
Soya	-40%	-50%	EU Dir (2009)
Rapeseed	-45%	-50%	EU Dir (2009)
Palm Oil	-36%	-62%	EU Dir (2009)
Sunflower	-58%	-58%	EU Dir (2009)

Sources: European Council, (2009). Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, EPA assessment, JEC estimates (substitution method).

** EPA (2009) Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program*

*** FAO (2008),The State of Food and Agriculture*

Sensitivity analysis: Alternative CO2 direct savings figures

As previously discussed, looking at alternative direct savings coefficients has different interpretations. On one hand, we can consider that our capacity to measure efficiently these coefficients today is delicate, in particular if we consider if we assume technologies implemented in 2020. On the other hand, it also represents how the country-level mix of different technologies for a biofuel will evolve with time. Since we rely on average coefficient in each country, looking for higher saving coefficients in absolute level will represent the increase of the share of energy-efficient producers (plants powered by gas or cogeneration) and the decrease of less efficient producers (e.g. coal powered plants). Using the set 2 instead of the set 1 does not change the main picture. Direct savings are improved slightly but the main difference is between the two trade scenarios. Indeed, trade liberalization leads to a decline in EU ethanol production, in particular wheat based ethanol and increase the share of sugar cane ethanol in EU consumption. Since the set 2 increases direct savings of wheat ethanol, the gap between the two scenarios is slightly reduced. Finally, the set 2 improves the net emissions of the palm oil and make it the most attractive vegetal oil (under a median assumption concerning peat land emissions).

Annex IX: The Role of Land Extension Coefficients

The choice of extension coefficients plays a critical role in the CO2 emissions related to the ILUC. Indeed, they distribute the increase (or decrease) of agricultural land over the different ecosystems. With each ecosystem being associated with different CO2 contents, the distribution of the land extension across them defines the CO2 emissions related to the ILUC. Put differently, for the same amount of "new" land requested by agriculture, the emissions outcome may vary largely just due to the value of these coefficients. In this report, we use coefficients computed by Winrock International for the US EPA as reported in Table 19.

Table 19 Land Extension Coefficients

	ForestManaged	ForestPrimary	Other	Pasture	Savannah & Grassland
Argentina	16.4%	0.0%	24.7%	35.6%	23.3%
Brazil	0.5%	16.3%	11.2%	23.5%	48.5%
CAMCarib	0.0%	30.4%	10.7%	16.1%	42.9%
Canada	1.4%	7.8%	42.5%	32.2%	16.1%
China	5.6%	2.2%	27.3%	39.0%	26.0%
CIS	3.7%	5.6%	33.3%	30.7%	26.7%
EU27	8.4%	0.4%	23.5%	36.8%	30.9%
IndoMalay	3.2%	51.7%	7.0%	7.0%	31.0%
LAC	17.8%	10.8%	14.3%	23.4%	33.8%
Oceania	9.0%	0.0%	32.6%	36.0%	22.5%
RoOECD	14.6%	0.0%	18.8%	20.8%	45.8%
RoW	3.4%	3.7%	36.9%	39.3%	16.7%
SEasia	1.1%	20.4%	21.5%	23.1%	33.8%
SouthAfrica	1.1%	5.1%	28.4%	43.2%	22.2%
SouthAsia	12.7%	0.0%	32.4%	31.0%	23.9%
SSA	0.1%	13.0%	16.7%	28.6%	41.7%
USA	5.4%	2.5%	21.1%	47.4%	23.7%

Source: EPA (2010) based on Winrock International computations
Note: For Brazil, the model used AEZ specific coefficients. Figures in the table are simple average of the AEZ values.

Annex X. Biofuels Policies

EU Biofuel Policies

The European Biofuel policy is quite complex because it is driven not only by the Biofuel Directive, but also by others directives and regulations related to Energy, Fuels Quality, Agriculture and Trade Policies.

The Biofuel Directive[30] introduces some constraints on the substitution requirements of fossil fuels by biofuels. The main goal of this policy is to reduce greenhouse gas emissions particularly in transportation and to lessen dependence on fossil fuels by diversifying energy sources, especially towards environmentally friendly technologies. For this purpose, this Directive prescribes several mandates for biofuel blending with current fuels at different dates. The first objective was, for each EU member to have a 2% market share for biofuels in 2005, then 5.75% in 2010. With the recent Renewable Energy Directive, a target of (at least) 10% in 2020 was added.

In order to help EU members with the implementation of the previous Directive, the Energy Tax Directive authorises the EU countries to introduce some tax reductions and exemptions for biofuels.[31] The application of both directives differs from one EU country to another. Austria, Belgium, Germany and Luxembourg have obtained the best results in response to the targets of the Biofuels Directive. They have reached a 2.5 to 2.75 % market share for biofuels. Moreover, other developing EU members have also attained the 2005-target: Slovenia (2.5% in 2006), Latvia (2.75% in 2006), Greece (2% in 2005 and 2006) and the Czech Republic (3.7% in 2005 and 1.78% in 2006). However, some other EU members have not yet fulfilled their biofuel commitments, despite various incentives (e.g. United Kingdom, Malta, Cyprus, etc.). For instance, the United Kingdom, although it has not applied any energy tax reduction/exemption, has favouring production subsidies and capital grants for biofuel projects. Austria, Germany and France have all taken similar approaches, reducing or exempting biofuel production from taxes imposed on mineral oils, depending on the biofuel type (e.g. ethanol or biodiesel) and the level of blending (i.e. Austria exempts 100% tax for pure biodiesel but only slightly reduces this tax for 5%-ethanol gasoline).

The Common Agricultural Policy also plays an important role in encouraging biofuels production. Since the 2003-CAP Reform, the supply of energy crops has benefited from direct payments and decoupled support without any set-aside obligation and without any loss of income support.

30 Directive 2003/30/EC of 8 May 2003 concerning biofuel promotion for transport use.

31 Energy Tax Directive 2003/96/EC of 27 October 2003.

Moreover, these energy crops also benefit from a premium over the price received by producers and following the Common Market Organisation regulation, sugar beet production for ethanol is exempted from production quotas.

EU trade policies also affect domestic biofuel production as well as reducing export opportunities and production incentives for foreign biofuel producers (e.g. USA, Brazil, Indonesia, Malaysia, etc.). The Most Favourite Nation (MFN) duty for biodiesel is 6.5%, while for ethanol tariff barriers are higher (€19.2 /hectolitre for the HS6 code 220710 and €10.2 / hectolitre for the code 220720). Even if tariffs for biodiesel were to be reduced, trade would still have to face more restrictive non-tariff barriers (NTBs) in the form of quality and environmental standards, which already mostly affect developing country exporters.

Nevertheless, some European partners already benefit from a duty-free access for biofuels under the Everything But Arms Initiative, the Cotonou Agreement, the Euro-Med Agreements and the Generalised System of Preferences Plus. Many ethanol exporters, such as Guatemala, South Africa and Zimbabwe, use this free access opportunity. However, most ethanol imports come from Brazil and Pakistan under the ordinary European GSP without any preference for either since 2006. Concerning European biofuel exports, the EU has a preferential access for ethanol in Norway through tariff-rate quotas (i.e. 164 thousand hectolitres for the code 220710 and 14.34 thousand hectolitres for 220720).

Trade liberalisation for biofuels is a contentious issue in the multilateral negotiation of the Doha Round (being relevant both to discussions on agricultural trade liberalisation and trade and environment) as well as in the bi-lateral negotiations between the EU and the Mercosur countries. Clearly key countries, products and interests are common to both.

Brazilian Biofuel Policies

Ethanol policies have been implemented in Brazil since the mid-70s and today blending obligations for ethanol are up to 20-25% for gasoline. More recently, Brazil has introduced biodiesel blending targets of 2% in 2008 and 5% in 2013, similar to the EU's.

In order to reach these obligations, Brazilian federal and state governments grant tax reductions/exemptions. The level of advantage varies on the basis of the size of the agro-producers and the level of development of each Brazilian region.

The Common External Tariff (CET) of Mercosur also protects domestic biofuel production, with ethanol duties of 20% and biodiesel 14%. These tariffs could be eliminated or significantly reduced under the Doha and/or the EU-Mercosur negotiations. Furthermore, no non-tariff barriers constrain Brazilian imports of biofuels (e.g. no TRQ on biofuels in Mercosur).

Another important explanatory factor in the growth of the ethanol sector in Brazil is the role of foreign investment. Most recent investments come from Europe and the United States. They not only concern distillation plants but also sugar cane production. The competitive prices of raw materials and the high level of integration in the process explain the lower costs for ethanol production in Brazil and the motivation of the foreign investors.

US Biofuel Policies

In the USA, as in Brazil, Biofuels policies date back to the 70s. However they are as complex as those of the EU because fiscal incentives and mandates vary from one state to another and differ from federal ones. The Energy Tax Act of 1978 introduces tax exemption and subsidies for the blending of ethanol in gasoline. In contrast, biodiesel subsides are more recent, they were introduced in 1998 with the Conservation Reauthorization Act.

Concerning mandates on biofuels consumption, they were instigated by the Energy Policy Act of 2005 at the federal level, although obligations for biofuel use existed at the state level (e.g. Minnesota introduced a mandate on biofuels before the federal government, which it increased to 20% in 2013). This 2005 Act sets the objective of the purchasing of 4 billion gallons of biofuels in 2006 and 7.5 billion gallons in 2012.

The current biofuels policies in the USA consist of three main tools output-linked measures, support for input factors and consumption subsidies. Tariffs and mandates benefit biofuels producers through price support. Tariffs on ethanol (24% in equivalent ad valorem) are higher than biodiesel (1% in equivalent ad valorem) which limit imports especially from Brazil. Moreover, producers benefit from tax credits based on biofuels blend into fuels. The Volumetric Ethanol Excise Tax Credit (VEETC) and the Volumetric Biodiesel Excise Tax Credit (VBETC) provide the single largest subsidies to biofuels, although there are additional subsidies linked to biofuel outputs.[32]

Investments in biofuels also receive financial support from the government, as a kind of capital subsidies. Support is also provided for labor and land used in biofuel production in some states (e.g. Washington). Input subsidies are another important element in biofuel support in the USA. US ethanol production overwhelmingly uses corn which is one of the most heavily subsidized crops in the country. In contrast, soybeans, which are the main feedstock used for biodiesel production in the USA, are not very subsidized in the USA, which means that prices are not inflated and production is less attractive for farmers. Finally, indirect biofuel consumption is also supported by the federal

[32] E.g. a federal small producer tax credit - equivalent to a 10% tax credit per gallon on the first 15 million gallons produced -, blenders' credits, supplier tax refunds and other subsidies at the state level

government through investment in infrastructure for transport, storage and distribution (Koplow, 2006; Koplow, 2007).

Modeling Biofuel Policies

In order to calibrate the model and to run the different simulation scenarios for the European biofuel policies, we need to build a “policy” data set and to identify some technical requirements to be incorporated into the model.

Obligations in Substitution Requirements for Biofuels

The EU members are required to report to the Commission on their implementation of biofuel policies. Considering the development disparities, the implementation of these policies is largely developed in larger countries such as France, Germany or Austria and not in small countries such as Malta and Cyprus. However, the EU mandate for the share of biofuel in fossil fuel according to their energy content is compulsory for all countries. Only 5 of 27 EU members have reached the 5% target for 2005. One year later this number had doubled and today it shows a positive trend.

Using the national reports to the European Commission relating each country’s biofuel policies, we have built a new database that contains the real percentage of biofuels in fuels according to their energy content (from 2003 to 2006) and the national and European targets for the years up to 2020. For a better use of this database, we differentiate between biodiesel and ethanol with details of how much these percentages in energy content terms represent in percentage of the final product (by volume), in order to have better information for the model calibration.

Table 20 shows detailed information about the past application of the biofuels mandates for the European Union since 2003 and the prospective application and targets up to 2020.

Table 20 Biofuel Use and Mandates in the European countries (% of energy content)

Countries	GTAP Consumption weight	2003	2004	2005		2006	2007	2008	2009	2010		2020	
				use	EU target					use (*)	EU target	use (*)	EU mandate
Austria	0,015	0,06	1,28	2,5	2	2,5	4,3	5,75	5,75	5,75	5,75	10	10
Belgium	0,028	0	1	2	2	2,75	3,5	4,25	5	5,75	5,75	10	10
Bulgaria	0,003	0	0	0	2	0	0	0	0	0	5,75	0	10
Cyprus	0,001	0	0,5	1	2	1	1	2	2	2	5,75	10	10
Czeck Republic	0,012	1,12	2,41	3,7	2	1,78	1,63	2,45	2,71	3,27	5,75	10	10
Germany	0,2	1,18	2,54	3,9	2	2	5,75	7,15	7,88	8,6	5,75	10	10
Danemark	0,009	0,17	0,24	0,27	2	0,39	1,73	3,07	4,41	5,75	5,75	10	10
Spain	0,079	0,76	1,38	2	2	3,34	4,62	6	7,26	8,66	5,75	10	10
Estonia	0,001	0	0,1	0,2	2	2	2,13	2,25	2,38	2,5	5,75	10	10
Finland	0,005	0,1	0,1	0,1	2	1,75	3,37	5,05	6,63	8,35	5,75	10	10
France	0,176	0,68	1,34	2	2	1,75	3,5	5,75	6,25	7	5,75	10	10
Great Britain	0,16	0,03	0,3	0,3	2	0,73	1,15	2	2,8	3,5	5,75	10	10
Greece	0,012	0	0,35	0,7	2	2,5	3	4	5	5,75	5,75	10	10
Hungary	0,012	0	0,4	0,6	2	1,63	2,66	3,69	4,72	5,75	5,75	10	10
Ireland	0,006	0	0,03	0,06	2	1,14	1,75	2,24	4,18	6,12	5,75	10	10
Italy	0,129	0,5	0,75	1	2	2	2	3	4	5	5,75	10	10
Lituania	0,002	0	1	2	2	2,75	3,5	4,25	5	5,75	5,75	10	10
Luxembourg	0,002	0	0	0	2	2,75	2,75	2,75	2,75	5,75	5,75	10	10
Latvia	0,002	0,21	1,11	2	2	2,75	3,5	4,25	5	5,75	5,75	10	10
Malta	0	0	0,15	0,3	2	1,92	3,5	5,15	6,7	8,38	5,75	10	10
Netherdlands	0,027	0,03	1,02	2	2	2	2	2,94	3,88	5,75	5,75	10	10
Poland	0,03	0,49	0,5	0,5	2	1,5	2,3	3,16	4,03	5,75	5,75	10	10
Portugal	0,022	0	1	2	2	2	3	5,75	5,75	5,75	5,75	10	10
Romania	0,006	0	0	0	2	0	0	0	0	0	5,75	0	10
Slovakia	0,006	0,14	1,07	2	2	2,5	3,2	4	4,9	5,75	5,75	10	10
Slovenia	0,003	0	0	0	2	1,2	2	3	4	5	5,75	10	10
Sweden	0,019	1,33	2,17	3	2	3,55	4,1	4,65	5,2	5,75	5,75	10	10
EU27		0,54	1,2	1,81	2	1,8	3,18	4,47	5,21	6,05	5,75	9,59	10

Source: Source: Cepii's calculations based on European Commission - National Reports

Notes: (*) calculated based on national targets and mandates

National incorporation rates will need to be aggregated at the EU27 level in order to be used with the model aggregation, first in the baseline up to 2007 and then in scenarios up to 2020.

In the baseline scenario, we also need to take into account the mandates for biofuel blending in other important countries, such as Brazil and the United States. According to the IEA databases and ACG (2005), Brazilian bio-ethanol consumption ratio between 2005 and 2010 should increase and, according to the forecast, lead to about a 40% increase in production. Today Brazil blends between 20-25% of bio-ethanol with gasoline. Since 2005, the Brazilian government has been trying to repeat their ethanol policy with biodiesel and new mandatory targets for biodiesel blending have been set for 2008, increasing up to 2013 (see Table 21). For the United States, some mandatory incorporation has also been ruled out.

Table 21. Current official targets on share of biofuel in total road-fuel consumption

Countries	Official Targets	Year	Products
India	5%	In near future	Biofuels
Japan	500 million litres	2010	
China	15%	2020	total renewable fuels
Thailand	2%	2010	Biofuels
Brazil	20-25%	2006	Ethanol
	40% increase in production	2005-2010	Ethanol
	2%	2008	biodiesel
	5%	2013	biodiesel
Indonesia	2% of total fuels	2010	biodiesel (palm oil)
	5% of total fuels	2025	biodiesel (palm oil)
Malaysia	5%	In near future	biodiesel (palm oil)
USA	2.78%	2006	Ethanol
Canada	3.5%	2010	Ethanol

Source: IEA database; ACG (2005); USDA Brazil report (2007); IFQC Biofuels Center (2006).

The modeling of the mandates requires firstly splitting the petroleum and coal product sector (p_c) from the GTAP database into the petroleum and coal sectors (p_c_fuels and p_c_others). This aspect was essential to introducing the consumption obligations for fuels in the transport sector.

Secondly, even if the biofuel demand without mandate is calibrated assuming a CES function, the introduction of the mandate implies removing substitution possibilities and using a Leontief structure. As a consequence, for our different mandate scenarios, we will impose fixed shares between each biofuel and fossil-fuels. Moreover, we interpret the blending requirement for each biofuel in a different way, which means that the mandate is global but rather there is a specific mandate modeling by biofuel type.

Tax Incentives for Biofuels

The implementation of biofuel consumption mandates is coupled with other support measures. Each European country can chose their policy tools independently in order to facilitate and encourage biofuel consumption. More specifically, each European member state can grant tax reductions/exemptions on biofuel production or consumption in order to reach the European mandatory consumption target. However, there is no prescription for implementing these tax incentives (e.g. type of biofuels, blending level, taxes, investment grants, etc.), and each member state can design its own policy in line with its tax system and the national context. This discretionary implementation of tax incentives makes it harder to represent the total biofuel support at the European level.

National reports of each Member State detail national taxes/subsidies support at the production and consumption level and these can be used to build a database for implementing the baseline and different scenarios in our model. Once the EU database on different biofuels support measures was completed, we calculated an equivalent ad valorem tax/subsidy on consumption, to get an estimate of the effect of support measures at the European level.

Table 22. Diesel and Biodiesel excise taxes in the European Union ($/liter).

	GTAP Consumption weight	Diesel tax 2004 dollar/liter			Biodiesel tax exemption 2004 dollar/liter			Biodiesel tax 2004 dollar/liter		
		2005	2006	2007	2005	2006	2007	2005	2006	2007
AUT	0,015	0,371	0,368	0,368	0,397	0,409	0,403	-0,025	-0,041	-0,035
BEL	0,028	0,407	0,423	0,407	0,000	0,459	0,202	0,407	-0,036	0,204
BGR	0,003									
CYP	0,001									
CZE	0,012	0,411	0,435	0,435	0,384	0,409	0,411	0,027	0,026	0,025
DEU	0,200	0,583	0,583	0,583	0,583	0,508	0,000	0,000	0,074	0,583
DNK	0,009	0,502	0,501	0,501	0,037	0,434	0,440	0,464	0,067	0,061
ESP	0,079	0,365	0,365	0,374	0,335	0,335	0,335	0,030	0,030	0,040
EST	0,001									
FIN	0,005	0,396	0,396	0,396	0,000	0,000	0,396	0,396	0,396	0,000
FRA	0,176	0,517	0,517	0,531	0,409	0,409	0,310	0,108	0,108	0,221
GBR	0,160	0,304	0,304	0,342	0,000	0,000	0,322	0,304	0,304	0,020
GRC	0,012	0,859	0,857	0,879	0,397	0,360	0,358	0,462	0,497	0,521
HUN	0,012	0,409	0,399	0,399	0,422	0,422	0,422	-0,012	-0,022	-0,022
IRL	0,006	0,456	0,456	0,456	0,459	0,459	0,456	-0,002	-0,002	0,000
ITA	0,129	0,506	0,512	0,516	0,471	0,512	0,474	0,035	0,000	0,042
LTU	0,002									
LUX	0,002	0,339	0,345	0,360	0,057	0,062	0,000	0,281	0,283	0,360
LVA	0,002									
MLT	0,000									
NLD	0,027	0,453	0,453	0,460	0,000	0,384	0,378	0,453	0,068	0,082
POL	0,030	0,320	0,362	0,363	0,000	0,310	0,322	0,320	0,052	0,041
PRT	0,022	0,386	0,389	0,451	0,000	0,000	0,000	0,386	0,389	0,451
ROM	0,006									
SKV	0,006	0,466	0,482	0,482	0,434	0,434	0,476	0,032	0,048	0,006
SLK	0,003									
SWE	0,019	0,472	0,491	0,498	0,459	0,484	0,484	0,013	0,007	0,015
EU27		0,439	0,442	0,454	0,311	0,338	0,260	0,128	0,105	0,193

Source: CEPII's calculations based on European Environment Agency, OECD (for diesel tax) and Biofuels at what cost? EU, IISD (for biofuels tax exemptions).

Table 23. Gasoline and Ethanol excise taxes in the European Union ($/liter).

	GTAP Consumption weight	Gasoline tax 2004 dollar/liter			Ethanol tax exemption 2004 dollar/liter			Ethanol tax 2004 dollar/liter		
		2005	2006	2007	2005	2006	2007	2005	2006	2007
AUT	0,015	0,517	0,517	0,517	0,533	0,533	0,552	-0,016	-0,016	-0,035
BEL	0,028	0,682	0,734	0,734	0,000	0,732	0,438	0,682	0,002	0,296
BGR	0,003									
CYP	0,001									
CZE	0,012	0,489	0,518	0,518	0,372	0,037	0,037	0,117	0,481	0,481
DEU	0,200	0,812	0,812	0,812	0,806	0,806	0,123	0,006	0,006	0,690
DNK	0,009	0,672	0,677	0,677	0,347	0,347	0,000	0,325	0,330	0,677
ESP	0,079	0,491	0,491	0,491	0,459	0,459	0,461	0,032	0,032	0,030
EST	0,001									
FIN	0,005	0,729	0,729	0,729	0,000	0,000	0,000	0,729	0,729	0,729
FRA	0,176	0,730	0,730	0,753	0,471	0,471	0,409	0,259	0,259	0,343
GBR	0,160	0,367	0,367	0,410	0,000	0,000	0,000	0,367	0,367	0,410
GRC	0,012	0,859	0,857	0,879	0,347	0,347	0,358	0,512	0,510	0,521
HUN	0,012	0,498	0,486	0,486	0,508	0,508	0,513	-0,011	-0,022	-0,027
IRL	0,006	0,549	0,549	0,549	0,546	0,546	0,549	0,004	0,004	0,000
ITA	0,129	0,686	0,699	0,699	0,000	0,000	0,000	0,686	0,699	0,699
LTU	0,002									
LUX	0,002	0,548	0,548	0,573	0,097	0,099	0,000	0,451	0,449	0,573
LVA	0,002									
MLT	0,000									
NLD	0,027	0,826	0,828	0,842	0,000	0,620	0,626	0,826	0,208	0,216
POL	0,030	0,429	0,444	0,525	0,000	0,459	0,484	0,429	-0,015	0,041
PRT	0,022	0,670	0,692	0,723	0,000	0,000	0,000	0,670	0,692	0,723
ROM	0,006									
SKV	0,006	0,498	0,516	0,516	0,459	0,459	0,461	0,039	0,057	0,055
SLK	0,003									
SWE	0,019	0,660	0,668	0,678	0,682	0,682	0,657	-0,022	-0,014	0,021
EU27		0,605	0,610	0,625	0,325	0,372	0,214	0,280	0,238	0,411

Source: CEPII's calculations based on European Environment Agency, OECD (for fuel tax) and Biofuels at what cost? EU, IISD (for biofuels tax exemptions).

In the European Union other incentives do exist, but since excise tax exemption represents more than 60% of biofuel fiscal policy incentive we will run our scenarios based on this consumption tax/subsidy.

In the case of Brazil, there are many different consumption and production incentives. Production incentives for oilseed production include tax reductions and exemptions, especially federal taxes whose reduction level depends on the agriculture type and on the production regions (e.g. only subsistence agriculture from the North are exempted from federal taxes, while large agricultural producers from the South only benefit from a 32% tax reduction). Each biofuel project also benefits from loan assistance and there are also some tax reductions at the industrial level. Brazilian states also apply different tax incentives on consumption (e.g. 12% tax for biofuels and between 12-17% for fossil-fuels). There are also price control policies for biofuels as well as other policies to motivate the use of flex-fuel vehicles. Since it is important to introduce Brazilian supports into the baseline, it will be necessary to have a national measure taking into account these differences across states.

Agricultural Policy

Since the 2003 CAP reform, decoupled policies have been applied to EU energy crops without any loss of income and without the initial restrictions due to set-aside obligations. Moreover, the production of energy crops benefits from a premium of €45 / hectare with a maximum of 1.5 million hectares. Biofuels production in the European Union is also encouraged by the special provision included in the CAP for agricultural inputs.

Concerning sugar beet for ethanol production, the CAP exempts this part of the supply from production quotas. This last policy is part of the last Common Market Organisation sugar reform.

Production quota exemptions for sugar and premiums on energy crops have to be taken into account in modeling EU biofuel support. The sectoral split between energy crops and food crops could be important to implementing these policies.

Focus on some Biofuels policies considered in the Baseline scenario

For the baseline scenario we introduce the current biofuel policies in the EU27, the USA and Brazil into the model. These countries mandate a target blend ratio for the percentage of biofuels, which should be incorporated into fossil fuels. In order to reach their objectives these countries simultaneously implement various fiscal aids and grants, which are incorporated into the model.

In the EU27, policy in this area is decided at Member State level. Biofuel blend targets are therefore compulsory for some countries, but not all. Today, only nine of the twenty-seven European countries have set a mandatory requirement for biofuel blend ratios. They couple these obligations with fiscal incentives, which also vary from one country to another. Most of them involve total or partial reductions in excise-tax on biofuel blended transport fuels or tax-free biofuel quotas. Others also include output or input subsidies, the latter supported by the Common Agricultural Policy (CAP). Finally, there are some countries that provide investment grants to biofuel development projects, such as flex-fuels cars or biofuel distribution infrastructure.

The heterogeneity in the European biofuels' policy makes it difficult to simulate scenarios at the EU level. For that reason we have introduced some assumptions into the simulations. In the case of the baseline scenario, we have introduced the EU targets for biofuel use (at least 2% in 2005 and 3.3% in

2008). At the country level, some countries, but by no means all, have reached the 2005 target. We construct our baseline scenario for the level of biofuels blending with fossil fuels on the basis of the mean (consumption weighted) development in blending shares at the EU27 level.

We modeled the excise-tax reduction by calculating the mean (consumption weighted) values for each year since 2004 at the EU27 level. For instance, in 2004 the average excise-tax credit was $0.578 per liter of biodiesel and $0.634 per liter of ethanol. In 2007 the tax credit for biodiesel was slightly lower ($0.544 per liter) while that for ethanol was slightly higher ($0.649 per liter) (Kutas et. al, 2007). For model calibration and for the baseline scenario we use the tax excise credit data from the existing literature because the values are very incomplete for the moment and in addition they are lower than those in other key papers. Although, as indicated above, there are several other more marginal policy measures which impact on the biofuel market and which could have been considered (energy crop payment, set-aside payment and market price support), we only model the excise-tax credit because it represent more than 60% of the total effective support for biofuels provided in the EU. The CAP is also modeled, but without taking into account certain detailed policies related to biofuels (e.g. the “no production quota” for sugar beet). Other key policies including biofuel trade protection are also considered and the mandate mechanism is explicitly modeled.

In the USA, both a federal mandate and state-level targets or mandates for biofuel blends exist. The federal objective is that 15.2 billion liters (equivalent to 2.78% of gasoline consumption) should be consumed in 2006 and 28.4 billion liters (equivalent to 5.2%) by 2012. At state level, these objectives may vary. For instance, Iowa State has set a target of 10% by 2009 and 25% by 2020. This is one of the highest targets in the USA, where targets do not generally exceed 20%. According to AgraFNP(2008) the ethanol industry is lobbying for a higher level of blending - up to 12 or 13%. However, so far levels have remained lower, so we only introduce a mandate of 10% for biofuel blending in the baseline.

Subsidies are an important policy tool. Since 2004 the federal and state governments replaced fuel-tax exemption for biofuels with volumetric subsidies or/and consumption mandates. At the federal level the volumetric excise-tax credit for ethanol is $0.135 per liter and for biodiesel it is $0.264[33]. Direct production subsidies are also significant. There is a federal small producer tax credit of $0.026 per liter and subsidies to support biofuel production of $0.05 per liter provided at the state level. Although there are other indirect support measures related to agricultural inputs or capital grants,

[33] Volumetric biodiesel excise-tax credit distinguishes two different products and thus subsidies: biodiesel derived from waste oil, which benefits from 0.132 US dollar per liter and biodiesel derived from agricultural fats and oils which receives 0.264 US dollars per liter. In our baseline scenario, we assume the second case since we do not have detailed information to model second generation biofuels.

we only consider the above policies support in the baseline scenario, since they together represent more than 65% of total biofuels support in the USA (Koplow, 2006; Koplow, 2007).

The third country we consider in the baseline is Brazil, where we also introduce detailed information about mandates and fiscal aids in the model. Historically Brazil has imposed a mandate for ethanol consumption, which presently varies between 20 and 25% depending on the ethanol price. The government officially launched the Biodiesel Program in 2004 and in 2005 the new law (LEI N°11097) authorized the voluntary blending of biodiesel with petrol diesel for the first 3 years, moving towards a mandatory target of 2% for biodiesel blending by 2008 and 5% by 2013 (Methanol Institute et. al, 2006).

Mandates in Brazil are therefore differentiated by biofuel type although our modeling does not include this distinction. In our baseline scenario however, we take the Brazilian ethanol mandate as representing the biofuel mandate. This is a realistic simplification given the predominance of ethanol (in the matrix, the biodiesel sector is currently almost nonexistent in Brazil). In modeling the fiscal support to biofuels, the excise tax reduction is the most significant element. For ethanol the excise tax levied is 67% lower than that applied to gasoline. Decomposing the ethanol excise tax credit by source we find that, in 2007, the federal element was $0.135 per liter and the Sao Paulo state part $0.224 per liter. The excise tax reduction for biodiesel was fairly stable over the 2004-2007 period. Initially it was $0.0973 per liter while at the time of writing it has increased slightly to $0.0992 per liter. Other tax exemptions linked to the type of feedstock and the feedstock origin also exist, but they are minor compared to the excise-tax credit (Jank et.al, 2007; FAO, 2008b).

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