Assessing the Land Use Change Consequences of European Biofuel Policies

Final Report

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This report has been prepared by:

David Laborde (IFPRI)

ATLASS Consortium

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Table of Contents

LIST of TABLES

LIST of FIGURES

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
CHP	Combined Heat and Power [plant]
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
LUC	Land Use Change
LES	Linear Expenditure System
LHV	Low Heating Value
MFN	Most Favored Nation
MIRAGE	Modeling International Relationships in Applied General Equilibrium
MIRAGE-Biof	Modeling International Relationships in Applied General Equilibrium for Biofuel analysis
MJ	Megajoule
MToe	Million Tons of Oil Equivalent
N2O	Nitrous Oxide
NREAPs	National Renewable Energy Action Plans
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
TJ	Terajoule
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 ton 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 ton/m3)

Biodiesel

1 m3 de biodiesel = 0,78 tep

Metric ton 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 tones/m3)

Vegetable oil density = 0.89 kg/l

Executive Summary

Background

On 23 April 2009, the European Union adopted the Renewable Energy Directive (RED) which included a 10 percent 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 percent in 2009 and rising to 50 percent 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 transport fuels consumed in the EU by 6 percent 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.

The Commission launched four studies in 2009 to examine ILUC issues, including a first general equilibrium modeling study that aimed to analyse the impact of the EU biofuels mandate, and 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. That report was published in March 2010[1] (Al-Riffai, Dimaranan and Laborde, “Global Trade and Environmental Impact Study of the EU Biofuels Mandate”). It showed that indirect land use changes were a valid concern, but that the degree of uncertainty regarding their magnitude was large. Since then, this study has been widely cited and commented on in discussions with stakeholders and civil society on EU biofuels policy. Numerous suggestions for improvements in the study were received. Research on biofuels modeling also continued and made progress since then. In order to feed this new information and insights into the Commission's impact assessment on the land use change effects of biofuels, and into the report to the Parliament and Council, the European Commission requested IFPRI to carry out the present updated study.

The new study

This new study contains several important changes compared to the previous report. It uses an updated version of the global computable general equilibrium model (CGE), MIRAGE-Biof, as well as a revised scenario describing the EU mandate based on the National Renewable Energy Action Plans of the 27 member states. In addition, a stronger focus has been placed on specific feedstock Land Use Change (LUC) computation and the uncertainties surrounding these values. Systematic sensitivity analysis is used to measure the potential range of LUC coefficients. In the

[1] http://ec.europa.eu/trade/analysis/chief-economist/

absence of empirical evidence on the impact of the direct land use change criteria in the RED this report revolves around total LUC, comprising both direct and indirect changes, instead of the narrower concept of indirect LUC only. There is a lack of data on the impact of the direct greenhouse gas savings thresholds on biofuel markets and LUC. However, the direct savings thresholds will ensure that all biofuels used in the EU in 2020 have at least 50 percent direct greenhouse gas emissions savings. We evaluate the impact of the EU mandate in accordance with the implementation scenarios in the National Renewable Energy Action Plans (NREAPs) of the 27 Member States. In the mandate scenario, we introduce a biofuels policy shock that assumes that the EU will consume 27.2 Mtoe of first generation land-using ethanol and biodiesel by 2020, involving an additional consumption – called additional mandate in this report – of 15.5 Mtoe. Total biofuel consumption reaches 8.6 percent of the mandated target of 10 percent renewable energy in road transport fuels. The remaining is expected to come from other types of renewable energy including waste products. The action plans forecast that 72 percent of this will be biodiesel and 28 percent ethanol (expressed in energy content). We analyze the effects of the implementation of the EU biofuels additional mandate under two different trade policy scenarios: i) A status quo trade policy scenario that leaves all currently existing import tariffs on biofuels unchanged in 2020 and ii) a free trade scenario that eliminates all tariffs on all biofuel imports, except for the contingent anti-dumping levy on biodiesel imports from the US.

The most important change compared to the previous study (Al Riffai and al, 2010) is the definition of the scenario considered (size of the mandate, ratio biodiesel/ethanol). Several other modifications have been done involving the treatment of co-products (higher substitution), the peatland emissions (higher factor), the land reallocation among crops (better calibration) and the dynamics of food demand (less elastic).

Overall findings

Overall, EU biofuel production will increase from 10.1 Mtoe in the baseline to 20.9 Mtoe without trade liberalization and 17.8 Mtoe with trade liberalization. First, since the way in which Member States intend to implement the EU mandate is expected to result in an increase in the relative consumption of ethanol to biodiesel (from 17/83 in 2008 to 28/72 in 2020), the scenario under the trade policy status quo reinforces local production of ethanol. Under trade liberalization, EU ethanol production declines, with sugar beet- and wheat-based ethanol most affected. As a result, local production capacity and feedstock production are dominated by biodiesel production. With trade liberalization, biodiesel represents 92.5 percent of total EU biofuel production.

The report confirms that the extent to which additional demand for biofuels will be met by an increase in supply depends on the feedstock crop. For example, for sugar the additional supply will nearly match the additional demand; for soybean oil and rapeseed oil, this matching is partial, while for wheat, we expect a decrease in the absolute level of supply due to land competition from oilseeds when we assess the additional mandate. The latter case is explained by a stronger price increase for oilseeds and therefore for the land rents for this product compared to wheat (the substitution effects among crops dominating the direct demand increase for wheat). The analysis also shows an increase in price for the biofuels crops, especially for oilseed, due to the strong biodiesel component in the mandate. EU biofuels policy causes the relative prices to change and therefore relocates production. It provides a premium to fats and oils at the expense of other production for which relative value declines.

In terms of trade effects of the EU additional mandate, EU import of rapeseed increases strongly (+ 6 million of tons). Imports of palm oil, and soybean (both oil and beans) also increase but to a much lower extent (+4.6 million of tons). Without trade liberalization, imports of wheat (+0.47 million of tons) and corn (+1.6 million of tons) increase due to greater domestic demand in the EU for ethanol. This ceases to be the case when trade liberalization is implemented. This scenario instead leads to higher sugar cane ethanol imports (+ 6.7 Mtoe). In addition, liberalization helps to release part of the feedstock used in the baseline for ethanol production. As a result, there is a decrease in maize imports.

Land use effects are of course at the center of this study. For ethanol, the effects differ depending on the trade policy scenario. Without any trade liberalization, the EU experiences land area extension for the production of sugar beets, while under trade liberalization, the EU can grow more rapeseed, taking land away from sugar beet and cereals. Globally, the additional biofuels mandate leads to an increase in cropland area by 1.73 million hectares without trade liberalization and by 1.87 million hectares with trade liberalization. The most affected regions are Latin America (primarily Brazil), CIS, and Sub Saharan Africa, while the cropland extension remains under 6 percent in the EU regardless of the trade policy scenario. Under trade liberalization, Brazil experiences the highest increase in terms of cropland, mainly due to the increase in demand for imported ethanol and thus for sugar cane. If free trade is not implemented, the CIS block benefits the most due to biodiesel demand and the role of sunflower (and also wheat relocation). Pasture and managed forest represent the two major sources of cropland extension, followed by savannah and grasslands and finally primary forest. It is worth noting that 80 percent of the land use change takes place within managed land.

Emission effects

LUC emissions induced by the additional EU biofuels mandate are estimated at 38 grams of CO2 equivalent per MJ of biofuels in the scenario without trade liberalization (40 g/MJ with trade liberalization). The difference between these two figures is explained by a slightly larger amount of land needed under free trade. Total amount of emissions vary between 495 and 516 million ton of CO2.

When estimated LUC emissions are compared with emission savings in biofuels production compatible with the RED target for all production, net emission savings can be computed (table ES1). Overall, land use emissions for the entire EU biofuels additional mandate eliminate more than two-thirds of the direct emission savings when we apply the direct savings coefficients of improved production technology expected in 2020.[2]

[2] We assume that all biofuels consumed in the EU in 2020 will meet the legal requirements of the RED threshold level of 50 percent direct savings. For palm oil this implies that the all palm oil consumed in the EU is produced with methane capture, which is the best available palm oil technology in the COWI-JRC direct savings estimations. See also table A15 in Annex VI.

Table ES1: Biofuels emissions and savings in 2020 (per MJ of biofuels)

	No change in trade regime			Free trade in biofuels		
	Direct savings (improved technology in 2020)	*LUC emissions*	*Net Savings*	*Direct savings (improved technology in 2020)*	*LUC emissions*	*Net Savings*
	in grams of CO2 equivalent					
Additional mandate	57	**38**	*19*	59	**40**	*19*
Bioethanol						
Wheat	57	**14**	*43*	57	**13**	*44*
Maize	58	**10**	*48*	58	**10**	*48*
Sugar Beet	63	**7**	*56*	63	**4**	*59*
Sugar Cane	70	**13**	*57*	70	**17**	*53*
Biodiesel						
Palm Fruit	58	**54**	*4*	58	**55**	*3*
Soybean	45	**56**	*-11*	45	**57**	*-12*
Sunflower	58	**52**	*6*	58	**53**	*5*
Rapeseed	50	**54**	*-4*	50	**55**	*-5*
	In percentage of GHG savings (with a 90.3 grCO2eq/MJ reference for fossil fuel)					
Additional mandate	63	**42**	*21*	65	**44**	*21*
Bioethanol						
Wheat	63	**16**	*47*	63	**14**	*49*
Maize	64	**11**	*53*	64	**11**	*53*
Sugar Beet	70	**8**	*62*	70	**4**	*66*
Sugar Cane	78	**14**	*64*	78	**19**	*59*
Biodiesel						
Palm Fruit*	64	**60**	*4*	64	**61**	*3*
Soybean	50	**62**	*-12*	50	**63**	*-13*
Sunflower	64	**58**	*6*	64	**59**	*5*
Rapeseed	55	**60**	*-5*	55	**61**	*-6*

Source: Mirage-Biof Simulations, JRC-COWI and EC Impact Assessment for direct savings values.

Note: Direct savings values are explained in Appendix VI. For wheat, it implies the full adoption of "natural gas as process fuel in CHP plant" pathway and for palm oil the "*methane capture at mill*" technology. In the case of soybean, the minimal threshold of 50 percent is assumed even if no pathway reaches this value yet.

It should be born in mind that these results are obtained without any explicit modeling of the impact of the sustainability criteria in the RED but just assuming that all the additional biofuel production achieved at least a 50 percent direct saving threshold. Assuming full substitution in land markets between areas devoted to provide feedstocks for EU biofuels consumption and other uses may well result in an overestimation of the LUC effects of biofuels, though the extent of overestimation can not be quantified in the absence of any empirical evidence on the degree of market segmentation or substitution. On the other hand, the study excludes some other sources of emissions in the estimations. For example emissions from additional fertilizers or the overall emission leakage effect through the oil price channel are not accounted for, nor are the emissions consequences of the price-effects of the blending obligations on fuel prices.

Emission leakage occurs when the introduction of biofuels in the EU results in a reduction in fossil fuel consumption which, in turn, reduces world demand for oil and oil prices; that leads to additional oil consumption in other countries, and additional emissions that partly off-set the savings realized in the EU. Similarly; higher fuel prices are due to the implementation of the blending mandates in the EU and thereby reduce oil consumption in the EU. Neither of these effects is included in our emission computations.

The trade liberalization scenario raises the level of CO2 emissions from LUC but also increases the share of sugar cane ethanol in EU biofuels consumption, with higher direct CO2 savings. On balance, trade liberalization is neutral on the emission reduction effects of the EU biofuels additional mandate. It will also reduce the cost of implementing the additional mandate since imported ethanol will be less expensive than domestic production. Combined effects will lead to a more efficient outcome for each ton of CO2 saved.

In terms of sources of CO2 emissions, peatland emissions represent one-third of total emissions, given the share of biodiesel and vegetable oils in the EU additional mandate. Peatland is associated with palm oil production in tropical countries. Palm oil plays an important role as a biodiesel feedstock and/or as a replacement for vegetable oils displaced from other uses.

At the feedstock level, we find that all ethanol feedstocks have a much lower LUC emission than biodiesel feedstocks. In our main scenario, and without considering uncertainty regarding direct savings value, net emissions reduction over 20 years are only achieved by ethanol crops, and at a lower level by sunflower and palm oil for biodiesel. Nevertheless, due to the uncertainties regarding the LUC factor discussed in the following paragraphs (see table ES2) and additional uncertainties regarding effective direct savings in the future – in particular if stronger emission threshold are not enforced, i,e, at least 60 percent for some feedstocks – the precise ranking among crops and the statistical significance of having net emission savings has to be considered with many precautions.

In terms of specific crops for bioethanol, sugar beet has the lowest land use emission coefficients, whereas sugar cane has the highest, but in terms of net emissions, sugar cane remains the best feedstock. The case of sugar cane is noteworthy. While LUC effects are moderate, the net effects are very favorable for this feedstock since sugar cane processing technology is the most efficient in terms of energy use and thus in direct emission savings. It produces electricity as a co-product of ethanol production and thereby saves CO2 not through the land market, but directly through the energy market. Among vegetable oil, sunflower appears to be the best feedstock in terms of LUC emissions, compared to soybean, which has the highest LUC emission coefficient – although differences among oilseeds are very small. Sunflower and palm oil are also the only biodiesel feedstocks that generate (small) net emission savings for biodiesel (4 to 6 grCO2eq/MJ, less than 6 percent of the fossil fuel comparator).

Three mechanisms explain the large differences in LUC effects among crops. First, the extent to which additional demand for biofuels leads to an increase in supply of the related feedstock plays an important role. Demand for cereals feedstocks (maize, wheat) is to a large extent met by displacement from other uses of cereals and therefore does not need to be completely replaced. Consequently, it will not require much additional land. Sugar crops on the other hand do not have much margin for demand displacement from other uses and therefore need to be nearly completely replaced, which leads to higher LUC effects in the case of sugarcane. Vegetable oils are an in-between category that does not lead to demand replacement by their own kind but by other vegetable oils, leading to large leakage effects on LUC and no true "savings". Second, where displacement of demand is limited and additional supply is needed, intensification of production per unit of land could be a solution. However, it appears that land intensification does not lead to large yield increases in the simulation model. Consequently, more extensive land use is the main source of increased supply (between 66 for wheat and 90 percent for peatland for the crop specific scenario with trade policy status quo). Third, co-products and the displacement in consumption of feedstocks for livestock play a key role as well.

Sensitivity analysis

This report is based on model projections that estimate the impact of the current EU biofuels policy in 2020. Such projections are inevitably subject to uncertainties related to the parameters in the model, to the database that provides the starting point for the projections and to possible changes in factors external to the model.

To overcome the uncertainties with regard to empirical estimates of key parameters, this study includes an elaborate sensitivity analysis on seven parameters that have the most important effects on the supply side of the model, using 1000 rounds of Monte Carlo simulations. It shows that the range of uncertainty on the overall LUC emissions is significant: with values ranging from 24 (5th percentile) to 50 grCO2eq/MJ (95th percentile) and a mean of 38.4 grCO2eq/MJ.

Table ES2: Results of sensitivity analysis on selected model parameters

	Distribution of LUC emissions (grCO2eq/MJ) for the Trade policy Status Quo scenario		
	5 percentile	Median	95 percentile
Additional Mandate	**24.4**	**38.8**	**50.4**
Wheat	8.3	13.8	18.4
Maize	6	10.1	13.2
Sugar Beet	0.8	7.2	12.6
Sugar Cane	6.5	15.4	26.5
Soybean	38.4	56.3	73.9
Sunflower	30.6	53.5	72
Rapeseed	28.2	54.9	80.7
Palm Fruit	47.1	54	60.3

Source: MIRAGE-Biof Simulations

Note that the sensitivity analysis does not cover the entire range of potential parameter values and does not investigate more extreme situations. For instance, assuming more rigid supply and very rigid demand (fixed consumption of food and feed, including that used for processing sectors), Laborde and Valin (2011) have shown that LUC emissions could reach 116 grCO2eq/MJ with a similar scenario. Last, this study does not investigate the uncertainty related to data or satellite parameters, i.e. without impact on economic behavior within the model, such as carbon stock per Ha or proportion of land type converted from pristine environment.

The LUC emissions gap between ethanol crops and biodiesel crops appears to be quite robust to a wide range of parameter values. For ethanol, the ranking among crops is not altered with the Monte Carlo analysis performed here. Maize and wheat display similar profiles and appear less uncertain than sugar beet and sugar cane. For biodiesel, the picture is slightly different, and the dispersion of the Monte Carlo distribution is quite large. These differences are explained by structural aspects of the production of feedstocks and the role of the geographical dispersion of land use changes. Trade liberalization has a limited impact on the distribution. Its effects are concentrated on ethanol crops, with large effects on sugar beet, sugar cane, and maize.

Uncertainty regarding cropland extension in the EU is very limited. EU capacity to intensify crop production (yield increase) or to free pasture land (livestock intensification) is limited overall, and altering the price sensitivity of key behaviors does not change this broad picture. The only crop for which EU cropland extension is a source of significant uncertainty is rapeseed. At the world level however, uncertainties are much stronger. Most of the uncertainty affecting the LUC of the EU biofuels policy takes place in the rest of the world. This is an important lesson since it implies that EU policymakers will have less control over the implementation of policies aiming to reduce this uncertainty.

The reduction of demand for feed or food plays a critical role in explaining the low LUC of key crops, particularly corn and wheat. This study tests the sensitivity of the LUC results for alternative demand assumptions in the human food market (fixed food consumption) and the animal feed market (no substitution between crops and co-products). The analysis suggests that, overall, the food consumption effect is the most important since it increases the LUC effect by 20 percent on average and by 15–20 percent for most oilseeds. For wheat, however, the effect of the livestock feed channel is as important as the human food channel. For this crop, the LUC effect increases by 40 percent compared to our central scenario. We also investigate the issue of non linearity i.e. the LUC coefficient is not constant regarding the scale of the biofuel demand. At the aggregate effect, the main effect is driven by the ratio ethanol/biodiesel in the additional mandate: compared to current situation, a smaller additional mandate with the average 72/28 mix will lead to a much larger share of ethanol in the additional biofuel consumption and a lower LUC. At the crop level, we also confirm the existence of non linearity: rapeseed LUC emissions are reduced by 8 percent if the additional mandate is halved. For sugar cane, a large shock like trade liberalization of EU ethanol market and the resulting doubling of imports of Brazilian ethanol leads to an increase of 30 percent in LUC emissions.

If this study has investigated uncertainties concerning the land use emissions, it has not analysed uncertainties regarding direct savings coefficients or potential uncertainty in the future CO_2 emissions by MJ of fossil fuel . Both factors are important to consider before drawing strong conclusions regarding the net emission balance.

Concluding remarks and policy issues

1. This report indicates that emissions related to land use changes driven by biofuel policies are a serious concern. This finding is robust as more than 99 percent of crop LUC coefficients in the Monte Carlo analysis are positive. The LUC effect reduces the environmental gains of the biofuel policy and should not be neglected. Biofuel policies may also be designed to achieve other goals (energy diversification, farm support, etc.) that are not considered in this analysis. However, in terms of environmental benefits, they may not be the best tool to achieve initial targets; therefore, careful assessment is needed.
2. Considering LUC effects for biofuel policies is legitimate since a key objective of such policies is emissions reduction. However, introducing a LUC component into biofuel legislation will lead to the question of why LUC measurements are not introduced for other policies that can have larger land use impacts (e.g. CAP reform, trade negotiations). Overall, mitigation strategy requests need to be consistent across a wide range of policies, and there is no a priori reason to think that biofuel production-related emissions are more adverse than those generated by other agricultural production. Taking a discriminatory approach to agricultural production based on its use will be inefficient and potentially unsustainable in both political and legal (e.g. WTO) ways;

3. A differentiated LUC emission coefficient by crop can be difficult to use since these factors are sensitive to leakages across different markets. Increasing the threshold of direct savings for all crops by the same factor (possibly with a differentiated factor for ethanol and biodiesel) may be easier to implement. By increasing the required energy saving targets, this will force firms to use the most efficient processing technologies and may also lead to a downward revision in the ambition of the mandate if it appears that not enough biofuel pathways qualify;
4. Despite all uncertainties, our findings show the hierarchy between ethanol and biodiesel in terms of LUC emissions. Therefore, promoting a larger share of ethanol than the current projection will be meaningful. Trade liberalization of the ethanol market appears to be an effective tool to achieve this.
5. Alternative trade policy options may be developed to promote good practices in terms of land conservation at a national level by trade partners. Crop specific sustainability criteria could be avoided in favor of a combination of tariffs, tariff quotas, and conditional unilateral preferences that will maintain existing trading interests but will limit adverse consequences of new demand;
6. Using available technologies to increase yield e.g. biotech, and low carbon agricultural practices may be an important solution to mitigate the emissions linked to land use changes by reducing the requirement of additional land;
7. Due to the level of uncertainty, monitoring capacities (land use patterns) and research have to be improved and a regular “health check” of biofuel policies should be implemented. The mandate policy should be flexible enough to allow for a redirection of the policy when new information is made available.

1 Introduction

In 2010, IFPRI completed the first assessment of the potential consequences of the EU biofuel mandate with a large focus on land use emissions (Al Riffai, Dimaranan, and Laborde, 2010)[3]. The assessment was commissioned by the Directorate General for Trade of the European Commission (DG TRADE) and showed that indirect land use changes (iLUC) were a real concern, but the degree of uncertainty about their magnitude was large. The report was one of four documents that fed into the EU public consultation on iLUC in 2010 and received numerous comments from stakeholders and requests for improvements (e.g. level of peatland emissions, role of co-products). In addition, the recent publication of the National Renewable Energy Action Plans (NREAPs) of the 27 member states provided a more accurate picture of the ongoing trend of biofuel policies in the EU.

Based on the slightly updated global computable general equilibrium model (CGE), MIRAGE-Biof, a new assessment of the EU mandate has been performed with a more realistic scenario (based on NREAPs). In addition, a stronger focus has been placed on specific feedstock LUC computation and the uncertainties surrounding these values. Indeed, many model parameters are based on weak estimates, and systematic sensitivity analysis is required to measure the potential range of LUC effects (areas and emissions). However, this study does not provide a comprehensive overview of all sources of uncertainties (e.g. demand response, carbon stock) and emissions (e.g. fertilizers) and does not aim to provide the absolute upper bound to LUC emission coefficients. As a matter of fact, the report discusses the net Land Use Change (LUC) instead of the narrower definition of iLUC. Box 1 explains the differences in the two notions and why we focus on the former.

In the mandate scenario, we introduce a biofuels policy shock that assumes that the EU will consume 27.2 Mtoe of ethanol and biodiesel by 2020 in order to achieve the mandated target of 10 percent renewable energy in road transport fuels. It will represent an estimated blending rate of 8.6 percent of first generation, crop (cereals, sugar crops or oilseeds) based, biofuel, the remaining renewable energy being provided by electricity, waste based biofuels and secong generation biofuels. Based on the action plans, we have 72 percent of biodiesel and 28 percent of ethanol (expressed in energy content). The additional amount of biofuels consumed in the EU compared to the baseline is 15.5 Mtoe. In this report, this amount is called the additional mandate. We analyze the effects of implementation of the EU biofuels mandate under two different trade policy scenarios: i) status-quo trade policy assumption; and ii) full, multilateral, trade liberalization in biofuels (contingent protection on US biodiesel remains).

As biofuels drive up the demand for feedstocks, it is important to know how much of this demand is met by additional production and how much is displaced from other uses, as well as

[3] http://ec.europa.eu/trade/analysis/chief-economist/

what the implications are both in terms of the way in which the land is used and in terms of the political economy issues embodied in the debate about fuel vs. food and fuel vs. feed. A key issue, then, is to see how the additional demand will affect land use patterns: displacement of other crops, pasture, or managed forest or extension in pristine environments.

Globally, the additional biofuels mandate leads to an increase in cropland area by 1.73 million hectares without trade liberalization and 1.87 million hectares if trade liberalization is implemented. The most affected regions in terms of cropland extension are Brazil, Latin America, CIS, and Sub Saharan Africa. The increased demand for sugar cane for ethanol production makes Brazil the most affected region in terms of cropland extension. More than 80 percent of increased production of key oilseeds and sugar crops comes from additional land (extensification) rather than from higher yields (intensification) while cereals are mainly displaced from the livestock sector.

Pasture and managed forest represent the two major sources of cropland extension, followed by savannah and grasslands and primary forest. In terms of the source of CO2 emissions, peatland is the most important source, representing one-third of total emissions mainly due to the share of biodiesel and vegetable oils in the biofuels mandate. Palm oil plays an important role here as a direct feedstock or as a replacement for other oils displaced from other uses.

Biodiesel feedstocks have larger LUC effects compared to ethanol feedstocks, and there is a relatively large difference in terms of the LUC emission effects between sugar beet and sugar cane (the lowest and the highest land use emission coefficients, respectively).

This report indicates that emissions related to land use changes driven by biofuel policies area serious concern, as more than 99 percent of crop LUC coefficients are positive. The LUC effects make nearly two third of the expected gains of shifting from fossil fuels to renewable biofuels disappear. The land use emissions, computed over a 20 year period, remain large, with a coefficient of 38.4 grCO2eq/MJ without trade liberalization and 39.9 with trade liberalization. This difference is explained by the larger amount of land needed under free trade. However, trade liberalization, while it raises the level of CO2, also increases the share of efficiently produced sugar cane ethanol and finally leads to similar net effects. Sensitivity analysis (Monte Carlo and study of demand behavior) does not invalidate our main conclusions, but it shows that uncertainty ranges remain high and that, in particular for cereals-based ethanol, the role of the food and feed markets' reaction is quite important.

Finally, we need to discuss how these results can be useful for policymakers based on inherent limitations. The final section of this report discusses different directions: size of the mandate, composition of the mandate, challenges due to leakage effects, consistency of the land use approach for biofuels and other EU-wide policies, and trade policy options.

Section 2 focuses on key methodological issues used for this assessment. Section 3 describes the baseline and the scenarios. Section 4 introduces the results for the additional mandate as well as detailed results for each crop, including the sensitivity analysis. Section 5 concludes.

Box 1.Land use effects or Indirect Land use effects?

We do not distinguish between indirect or direct effects. The following paragraphs explain why this distinction is not made in our analytical framework and how the current lack of evidence does not allow us to modify our approach at this stage. Our dynamic CGE model compares the state of the world with and without the additional demand for biofuels for the final year of the simulations (i.e. 2020). Thanks to these results, we can compare the pattern of land use with and without the policy. However, if we look at one unit of land used to produce e.g. rapeseed on non-cropland, we do not know if this specific unit of land is used:

1. to produce rapeseed, and then rapeseed oil for biodiesel;
2. to produce rapeseed, and then rapeseed oil for non–biofuel, used to replace a unit displaced by biofuel consumption;
3. to produce rapeseed oil to replace soybean (for instance) that has been diverted to biofuel production directly or indirectly;
4. to produce rapeseed, and then rapeseed oil and meals, driven by an increase in demand by the livestock sector or the food processing industry related to general equilibrium effects.

Obviously, the first item describes a direct land use effect, while the others can be classified as indirect effects. Nevertheless, the model does not include the traceability of each unit of agricultural production and, therefore, does not differentiate between direct and indirect land use effects, and thus not between feedstocks in compliance with the sustainability criteria and those that are not. To be relevant, it is also important to keep in mind that such traceability should be implemented at the global level to know, for example, if one unit of soybean produced on a specific piece of land in Paraguay that will be crushed in Argentina to produce vegetable oil will be processed in Germany to be refined for biodiesel or for another use. Implementing such a system will be tremendously costly and complex. In addition, if it will help to differentiate between direct and indirect land use effects, it will not change the total balance of emissions since the critical question is not to know where the unit of feedstock consumed for biofuel comes from but if and where additional production occurs as a reaction the new demand of biofuels. To ensure the sustainability of EC biofuel consumption, a system has been put in place, the "mass-balance" system, which aims to physically link the EU biofuel supply chain from its origin to consumption in the EU. However, this system does not ensure traceability of each unit of feedstock but the net (balance) effect: if *x* units of sustainable feedstocks are needed to provide biofuels in the EU the company should demonstrate that it has bought them. However, there is no guarantee that the sustainable feedstock, e.g. palm oil, finally reached an EU engine and not an EU plate. [i] The requirement for all biofuels to be in compliance with the sustainability criteria, as set out in the Renewable Energy Directive and

Fuel Quality Directive, may create a premium for such biofuels, which in turn may influence the behaviour of economic actors, and thus also aggregate land use change. However, due to limited amount of knowledge on how such a premium market would work in terms of global impact, there is no distinction between "sustainable" and "non-sustainable" biofuels, and thus also not between direct land use change or indirect land use change. This will need to be further explored when empirical data is available.

The lack of information and uncertainty about the effects of sustainable criteria has been pointed out in the latest EC report on the "mass balance" system:[ii] "*However, as the sustainability scheme became operational on 5 December 2010, little information is yet available on its operation in the market.",* p.2.

We have explained why the model does not differentiate between direct and indirect effects. This feature may be seen as a model limitation. However, it is difficult to find actual empirical data to modify the model on this issue.

[i] As stated by market operators "*The storage tanks and pipework that would be needed for segregate production would be too expensive to be profitable*".
http://www.nesteoil.com/default.asp?path=1,41,11991,12243,15658,16675

[ii] Report on the operation of the mass balance verification method for the biofuels and bioliquids sustainability scheme in accordance with Article 18(2) of Directive 2009/28/EC. .
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2011:0129:FIN:EN:PDF

2 Methodological changes

The methodology and dataset we use very closely follow Al Riffai, Dimaranan, and Laborde (2010). The same model, the global CGE MIRAGE-BioF (Valin, Dimaranan, and Bouet, 2010), and the same dataset are used. Only a few modifications have been done. The Appendix IV provides the key features of the database and the model and Appendix V emphasizes the recent changes, in many cases based on information provided by stakeholders during the public consultation process. This section details three important aspects for the understanding of the report: the computation of crop-specific LUC effects, the implementation of sensitivity analysis using Monte Carlo simulations, and the role of alternative closures as another type of sensitivity analysis.

2.1 Computing Crop Specific LUC coefficients

When computing a specific feedstock LUC emission coefficients, we increase the blending rate in the EU by 0.5 percentage points (from 8.2 percent to 8.7 percent for instance), maintaining the consumption of all other feedstocks by all other biofuel industries in the world constant.[4] Therefore, any increase in biofuel supply that should match the new EU demand could be generated only with one feedstock. However, there is no restriction of the location of production and transformation of the crop. It may be the case that feedstock is not provided by additional supply, but by demand displacement.

During the shock, all trade flows can adjust, but the macroeconomic trade surplus/deficit are maintained constant. Therefore, some real exchange appreciation can occur in some regions, and we may face contraction of agricultural exports for some countries providing the key feedstock in the simulation. In this case, we face a double source of land reallocation: direct competition effect (I,e, the price of studied feedstock increases, the land rent increases for this crop, and other crops are displaced) and the external account effect (additional exports of the key product in volume plus increase of the world price of this commodity will increase export values). Depending on the hierarchy of import demand elasticities across products and regions, some exports will decrease (and they can be land-intensive) or some imports may expand (and they can save local use of land). The later effect remains quite limited but can still generate some additional land savings in particular cases.

[4]Taxes or subsidies on the different feedstocks are endogeneised to maintain their quantity fixed.

Box 2. Overview of the source of uncertainties

Despite our best efforts to improve the complex modeling of land use effects of biofuels, significant uncertainties remain with regard to the estimates. We summarize below the main source of uncertainties and their expected effects on our results. It should be kept in mind however that these uncertainties are not a valid argument to reject this modeling exercise or the policy conclusions. Indeed, rejecting this exercise boils down to assuming that LUC is equal to zero and that there is no need to address this problem. This study demonstrates that zero LUC is far more unlikely than a positive LUC. Consequently, there is a need to address the problem.

Looking at the land use related emissions, uncertainties will affect our answers to the two main questions: How much land do we need to face the new demand? Where is this land taken?

We list the many sources of uncertainty below. , Some are only a minor, others are major contributors to uncertainty. For instance, economic growth has less impact on LUC values and is less uncertain (reasonable range of values for the next ten years) than corn yield. The most important sources are marked with an asterisk *.

Uncertainties concerning the additional land needed

Some are largely independent from policies and can be seen as structural (economic behavior of agents defined by preferences and technologies) or depending on key baseline assumptions:

1*- Crop yields in the baseline, biofuel yields per unit of feedstock. The higher the yield, the smaller the LUC. They depend on technology, which in the medium / long term depends on expected profitability. They can also be impacted by exogenous conditions (climate change...);

2*- Crop yield response in the scenarios. The more yields react to crop price increases, the smaller the LUC. It depends on the price sensitivity of farm decisions (e.g. fertilizer, reduction in waste);

3*- Yield on new land. When crops expand into new land, yield depends on the quality of the new land, previous uses of that land and availability of services such as irrigation for the new area;

4- The supply response of farm inputs such as fertilizer. The less elastic the supply of farm inputs, the less elastic the crop supply. Effects on LUC can go either way.

5*- The demand response for all the crops. If the price of crops increases, how will consumers react? How do intermediate sectors modify their demand for inputs? Do they substitute some inputs by others (e.g. cotton replaced by synthetic fibers, farm fishing using biofuels co-products like DDGS instead of other animal based meals?)? The more elastic the supply, the more limited the LUC.

6*- A particular issue is the degree of substitution among vegetable oils. To what extent can rapeseed, sunflower, soybean and palm oil be substituted in the demand of different agents (households, industrial demand, biofuel production)? The higher the substitution, the larger the peatland effect – a large source of carbon emissions – for all biodiesel feedstocks.

7*- The livestock sector. It is important to single out livestock sector behavior due to the role of co- and by-products of biofuels as feed for livestock. Could livestock production intensify? How flexible is the composition of the feed ration? And ultimately, how will this affect demand for meat?

8*- Price sensitivity of land allocation decisions, i.e. the land elasticities in the model. It has two dimensions. First, can farmers re-allocate their land among different agricultural uses? It depends on the way prices will affect cropping decision under a set of technical (soil quality, needs for crop rotation) and behavioral (risk aversion of farmers and needs to keep a diversified portfolio of products) constraints. Second, the potential scope for farmers/ranchers to extend their agricultural land in new areas has a direct bearing on the LUC effect. If land extension is not possible due to the lack of suitable land, the high cost of accessing the new land (transport cost), the high cost of putting this new land into cultivation (needs of irrigation etc.), than land extension will be limited and biofuel demand will lead to higher agricultural prices and more constraints on the demand components, as well as more incentives for intensification;

7- How do business networks operate and to what extent is the supply chain exposed to international competition? It defines the possibility of importing foreign inputs. The LUC consequences depend on the extent to which trade facilitates the relocation of production from low to high yield regions, or the reverse;

8*- The global level of biofuel production and the level of oil prices. In the case of high oil prices, many countries can have profitable biofuel production at market prices (even without mandates). In this context, a stronger demand in Europe, driven by policy, will increase the price of biofuels, attract foreign production and at the same time deter foreign consumption (for the share not constrained by foreign mandates). In this case, EU demand does not necessarily lead to an increase in production of biofuels but just a reallocation of consumption at the world level, leading to minimized LUC effects;

9- Macroeconomic conditions such as exchange rate, foreign direct investments, etc. For instance, if macroeconomic conditions leads to a strong real appreciation of the Brazilian currency compared to the US dollar, US ethanol is more competitive than Brazilian and EU demand patterns, both in the baseline and in the scenario, will be different, as well as the global land use pattern (even for non biofuel crops). If macroeconomic conditions favor farm expansion in regions with high yields and/or strong land market governance, the LUC effect will be reduced;

10- Economic growth in the baseline and its consequences for the demand of agricultural products, for food and non food, and for land (urbanization). It affects the amount and quality of land when the policy shock is introduced. If land availability has been reduced, the LUC effect will be reduced, but if high quality land availability has been reduced first, it decreases marginal yield and leads to stronger LUC.

Others are directly impacted by policies and model uncertainties and can be reduced by targeted policies:

11*- Biofuel policies and their degree of flexibility. It impacts on the overall investment in biofuel technologies and yield improvements (creating positive externalities and reducing LUC for EU policies), the capacity of EU to use foreign production (see 8) but also the global pressure on land and agricultural markets in the baseline

12*- Trade policies that shift competitiveness among suppliers or can reduce the access of some producers to the EU market (e.g. antidumping, export restrictions);

13*- Land governance in the different countries and the capacity to enforce conservation programs that will limit the agricultural land expansion following a price increase;

14*- Public investment in infrastructure (transportation, irrigation) to make new land more easily available (increase LUC, but at the same time improved irrigation on existing land also increases yield leading to reduction in the LUC);

15- Public R&D in new technologies to increase yields (at the crop level or at the biofuel conversion/crushing level) will reduce LUC (see item 1);

16- Agricultural policies that promote less intensive schemes with lower yield production (e.g. organic farming). They will increase the LUC effect.

17- All policies that will have an impact macroeconomic conditions discussed in item (10).

Uncertainties concerning the type of land converted

Technical and economic uncertainties

18*- The country and sub-region where the land expansion takes place. This depends of the crop mix required and other factors affecting competitiveness (see items 7, 9…). Different regions have different biotopes and carbon stocks associated.

19*- How easily can pasture be converted to crop land? If it is easy, cropland will extend more in pasture and it will mitigate the related emissions compared to deforestation.

20 -How elastic is the demand for wood products and how easy is the conversion of managed forest to cropland?

21*- What is the right average value of carbon stocks per hectare in a region? Does the use of averages (as done in this report) induce a bias? Is there a correlation between the initial carbon stock of an area and the potential crop yield? If so, when extension takes place, farmers will naturally targets high carbon stock regions first, leading to increased LUC emissions. How to value recently afforested areas?

22*- Peatland emissions. Among all source of emissions, the case of palm trees grown on peatland is among the most sensitive for our results. In recent years, estimates of carbon emissions from peatland have increased systematically and recent research gives a range of 50 to 120 tons of CO_2 / Ha / year.

23*- What will be the agronomic practices in 2020 on the new land? Different depth for tillage leads to different emissions of mineral carbon stored in the soil and can significantly reduce overall emissions. It depends of the availability of technology but also the capacity to adopt them (e.g. Genetically Modified soybean with Round-up and no tilling)

Policy dependent uncertainties:

24- Any land management policies will have an impact on the type of land that can, or can not, be converted. Legislation, and even more importantly its enforcement, play a critical role in protecting high carbon value areas (conservation programs, forestry code. etc.). Analysis of past behavior through satellite images is a relevant exercise but the margin of errors in such exercise is also very large;

25- Regulations affecting the agricultural sector: animal welfare, land set aside etc, may influence the type of land converted (pasture vs forest etc.);

In addition to these uncertainties affecting directly the land use effect or the emissions related to land use changes, it is important to keep in mind that the net emission balance of biofuels is an even more delicate measure. It includes the choice of processing pathways for biofuels and the source of energy used for processing (more or less polluting), the capacity to innovate in this field and to do the investments required to increase the efficiency of plants. Macroeconomic leakage effects also play a role: how will the oil price react to increased competition from biofuels? If oil prices are reduced, a significant share of the reduction in oil consumption in the EU will be consumed elsewhere and the world will not save emissions.

To summarize, crop specific LUC effects is computed with the following procedure:

1. Biofuel demand in the EU is increased by a given amount of MJ;
2. Biofuel industries in all countries will maintain constant the use of all feedstocks, except the one studied;
3. Consequently, the additional demand of biofuels could be supplied by only feedstock, processed in the EU or abroad;
4. The additional demand of feedstock can be met by new supply or demand displacement;

5. The production (and land use) of other crops is affected by direct competition with the demanded crop, but also through macroeconomic effects: real appreciation / depreciation of the exchange rate, change in the level of income that leads to shift in demand for agricultural crops (level and pattern). These last categories of effects are purely CGE effects.

Lastly, we compute the crop LUC emissions at two points, half additional mandate and full additional mandate, to see if the size of the mandate affects the value of the LUC coefficient. Therefore, we test for an overall non-linearity property.

2.2 Monte Carlo Simulations

Despite all our efforts devoted to improve the modeling of a global and complex issue such as the land use effects of biofuels, it should not mask the significant uncertainty surrounding the provision of such estimates. Indeed, many behavioral parameters are important in the representation of land use emission coefficients and the precise values of these parameters is unknown[5]. This was already emphasized in Hertel et al. (2010) and very clearly illustrated by the paper on uncertainty from Plevin et al. (2010). Box 2 reviews the different, and numerous of uncertainties that scientists and policy makers faced. In this section, we therefore investigate intervals of confidence around our initial estimates by providing many alternative runs, combining in a systematic approach all probable bounds for our parameters using a Monte Carlo approach. We mainly focus on parameters affecting directly the land use consequences of the biofuel policies -elasticity of transformation between land activities, elasticity of extension of cropland into pristine environments – or indirectly (yield elasticity). We do not analyze other important issues such as uncertainty about some data, the carbon value of new units of land put into cultivation and/or the uncertainty about the agricultural practices, such as tillage, that may lead to a lower carbon emitting agriculture in the future.[6]

We follow the original approach developed by Valin and Laborde (2010) for conducting sensitivity analysis using the MIRAGE-BioF model on several parameters at the same time. Indeed, due to the large number of parameters for which uncertainty exists, we prefer to rely

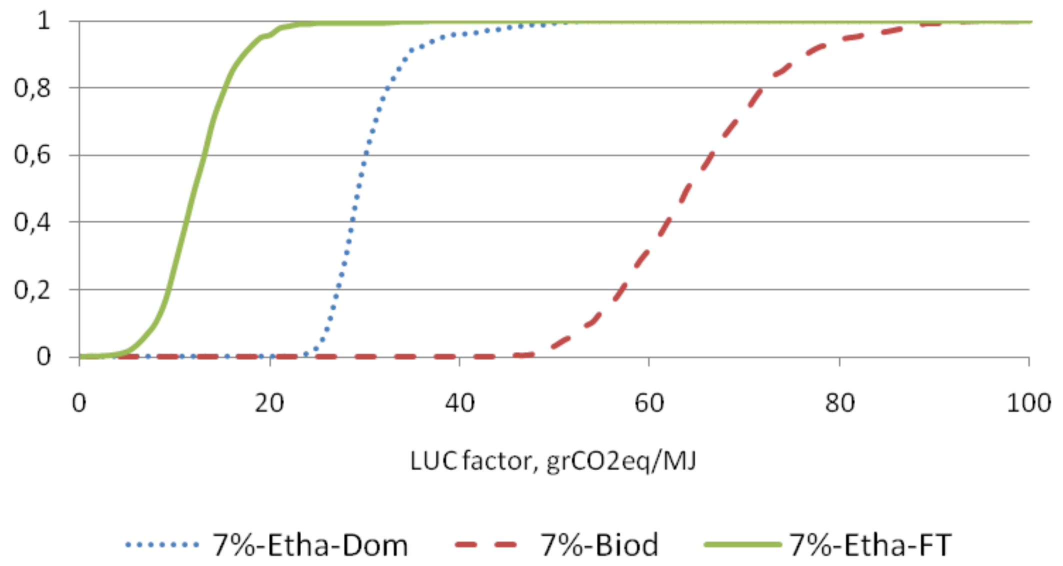
[5]Uncertainty includes not only the existing values of some behavioral parameters but also how they may evolve in the future. For instance, environmental regulations and agricultural policies have obvious effects on how farmers are likely to react to agricultural price changes. Many institutional aspects are not represented in the model and are likely to change in the next ten years, in particular in developing countries, and will influence the behavior of economic agents.

[6]Since the later parameters have no impact on the economic outcomes of the model – no behavioral impacts – interested users and readers could use the details results of our simulations, provided as an appendix of this study to perform such computations ex-post.

on a Monte Carlo approach rather than on Gaussian Quadrature. In non-technical terms, the Monte Carlo approach implies to draw a large number of parameter values – for relevant parameters – from assumed parameter distributions, and considering these alternative sets of parameter values to run simulations in these alternative universes. This approach is more robust to just picking a few parameter values, even extreme ones, in order to get a distribution of probable values.

As shown in Figure 1, the first attempt to use such methodology has shown that previous conclusions from Al Riffai, Dimaranan and Laborde (2010) remain relevant: biodiesel is more adverse than ethanol, trade liberalization appears to be better than a protectionist policy under current technologies, i,e, default direct savings coefficients from the directives, and even though the distribution may overlap, stochastic dominance is preserved. Another feature of this first analysis is confirmation of the "right tail" feature of the LUC emissions distribution, meaning that very high values may exist.

Figure 1 Cumulative distribution for Ethanol and Biodiesel from Valin and Laborde (2010)



Source: Adapted from Valin and Laborde, 2010

Note: The authors study three scenarios using a slightly different version of the MIRAGE-Biof used in this study. They consider a 7 percent EU mandate, compared to a 3.3 percent blending rate in the baseline, where all additional biofuel is domestic ethanol (*7-Etha-Dom*), or ethanol from any origin in a free trade context (*7-Etha-FT*) or biodiesel (*7-Biod*).

Implementing a similar methodology, we create 1000 baselines and then perform simulations using 1000 sets of seven parameters. The parameters are drawn from a log uniform distribution, centered on the default value of the model, and the range of values is based on the literature review done by Laborde and Valin (2011): it includes OECD (2001), CARB (2011), Huang and Khanaa (2010), Barr et al. (2010) and Roberts and Schlenkers (2010). For some parameters, such as the yield elasticity discussed in the literature mainly based on partial equilibrium analysis, we need to translate them into the relevant combination parameters in our CGE model, e.g. elasticity of substitution between key inputs and between production factors. The range aims to include the large set of parameter values discussed in these papers. However due to the widespread of estimates and the lack of information on their probability distribution, we should remain cautious about the interpretation of the average value and keep in mind that the full range of estimations may include realistic values. Key elements of the parameter distribution are displayed in Table 1. As shown by the ratio average/median, nearly all distributions of the sample have a right tail,[7]a feature driven by the log uniform assumption of the probability support used to build these samples. The same set of parameters is used for assessing the LUC (areas and emissions) uncertainty of the additional mandate as well as each individual crop LUC coefficient.

Table 1 Range of parameters for Monte Carlo analysis

	Shifter in the share of extension occurring in primary forest	Shifter in intermediate demand price elasticity of agricultural inputs	Ratio between yield on new cropland and average yield	Elasticity of substitution between land and other factors (factor intensification)	Elasticity of substitution between key inputs (feedstuff or fertilizer) and land (input intensification)	Elasticity of transformation of land (intermediate level)	Land extension elasticity
Average							
DC	0.99	1.18	0.75	0.07	0.11	0.30	0.02
DV	0.99	1.18	0.75	0.07	0.20	0.30	0.05
Median							
DC	0.91	1.21	0.75	0.06	0.08	0.25	0.01
DV	0.91	1.21	0.75	0.04	0.15	0.25	0.04
Maximal Value							
DC	1.81	1.83	0.99	0.18	0.29	0.74	0.04
DV	1.81	1.83	0.99	0.33	0.59	0.74	0.17
Minimal value							
DC	0.46	0.47	0.50	0.01	0.02	0.09	0.00
DV	0.46	0.47	0.50	0.01	0.04	0.09	0.01
Standard Deviation							
DC	0.39	0.41	0.13	0.05	0.08	0.18	0.01
DV	0.39	0.41	0.13	0.06	0.16	0.18	0.04

Source: Mirage-BioF Monte Carlo parameters
Note: DC=Developed countries. DV=Developing countries

[7]However, since some parameters can increase LUC when other can reduce it, the right tail distribution of the parameter distribution does not involve a right tail bias in the LUC expected distribution.

Before discussing the list of parameters and their expected effects, we need to indicate how the draws are done. A first solution would be to consider that the value of a parameter for each sector (if relevant) and each region and AEZ is independent of the value of the other sectors/regions. This solution would consider that the value used for the elasticity of land transformation into European AEZ is independent or that the level of potential factor intensification in the wheat sector in the US is uncorrelated with the level for the corn market. In such a case, for each parameter, we would have drawn a specific value for each sector/region combination, considering systematic uncertainty. While this approach may be relevant, we do not follow it here. We consider that the key uncertainty does not deal with the exact value for a country/sector and its correlation with other regions/sectors, but rather with the real location of the parameter's distribution in the space of potential value and the fact that all sectors/regions are affected in a similar way. This implies that we consider a perfect correlation between parameter values across sectors and across countries (or groups of countries). For instance, for each draw, we shift the value of a parameter (e.g. land elasticity of transformation) for all developed countries in the same direction. All developed countries will be able to relocate land more (or less) easily among crops at the same time. However, the distribution for each parameter is also considered from other parameters: the shifter in demand behavior is drawn independently from the value of the fertilizer intensification parameter. Therefore, our experiment displays two important features. First, we do not have mitigation of the uncertainty of one parameter through international diversification and trade (and crop mix looking at the total mandate). Indeed, if parameter values would be uncorrelated, a high elasticity in one region may be compensated by a lower elasticity in another. Consequently, for each draw, the world median would have been closer of the distribution median, and the overall land use effects would have been closer to the median value (even if the geographical pattern of the land use would have been much more dispersed).[8] We have chosen the other approach (full correlation) because we think that the key challenge for many parameters (e.g. yield price response) is to understand the change in average magnitude and not to address the question of the correlation and heterogeneity among countries/sectors. In addition, assuming no correlation among regions would also have introduced an aggregation bias in the experiment: changing the number of regions would have changed the dispersion of parameter values within each draw. Second, we still have independent draws across parameters. A large yield response can still be combined with a strong sensitivity of cropland extension to land prices. The combination of effects among parameters is not biased in a way that will increase/decrease the results dispersion.

[8] Indeed, assuming perfect correlation among crops or regions does not affect the relative properties and comparative advantages of different crops. The geographical pattern of effects and the feedstock mix for the overall scenario will not be subject to large modifications in this framework.

We have selected seven parameters to study; most of these– except the two first in the following list – focus on the agricultural supply response and the extensification/intensification trade-off:

- Shifter in the share of extension occurring in primary forest. This coefficient multiplies[9] the initial share of land extension that took place in primary forest in the Winrock coefficient dataset. It does not affect the economic response of the model and only modifies the carbon release by unit of exploited land expansion: a value above one will increase the share of primary forest and the carbon release;
- Shifter in intermediate demand price elasticity of agricultural inputs. This coefficient multiplies the price elasticity of intermediate demand (by non-primary sectors) for agricultural commodities. In the model, the elasticity of substitution in the intermediate consumption nested CES structure is recalibrated accordingly. A value above one implies that processing sectors will more easily release inputs (crops or vegetable oils) following the biofuel demand shock, and therefore reduce the LUC effect;
- Ratio between yield on new cropland and average yield. This parameter gives the marginal productivity of a new hectare of cropland compared to an existing one. The expected direct effect is that reduced yield will lead to a larger requirement of new land to meet the additional crop demand; this will increase LUC. However, more complex effects take place in the model. Indeed, in the dynamic baseline, assuming lower yield on marginal land leads to more land extension.[10] Since the "managed land" supply elasticity in the model is not constant but decreases with the ratio between used agricultural land and total suitable land for agriculture, the large expansion in the baseline needed to compensate for the low productivity of new land reduces the remaining amount of available land in the baseline and decreases the price elasticity of land expansion that prevails when the biofuel scenario takes place. Therefore, the net effect of a low/high marginal yield is ambiguous;[11]
- Elasticity of substitution between land and other factors (factor intensification). This is a core parameter in the endogenous yield response of the model; it shows how

[9]Other shares (grassland, shrub) are rescaled to be sure that the sum of share is equal to one.

[10]Indeed, cropland extension in the baseline, driven by economic and demographic growth, is much larger than the effects of the biofuels scenario studied here.

[11]It also emphasizes the role of the baseline behavior in our assessment and the importance of understanding that we compute the effects of the biofuel policy as a marginal deviation from this baseline when all other ongoing changes have already been taken into account.

production can increase through additional capital/labor use by unit of land. A larger value describes a more flexible production system that will reduce the LUC effect (more intensification);

- Elasticity of substitution between key inputs (feedstuff or fertilizer) and land (input intensification). This is the other driver of intensification, both in crop production and in the livestock sector, since it allows for the substitution of land to inputs (fertilizer or feed). A larger value is associated with a lower LUC (more intensification);
- Elasticity of transformation of land (intermediate level) among broad categories of agricultural production. A larger value is associated with a lower LUC since increased production of energy crops – crops used for producing biofuels - can displace other agricultural production before requiring new cropland (more land reallocation).
- Land extension elasticity. This parameter describes the land supply response – extension of managed agricultural land to pristine environments – following an increase in cropland price. Even if this value is not constant in the model, as discussed above, it involves the ratio between used and available land for agriculture, while the change in the Monte Carlo modifies the initial value and its path of evolution. A larger elasticity value reinforces the LUC effect (more extension).

Lastly, for several parameters, we assume more uncertainty (i.e. a more dispersed distribution) for developing countries parameters which should lead to more dispersed LUC for crops produced in these regions (e.g. sugar cane) than for crops produced in other regions. The parameters involved are the intensification parameters (fertilizers, feed, and factors) and the land extension elasticity.

Similar crops with similar initial technology (share of fertilizer in total cost) and production location (concentrated in developed countries or in developing countries for as tropical crops) are expected to display high correlation in LUC emissions in our Monte Carlo simulations.

We do not implement uncertainty of the household demand behavior, nor do we look in detail at the uncertainty on substitution among subsets of inputs (animal fat vs. vegetable oil, for instance). Other aspects such as carbon stocks or direct saving coefficients from the life cycle analysis are considered to be known even if their role in overall LUC uncertainty should not be neglected (see Plevin et al, 2010).

2.3 Alternative closures

To partially check the effects of the demand displacement on both the final consumer (household) and the livestock industries, we investigate two alternative closures.

First, we fixed all final consumption at its level in the baseline (per capita, per country) for each individual food product (raw or processed). This still allows for reallocation among inputs for different agrifood sectors and/or the relocation of production around the world (in other words, total consumption of wheat by household is maintained constant in Africa, but the origin of this wheat can change). Therefore, the final demand is not totally frozen and some land-saving combination can take place (for example, animal fat replacing vegetal oil in the food processing industry). Non-food uses of agricultural commodities (e.g. cotton) are not fixed.

To assess the role of co-products in our analysis, we run some simulations in which co-products cannot be substituted with crops in the livestock sector. This is not a complete removal of co-products from the model, but it still generates interesting land use considerations without affecting the cost structure and profitability of the different sectors.

3 Baseline and scenarios

This section presents the baseline assumptions and the scenarios design. The reader should be aware that both aspects are critical and the role of the baseline should not be underestimated since it may affect the results of the scenarios significantly. Indeed, the baseline involves assumptions about base level of biofuels, overall demand for land and therefore, defines the availability of land in the scenario, the level of yield, the trade pattern…

3.1 Baseline design

In this study, we use the same baseline as that used in Al Riffai, Dimaranan, and Laborde (2010) except for two elements: yields projection and Brazilian domestic market demand.

First, the yield projections are not based on Ludena et al. but follow the new 2010 baseline of the Aglink-Cosimo used in the Agricultural Outlook of DG Agri. This leads to an increase of yield in 2020 for most countries compared to the previous study. We do not perform sensitivity analysis on the yield trend, but this baseline level plays a significant role in the LUC estimation. An additional assumption made in this study is the strong catch-up effects for new EU member states. Therefore, the assumption of 8 ton/ha by 2020 for the EU average is strongly optimistic. Similarly, the yield increase for maize in the USA and in Brazil should be considered carefully. Details are provided in Table 2.

Table 2 Yields. Tonnes per Ha. 2020. Baseline

	Maize	**OthCrop**	**OthOilSds**	**PalmFruit**	**Rapeseed**	**Rice**	**Soybeans**	**Sugar_cb**	**Sunflower**	**VegFruits**	**Wheat**
EU27	8.1	6.1	0.4		3.9	9.8	1.9	70.4	2.3	14.1	8.0
Brazil	10.5	2.1	0.0	41.4	3.5	7.6	3.5	96.7	3.1	10.3	5.0
CAMCarib	3.0	0.6	0.1	26.1		6.4	4.7	121.0		15.6	5.2
China	6.8	2.2	3.1	36.4	2.5	8.5	2.3	146.0	2.1	16.3	5.4
CIS	5.2	2.3	1.3		1.9	6.0	1.4	54.2	2.2	6.3	2.6
IndoMalay	5.0	0.1	0.2	34.1		7.9	1.9	94.5		9.1	
LAC	5.7	2.8	0.6	26.0	2.6	9.2	3.2	120.1	1.8	13.7	3.8
RoOECD	11.6	3.1	0.2	6.4	2.4	6.1	3.4	129.3	2.9	10.5	2.4
RoW	6.8	2.4	0.1	4.7	2.6	8.5	2.0	130.7	2.0	10.4	4.9
SSA	2.4	1.3	0.4	6.6	1.9	5.4	2.0	99.5	1.7	3.1	3.1
USA	13.7	3.1	0.3		2.7	6.6	2.7	84.9	1.6	25.3	3.9
World	**7.7**	**2.3**	**0.3**	**20.5**	**2.8**	**8.**	**2.9**	**108.4**	**2.1**	**10.7**	**4.3**

2

Source: MIRAGE-Biof baseline

The other modification is a Brazilian domestic blending ratio of ethanol of 35 percent, much stronger than in the previous baseline. This is based on the conservative projection of UNICA. It implies that a larger share of Brazilian production is focused on the domestic market and reduces its overall export supply capacity. However, the 35 percent target does not lead to significant results concerning the EU-Brazil trade pattern.

For other elements, we follow the previous methodology. Sugar reform is implemented in the EU, end of the set aside, and trade policies remain constant (no DDA) except for the antidumping and countervailing duties applied on US exports of biodiesel to the EU. This last measure brings to zero the US biodiesel exports that are partially replaced by biodiesel originating from South East Asia and Argentina. The US biofuel program is fully implemented in the baseline. Similarly, China, Indonesia and Malaysia, and the rest of the OECD have a 5 percent mandate in place by 2020.

For oil, the baseline scenario reflects recent International Energy Agency forecasts (2008) with oil prices reaching $120 a barrel in 2030 based on current prices. This implies an increase of 39 percent in real terms. Economic growth projections, now taking into account the effects of the economic crisis, have also been updated with projection data from the World Economic Outlook (April 2009) of the International Monetary Fund.

EU biofuels consumption in the baseline is kept at the 3.3 percent blending ratio of 2008. The feedstocks composition has been adjusted based on the latest data available. It implies that the ratio biodiesel/ethanol in the baseline, up to 2020, remains constant at the 2008 level (83 percent biodiesel, 17 percent ethanol).

During the baseline period, 2008-2020, significant land use changes take place driven by the additional food demand, but also non food use e.g. cotton or feedstock for non EU biofuel programs. World cropland increases by 3.6 percent (442,000 km2) when primary forest endowment is cut by 5 percent. Overall exploited land increases by 1.40 percent. Largest cropland extensions will occur in sub Saharan Africa (+18 percent), Brazil (+11 percent) and Central America (+7 percent) and South East Asia (+7 percent). Deforestation occurs mainly in South East Asia (-18 percent of primary forest) and Brazil (-10 percent). At the opposite, cropland is reduced in the EU (-1.7 percent) or in the US (-1.1 percent).

3.2 Scenario description

Against this baseline scenario and its reference level consumption of 10.2 Mtoe in the baseline, we evaluate the impact of the EU mandate as described in the National Renewable Energy Action Plans of the 27 member states (following the DG ENER quantification for the PRIMES model). In the mandate scenario, called "additional mandate", we introduce a biofuels policy shock that assumes that the EU will consume 27.2 Mtoe of ethanol and biodiesel by 2020 in order to achieve the mandated target of 10 percent renewable energy in road transport fuels, increasing the consumption in the EU by 15.5 Mtoe compared to the baseline. Based on the PRIMES model projection done by DG ENER, the fuel consumption of the EU by 2020 will be 316MToe. Therefore, we have a blending rate of 8.6 percent. This figure is still consistent with the 10 percent overall target of renewable energy since we only focus on first generation biofuels made from crops (cereals, sugar crops and oilseeds). The remaining renewable energy inputs will be provided by non land-using first generation biofuels such as recycled waste oil, animal fats and some advanced biofuels from waste, lingo-cellulosic (second generation biofuels) and non-cellulosic materials, and electric cars. Based on the action plan, we have 72 percent of biodiesel and 28 percent of ethanol (expressed in energy content).[12]

The mandated target is achieved in the model by mandatory regulation (explicit biofuels mix constraints built into the supply of road transport fuels) and not by means of explicit subsidies or tax credits.

Our trade policy scenarios are:

- **Trade policy status quo:** Implementation of the EU biofuels mandate of achieving 8.6 percent consumption of ethanol and of biodiesel in 2020 under a status-quo trade policy assumption;
- **Free trade:** Implementation of the EU biofuels mandate of achieving 8.6 percent consumption of ethanol and of biodiesel in 2020 with the assumption of full, multilateral trade liberalization in biofuels. Contingent protection on US biodiesel remains.

[12] This is a major change compared to the previous study in which the mandate only reached 17.6 Mtoe with a 55/45 ratio. Additional demand for bioliquids has not been considered as it is expected to be very small.

4 Results

In this section, we discuss key results of the simulations, focusing on land use and emission effects. Detailed results, including a wider range of indicators, are available in the electronic appendix of this report. We start by discussing the additional mandate effects (changes from the 3.3 percent 2008 blending ratio to the 8.6 percent target), followed by a discussion of crop-specific results. The last two sub-sections are devoted to sensitivity analysis, first through the Monte Carlo approach and then with alternative closures in terms of food/feed and co-products.

4.1 Additional Mandate

The additional mandate brings the EU consumption from 11.7 Mtoe of biofuel in 2020 in the baseline to 27.2 Mtoe in 2020 (+132 percent). The EU market will then represent nearly 25 percent of the total biofuel consumption in the world[13] compared to 12.4 percent in the baseline. For biodiesel, its markets share will reach 69 percent instead of 52 percent in the baseline and for ethanol, 9.21 percent instead of 2.6 percent. The magnitude of this shock has consequences for the EU but also for global markets. We analyze the consequences of the policy in three steps: production and consumption of biofuels, trade consequences, and the core issue at stake in this study: implications for land use and decomposition of the effects.

4.1.1 Consumption and Production

Table 3 shows the evolution of consumption in the EU following the mandate implementation. The mandate still involves a larger development of biodiesel (+10 Mtoe from 9.7 to 19.7 Mtoe) than ethanol (+5.5 Mtoe from 2 to 7.5 Mtoe) to catch up with the biodiesel/ethanol blend (72/28) implied by the NREAPs. It involves a 65/35 percent composition of the additional mandate, i,e, the additional amount of biofuel needed to reach the NREAPs level from the baseline. Biodiesel expansion will be translated by a stronger growth in palm oil based biodiesel[14] (see Figure 2) even if rapeseed remains the most used feedstock in absolute level. For ethanol, the scenario will lead to an extension of all feedstock use; sugar cane appears to be marginally more competitive, while maize is the least efficient.[15] Without trade barriers,

[13]Based on our baseline assumptions. This figure may be seen as slightly overestimated if India implements its recent target and if the domestic Brazilian market grows strongly.

[14]It is important to keep in mind that we do not consider any technical constraint about the use of different types of vegetal oils, including palm oil, for the processing of biodiesel.

[15]Due to initial trade pattern and exchange rate assumptions, US ethanol is not competitive in the EU. In 2010, however, the US has started to export its ethanol production to many countries, including to Brazil during a short period of time. Since a share of US competitiveness is tied to the tax rebate for blenders that create subsidized exports, we consider that alternative assumptions in the baseline, e.g. large US exports to the EU, may have led to trade policy measures as in the case of biodiesel.

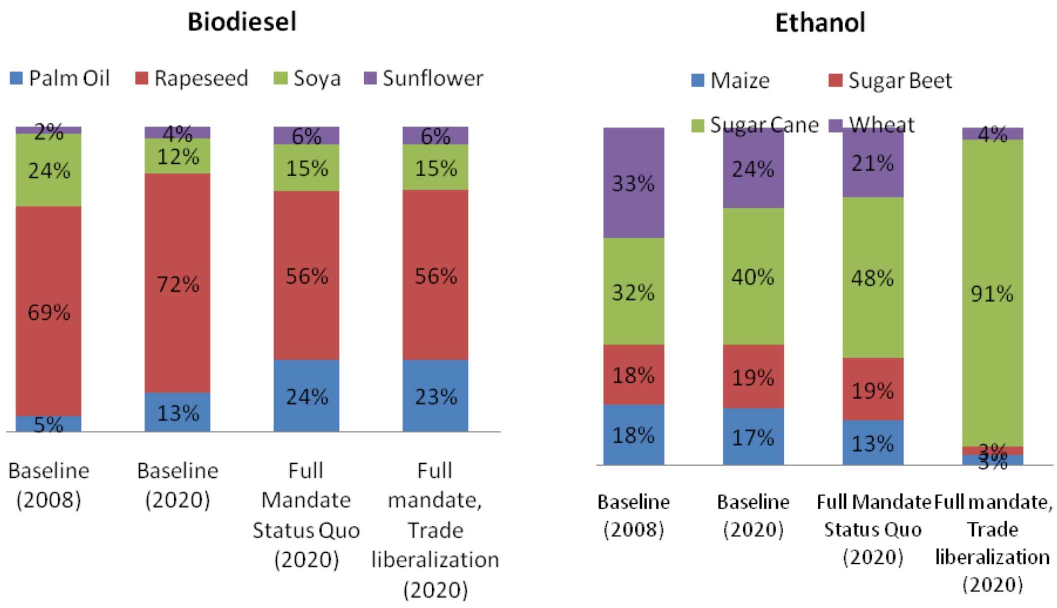
sugar cane could occupy 91 percent of the EU ethanol market. Interestingly, looking at the baseline evolution from 2008 to 2020, we can also note important changes in consumption patterns: soybean biodiesel has shrunk, due mainly to import restrictions on US biodiesel in 2009 but also to the relative price increase of soybeans, driven by Asian growth and the needs of the livestock sectors. Similar effects take place for wheat among ethanol feedstocks. This last effect is due to the combination of eroded competitiveness of EU wheat (weak yield gain compared to sugar cane) and the strong price increase of wheat compared to other crops, driven by food and feed demand during the period (real price of wheat +11 percent between 2008 and 2020, while sugar crops have stable real prices).

Table 3 EU consumption pattern by feedstock. Percent

	Palm Oil	Rapeseed	Soya	Sun-flower	*All Biodiesel*	Maize	Sugar Beet	Sugar Cane	Wheat	All Ethanol
Structure of consumption in 2008										
Baseline	4	57	20	2	***83***	3	3	5	5	***17***
Structure of consumption in 2020										
Baseline	11	60	10	3	***83***	3	3	7	4	***17***
No Trade liberalization	17	41	11	4	***72***	4	5	13	6	***28***
Full Trade Liberalization	17	41	11	4	***72***	1	1	25	1	***28***
Additional Mandate Composition										
No Trade liberalization	22	26	12	5	***65***	4	6	18	7	***35***
Full Trade Liberalization	22	26	12	5	***65***	-1	-1	38	-1	***35***

Source: Mirage-Biof Simulations

Figure 2 EU consumption pattern by feedstock, by type of biofuel



Source: Mirage-Biof Simulations

Table 4 displays the structure of the world production of biofuels. The EU additional mandate leads to an increase of 50 percent of the global biodiesel market; however, this remains much smaller than the ethanol market (15 percent market share). The EU trade policy option does not significantly affect the biodiesel/ethanol ratio, since we consider that the EU additional mandate is fixed in its composition. In addition, the biodiesel/ethanol markets are quite segmented (trucks vs. cars and mandate policies) in both Brazil and the US, leading to no shift from one biofuel to another in these countries in response of the EU shock.

Table 4 World Production in 2020 by feedstock. Energy content. Percent

	Baseline	No Trade Liberalization	Trade Liberalization
Biodiesel	**10.99**	**14.89**	**14.99**
PalmFruit	2.66	4.16	4.14
Rapeseed	4.55	6.00	6.05
Soybeans	2.83	3.42	3.49
Sunflower	0.95	1.30	1.31
Ethanol	**89.01**	**85.11**	**85.01**
Maize	54.72	49.59	49.00
Sugar_cb	28.88	29.47	31.04
Wheat	5.42	6.05	4.97

Source: Mirage-Biof Simulations

The production pattern by feedstock is also resilient to alternative trade policies, especially for biodiesel due to low initial distortions (EU tariffs below 7 percent on average) on this product. Rapeseed oil will remain the main biodiesel feedstock at the world level, followed by palm oil and soybean oil. For ethanol, US production shifts the world pattern, with nearly 50 percent of global ethanol production made from maize. For ethanol, EU trade policy options matter: maintaining protection, the EU will process more wheat ethanol than under trade liberalization, while sugar ethanol will occupy most of the market. Table 5 illustrates the shift in the EU production structure. Overall, EU biofuel production will increase from 10.1 Mtoe in the baseline to 20.9 Mtoe without trade liberalization and to 17.8 Mtoe with trade liberalization. First, since the EU additional mandate increases the relative consumption of ethanol to biodiesel (from 17/83 to 28/72), the scenario under the trade policy status quo reinforces the local production of ethanol. It will represent nearly 31 percent of EU biofuel production in 2020, compared to 21 percent in the baseline. The first feedstock in the EU will be wheat (38.7 percent of ethanol production), followed closely by sugar beet[16] (35 percent). Maize production remains more limited (26.3 percent). For biodiesel, the share of processed rapeseed oil in the biodiesel sector falls from 78 percent to 64 percent under the competition of palm oil (from 10 to 19 percent). If trade liberalization occurs, EU production of ethanol collapses from 3.8 Mtoe under tariff protection to 0.7 Mtoe (-40 percent compared to the baseline, -72 percent compared to the protectionist situation). Sugar beet ethanol is most affected, followed by wheat ethanol when corn ethanol appears more resilient. Following the withdrawal of the ethanol sector, local production capacity and feedstock production are dominated by biodiesel production. With trade liberalization, biodiesel represents 92.5 percent of total EU biofuel production. However, it does not involve a growth of the biodiesel sector in absolute (17.08 Mtoe without trade liberalization, 17.13 Mtoe with).

[16] In order to reproduce the current share of sugar beet ethanol based on prices and cost information, we need to add a production subsidy to this pathway as discussed in the appendix IV, Figure A1. This price distortion is maintained in the policy scenario and plays an important role in the profitability of this value chain. It can be interpreted has alternatively as a real governmental subsidy, a different price for sugar beet for food and energy use, or a transfer done in a vertically integrated sector by the upward component (sugar beet production) to the downward one (bioethanol) to ensure the existence of this new market.

Table 5 EU biofuel production in 2020 by feedstock. Energy content. Percent.

	Baseline	No Trade Liberalization	Trade Liberalization
Biodiesel	**79.29**	**69.25**	**92.54**
PalmFruit	7.55	12.87	16.96
Rapeseed	62.04	44.37	59.58
Soybeans	6.52	7.45	9.90
Sunflower	3.17	4.56	6.09
Ethanol	**20.71**	**30.75**	**7.46**
Maize	5.83	7.59	2.16
Sugar_cb	6.53	10.96	2.17
Wheat	8.35	12.20	3.12

Source: Mirage-Biof Simulations

The global consequences of the incremental EU demand for crops, food, and feed markets are displayed in Table 6, showing a balance sheet analysis. Each row represents a commodity directly or indirectly involved in the biofuel production. The first column displays the feedstock consumption for biofuel production, the second the additional production (a negative figure represents a decrease in production), the third column displays the change in other demands when the displacement specific to feed is indicated in the fourth column. Two additional indicators are computed to see how additional production is needed to adjust to the biofuel shock and the role of feed adjustment in total demand balance. We focus on the constant trade policy case. Several remarks have to be made, in particular to illustrate the role of the demand reduction by final and intermediate consumers to absorb the biofuels shock (an important issue in terms of political economy implication), as well as the role of inter-sectoral linkages.

First, we confirm that the biofuels demand will require more energy crops; in tons, the amount of sugar cane/sugar beet needed is the most important. However, in some cases, this additional demand may not be matched by an additional supply; different cases appear as follows:

- additional biofuel demand is nearly matched by additional supply: This is the case for sugar-based ethanol. Substitution possibilities are limited and demand is narrow and relatively inelastic. New demand has to be met by new production;
- additional biofuel demand is partially matched by additional supply: This is the case for soybean oil and rapeseed oil. About 60 percent of the biofuel demand is met by new production. The remaining oil is displaced from other sources of demand (processed food, direct household consumption);
- additional production of some crops is larger than the demand originated in the biofuel sector. Indeed, the production of palm oil and, to a lower extent, sunflower oil needs to increase in order to supply the biofuel markets, but also to replace soybean and rapeseed oils used for biodiesel production and not replaced by additional productions of these crops. Overall, only 10 percent of total vegetable oils is not replaced;
- despite the additional demand from biofuels, supply of some crops is reduced. This is the case for wheat and, in particular, maize. Indeed, due to land competition with oilseeds (mainly soybean and rapeseed), cereals production declines. Therefore, the demand displacement of cereals has to be larger than the direct needs of the ethanol

sector to compensate the additional use by this sector but also the overall supply decrease;

- crops that do not benefit from the incremental demand generated by biofuels are displaced by energy crops (land competition and other input/factor costs). The production of other crops (including tobacco and cotton) and vegetable and fruits decreases. Processing sectors using different agricultural inputs also reduce their production (processed food, sugar). For sugar, this is the direct consequence of the 10 percent of sugar cane/beet that is not replaced.

This reallocation of production is the result of how other demands react for each feedstock and how the relative feedstock prices will evolve. Even if the price of all crops increases, the result remains contrasted. The strong biodiesel component in the additional mandate leads to higher increases in oilseed prices compared to other crops. Following the hierarchy of relative prices, land is displaced from other crops to cereals/sugar and from cereals/sugar crops to oilseeds.

Table 6 Changes in Commodity balance sheet - World - Additional mandate - No trade liberalization. 1000 tons

	Biofuel demand	Additional Supply	Total Demand displacement	Livestock demand displacement	Ratio Additional Supply / Biofuel demand	Share of livestock demand displacement in total demand displacement
Wheat	5,366.6	-1,595.9	-6,962.5	-6,326.6	-30	90.9
Maize	4,353.0	-2,986.3	-7,339.3	-6,471.7	-69	88.2
Sugar Cane & Beet	76,616.8	69,574.6	-7,042.2	-6.6	91	0.1
Soybeans		4,677.6	4,677.6*	-1,889.9		-40.4
Sunflower		2,676.0	2,676.0*	-344.2		-12.9
Rapeseed		7,135.4	7,135.4*	-544.2		-7.6
PalmFruit		22,207.0	22,207.0*	-208		-0.9
Rice		-101.9	-101.9	418.1		-410.4
OthCrop		-765.9	-765.9	-363.4		47.5
OthOilSds		-395.4	-395.4	-322.4		81.5
VegFruits		-3,372.2	-3,372.2	25.6		-0.8
OilPalm	3,850.6	5,342.0	1,491.4		139	0.0
OilRape	4,456.9	2,474.4	-1,982.5		56	0.0
OilSoyb	2,063.5	1,270.8	-792.8		62	0.0
OilSunf	933.3	1,172.4	239.1		126	0.0
DDGSWheat		2,107.3		2,107.3		
DDGSMaize		2,261.7		2,261.7		
DDGSBeet		1,155.2		1,155.2		
MealPalm		59.8		59.8		
MealRape		3,645.6		3,645.6		
MealSoyb		5,463.4		5,463.4		
MealSunf		702.7	702.7	702.7		
OthFood		-3,139.2	-3,139.2	-114.6		3.7
Sugar		-1,881.3	-1,881.3			0.0

Source: Mirage-Biof Simulations

Note: A negative value for a demand displacement indicates a reduction in demand. A * indicates that demand displacement is positive for oilseeds since intermediate demand by the crushing sector is included here in the net demand from all sources.

If processed food sectors play an important role in releasing agricultural inputs, they are not the only contributing factors. Of course, non-food use of some goods (palm oil by chemical/cosmetic industries) is going to be reduced as well. However, the key sector for balancing the cereals markets is the livestock industry. As shown in Table 6, 90 percent of the displaced wheat and corn, about 13 million tons, is released by the livestock industry. However, the sector benefits from important replacement of these cereals by the DDGS and the meals generated by the biofuel scenario. On a ton basis, the 12.8 million tons of cereals and the 3 million tons of oilseeds released by the livestock sector are replaced by 15.4 million tons of co-products.[17] This shows the critical role of the livestock sector in the biofuel dynamics and the importance of modeling co-products and by-products.

The trade liberalization scenario will differ mainly through the effects on the ethanol feedstock channel, in which demand addressed to cereals will be weaker and decline in cereals production larger. They will generate less DDGS; the cereals consumption in the livestock sector remains important. However, the intermediate and final demands release more sugar.

As far as the livestock industry is concerned, the biofuel policies increase the price of energy contents in the crops (fats and sugar) but lead to a relative reduction of the price of proteins, increasing incentives to use more proteins. The overall effects on input costs for the industry depend on the proteins/energy ratio in the feed ration of animals by region and sectors and can lead to a different situation: the increased crop price can compensate partially or completely for the decrease in protein prices. This depends on the region and the sector. Table 7 shows that in the EU, the cattle sector benefits from the relative price decrease of proteins, whereas other animal sectors more intensive in cereals (poultry and hogs) are still hurt by the policy shock when looking at the total ration cost (total feedstuff cost).

An important principle in the CGE analysis is the interaction between relative prices and production allocation. Even with constant cropland area and constant yield, more energy, more fats, and more calories can be produced: it is just a matter of what is grown and where and what other agricultural production is sacrificed. The biofuels policy causes the relative prices to change and therefore reallocates production. The policy also provides a premium to fats and oils. This means that the world produces more fats and oils at the expense of other production for which relative value is declining, such as vegetable and fruits with low fat contents but high vitamin contents, the latter being depreciated in the scenario and without carbon consequences per se (reduced vitamin supply is bad for health but rather good in terms of carbon balance).

[17] The net balance will lead to an improved intake of proteins and a slight reduction in calories. Without having a more detailed model of the livestock sector (splitting dairy and meat cattle, hogs, poultry, etc.), it is difficult to consider whether this evolution is completely realistic or flawed.

Table 7 Average Feedstuff prices for the Livestock sector

	All Feedstuff		**Proteins feedstuff**	
	No Trade Liberalization	*Trade Liberalization*	*No Trade Liberalization*	*Trade Liberalization*
Cattle				
EU27	-0.16	-0.12	-3.87	-2.83
Brazil	-0.77	-0.52	-1.73	-1.37
SSA	0.20	0.16	-2.33	-2.08
USA	-0.03	0.04	-0.82	-0.64
OthAnim				
EU27	0.48	0.34	-3.87	-2.83
Brazil	0.11	0.25	-1.73	-1.37
SSA	0.33	0.30	-2.35	-2.07
USA	0.28	0.31	-0.82	-0.64

Source: Mirage-Biof Simulations

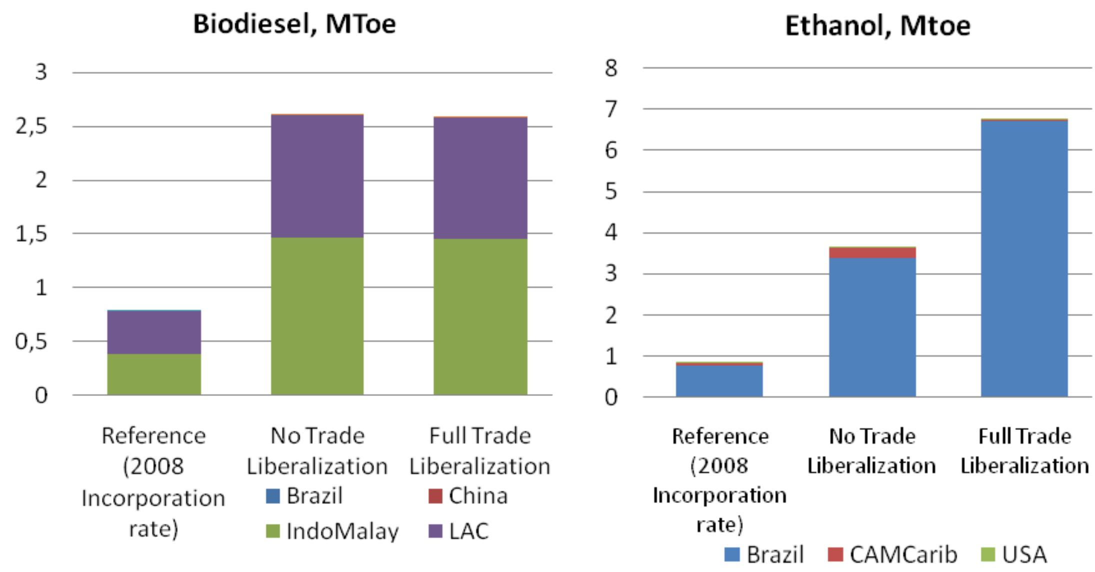
4.1.2 Trade consequences

Figure 3 shows the evolution of biofuel imports by the EU by type of biofuel and by origin. The picture is quite simple. Biodiesel imports[18] will triple with the scenario (additional mandate), while consumption will only double. The EU market will become more open due to the evolution of relative competitiveness between local and domestic sources. Trade liberalization does not have direct effects on the import of biodiesel when compared to the trade status quo scenario[19] and, with the elimination of US exports in the baseline, the main suppliers are South East Asia (Indonesia and Malaysia based on palm oil) and the rest of Latin America (Argentina based on soybean oil). For ethanol, the effects are much stronger. The additional mandate increases the imports five-fold without trade liberalization and nine-fold with trade liberalization. The multilateral trade openness will also eliminate small exports from Caribbean countries that would have otherwise benefited from preferential market access through the CARICOM Economic Partnership Agreement.

[18] Both biodiesel feedstocks and processed biodiesel.

[19] A small effect is driven by the ethanol market effect: by producing less ethanol domestically under trade liberalization, the EU can produce slightly more domestic feedstock for the biodiesel sector and marginally reduce its imports.

Figure 3 EU imports of Biofuels, Mtoe, 2020

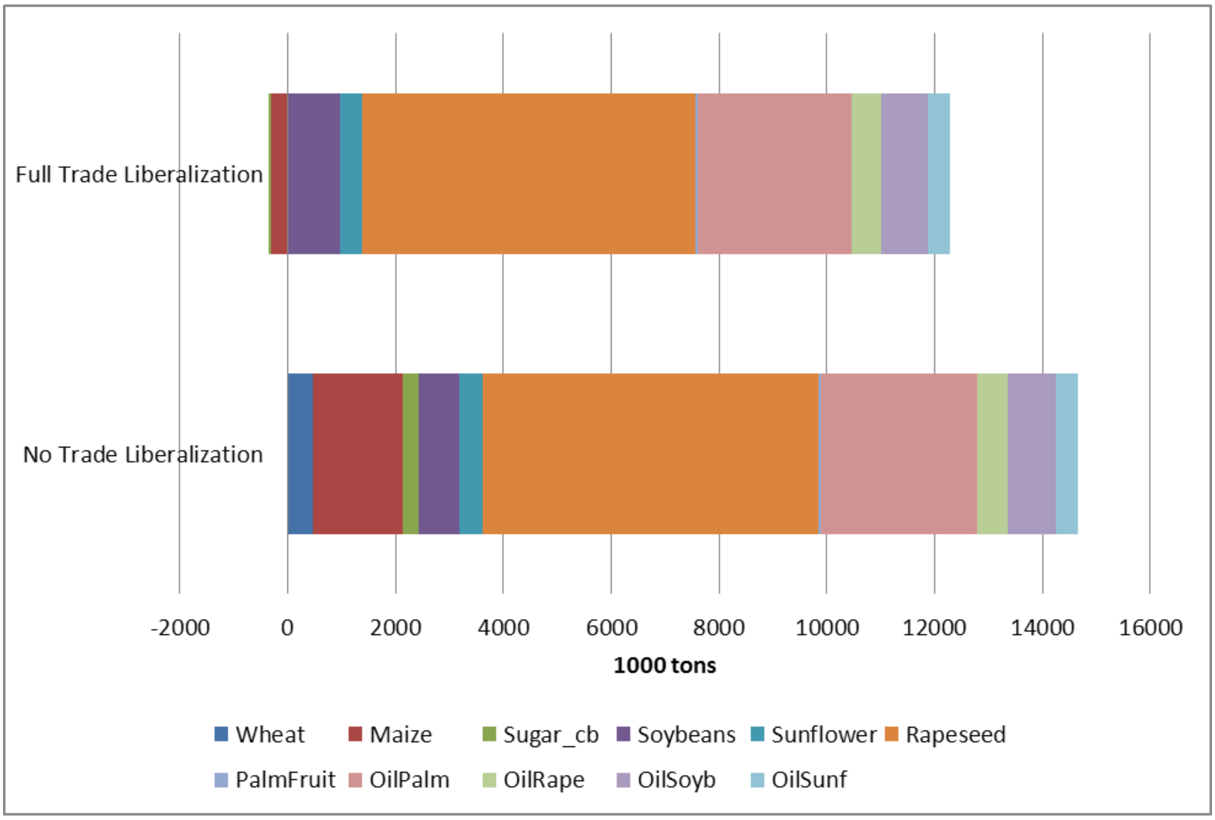


Source: Mirage-Biof Simulations

In terms of feedstock effects, imports of rapeseed increase drastically (see Figure 4). In addition, imports of rapeseed oil, palm oil, and soybean (both oil and beans) increase, although to a much lower extent than rapeseed imports.

Under no trade liberalization, the imports of wheat and corn increase due to greater domestic demand. Trade liberalization, on the other hand, leads to higher sugar cane ethanol imports, and less feedstocks, and does not generate an increased demand for cereals, as in the case with no trade liberalization. In addition, liberalization helps release a part of the feedstock used in the baseline; as a result, there is a decrease in maize imports.

Figure 4 Changes in EU imports of Feedstocks compared to the baseline, 1000 Tons

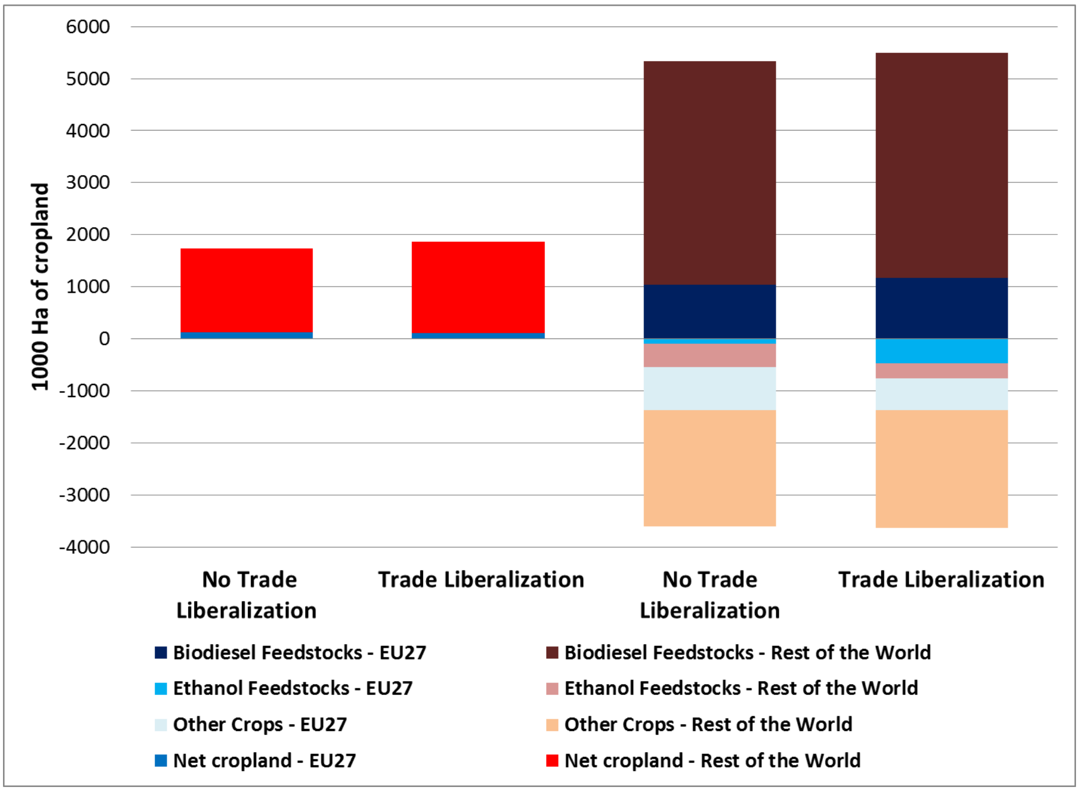


Source: Mirage-Biof Simulations

4.1.3 Land Use effects

The biofuels additional mandate will have important implications for land use patterns. The additional agricultural production requires additional cropland. Globally, the biofuels EU mandate simulated here leads to an increase in cropland area by 1.73 million hectares without trade liberalization and by 1.87 million hectares if trade liberalization is implemented. For comparison, it represents at the world level an area equivalent to one-tenth of the total amount of arable land in France or 60 percent of the total area of Belgium. The cropland extension taking place within the EU remains under 6 percent of global cropland extension and represents less than 0.15 percent of EU cropland regardless of whether free trade is implemented or not. Figure 5 shows this net cropland extension in the EU and in the rest of the world. It also displays how the extension of biodiesel feedstock takes land on the ethanol ones and other crops. With trade liberalization, we see that larger amount of land can be displaced in the EU from ethanol feedstock, allowing to limit the reduction in area used by other crops while in the world the ethanol production will be concentrated in sugar cane that has the highest energy yield by hectare.

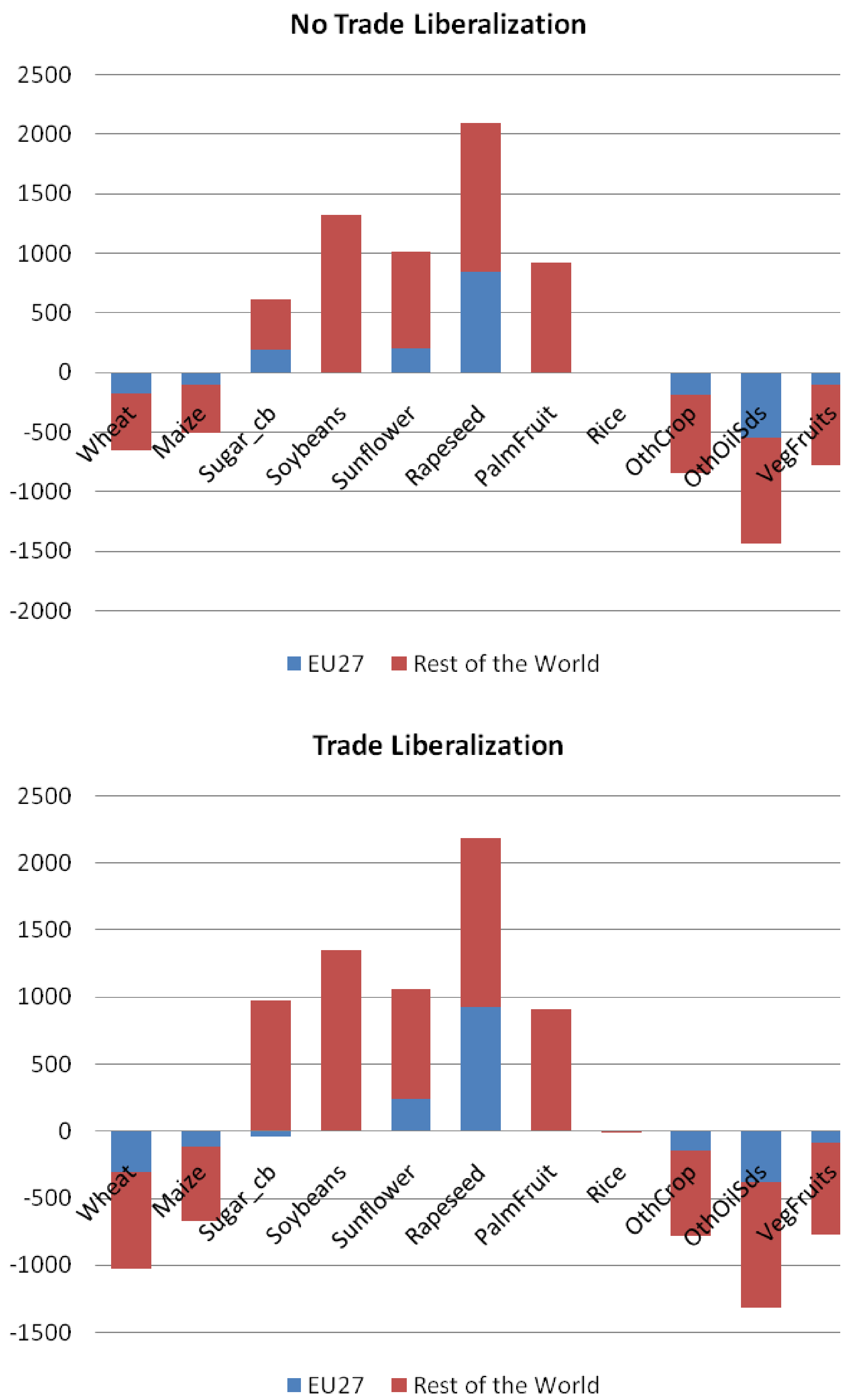
Figure 5 Overview of cropland changes, 1000 Ha



Source: Mirage-Biof Simulations

Figure 6 provides land use change effects for main crops. The increase in demand for biodiesel leads to an extension of the land area used for oilseed production. There are, however, important differences among feedstocks. Within the EU, the land area increases mainly for the production of rapeseed and, to a lower extent, sunflower. In addition, the land area for other crops and cereals decreases, especially in the EU. It is important to note here that rapeseed production displaces EU cereals. In terms of ethanol, the increased demand leads to the extension of the land area used for the production of sugar beet in the EU. This is not the case, however, if trade liberalization is implemented. Under trade liberalization, the world (mainly Brazil) expands sugarcane production and EU can grow 10 percent more rapeseed, taking land away from sugar beet and cereals. These results are consistent with the balance sheet analysis provided in Table 6.

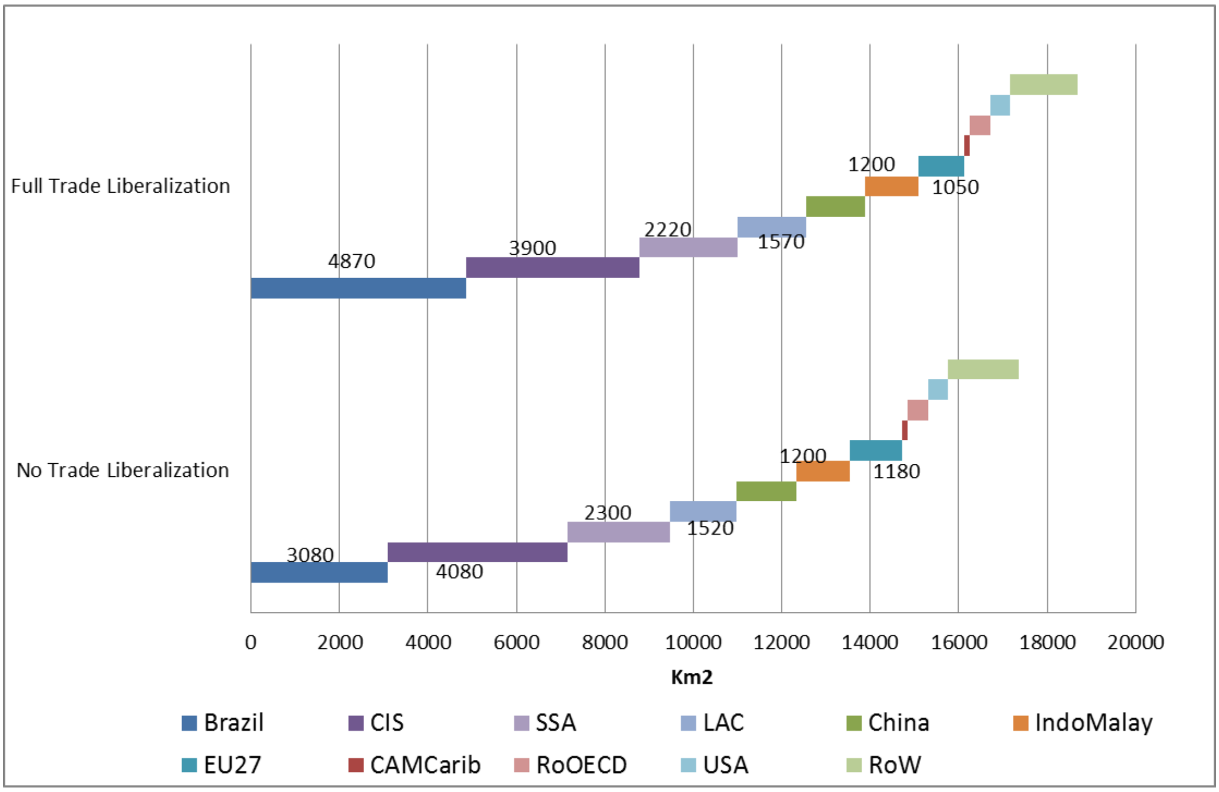
Figure 6 Land use changes for main crops, 1000 Ha



Source: Mirage-Biof Simulations

Figure 7 displays the regional breakdown of cropland extensions. The most affected regions in terms of cropland extension are Brazil, Latin America, CIS, and SSA. Without trade liberalization, the extension of oilseed (rapeseed, sunflower) and the relocation of cereals (wheat) production dominate the global pattern, leading to the concentration of most land use changes in CIS countries (e.g. Ukraine). Under the trade liberalization scenario, Brazil experiences the highest increase in terms of cropland, mainly due to the increase in demand for ethanol and thus for sugar cane. It is also important to note here that Brazil is characterized by a high elasticity of land extension, which also contributes to the increase in the amount of cropland in that country.

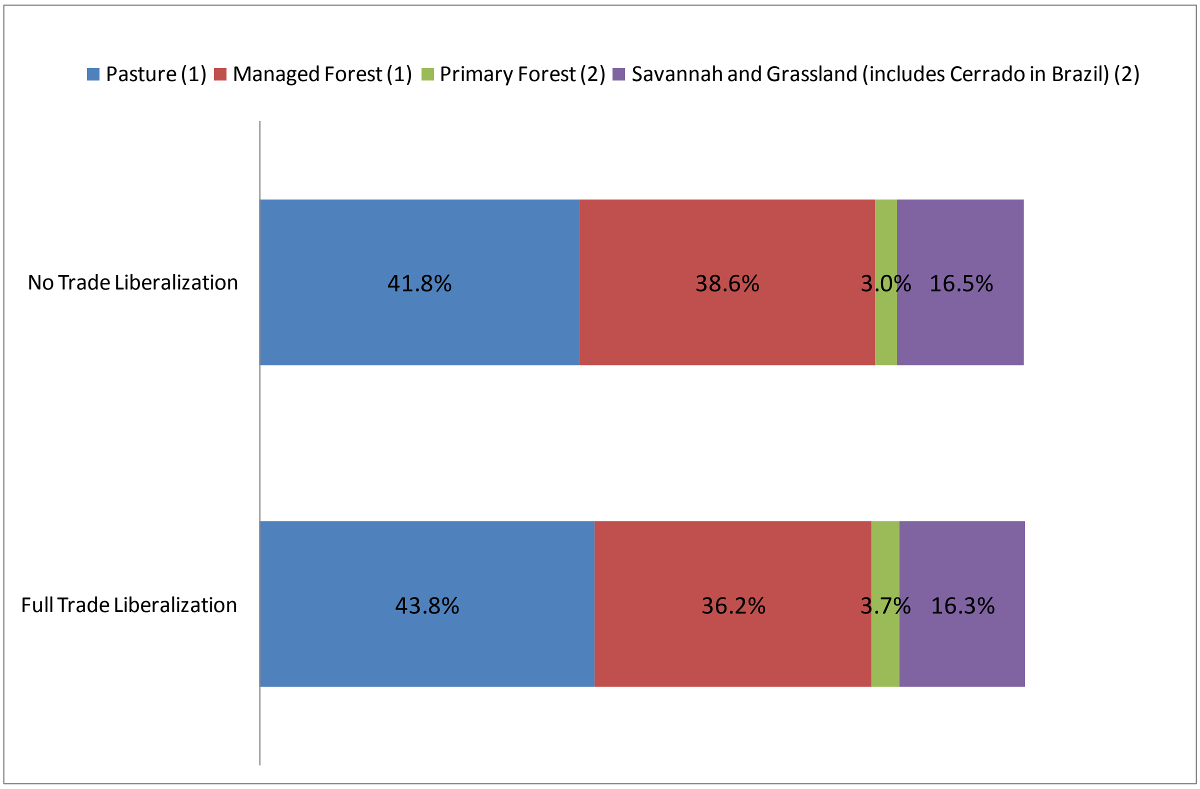
Figure 7 Location of cropland extension. Changes compared to the baseline. Km2



Source: Mirage-Biof Simulations

Figure 8 displays the sources of extension of cropland worldwide. Pasture and managed forest represent the two major sources of cropland extension, followed by savannah and grasslands and primary forest. Pasture can shrink for two key reasons: i) a decrease in meat production (due to land competition with cropland and increased price of cereals in countries with cereal-rich feeding strategies and limited substitution with co-products) and ii) more intensification due to lower protein prices. The case of Brazil illustrates how sugar cane displaced pasture upon the implementation of trade liberalization. Primary forest also plays a minor role as a source of cropland extension; the effects are slightly larger with trade liberalization in which some displaced pasture in Brazil can still increase deforestation *in fine*.

Figure 8 Distribution of source of cropland (world)

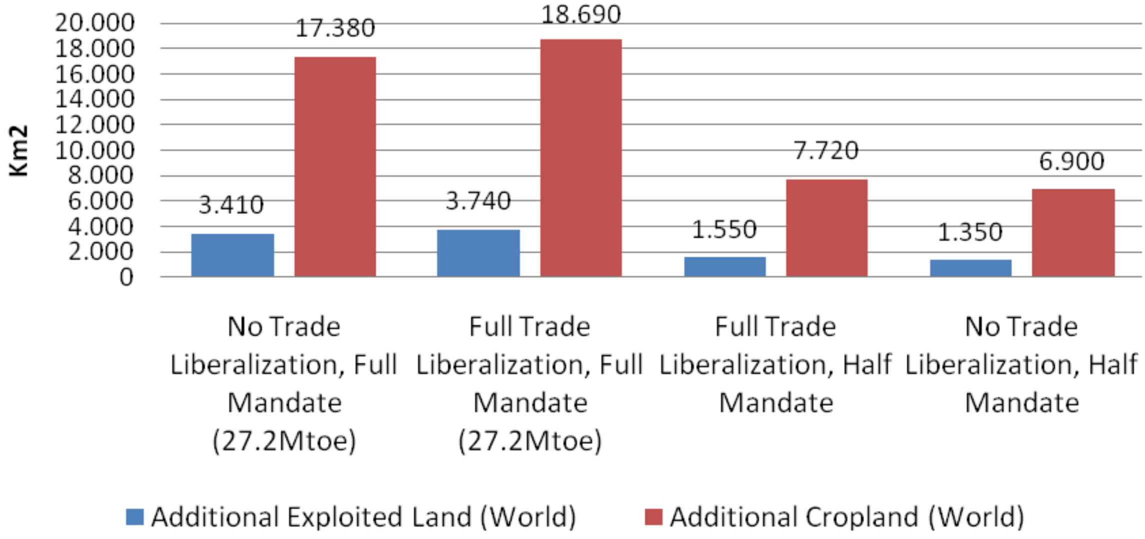


Source: Mirage-Biof Simulations

Note: (1) indicated managed land, (2) unmanaged land. Total amount of additional cropland is 1.7 Mio Ha without trade liberalization and 1.8 Mio Ha with trade liberalization.

Figure 9 compares the expansion of cropland into previously unexplored land with the total additional cropland necessary in the additional mandate. This confirms the findings in Figure 8, in which 80 percent of the land use change takes place within managed land. To look at the potential non linearity of the policy, we compare the effects of the half additional mandate to the full additional mandate. We find that this ratio is quite stable even if the amount of land required increases more than proportionally with the policy.

Figure 9 Cropland extension vs. Exploited land extension. Km2



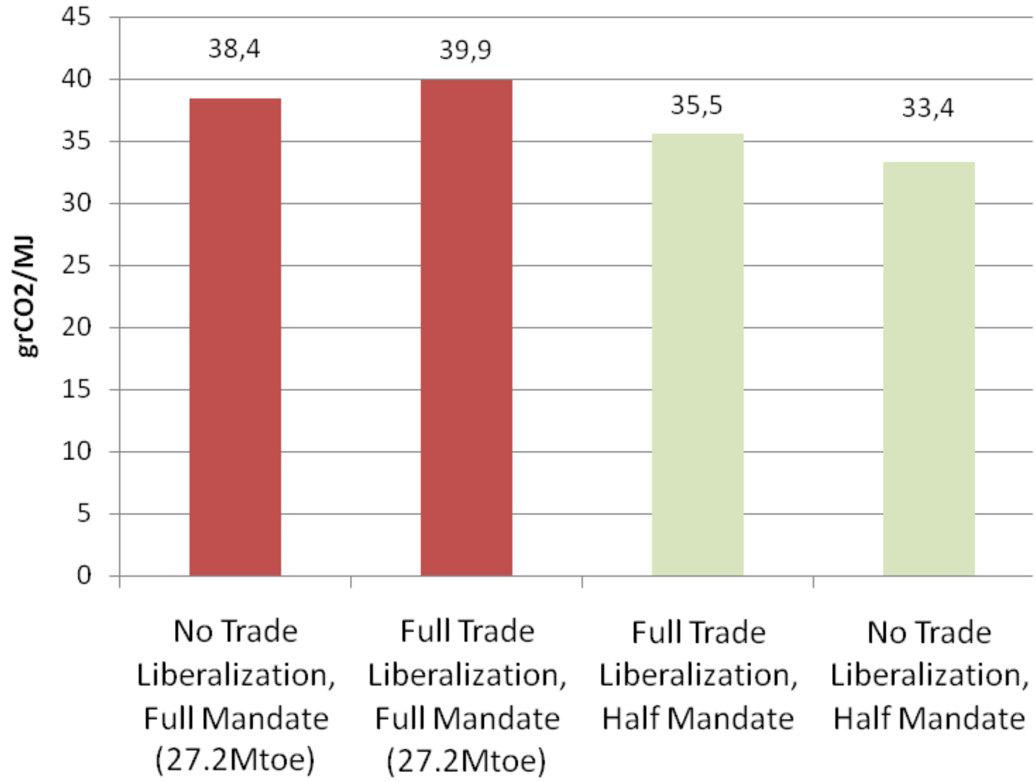
Source: Mirage-Biof Simulations

Note: Additional Exploited land represent the net increase in total pasture, cropland and managed forest that has to come from pristine environments (unmanaged land: primary forest, savannah and grassland in figure 8). Therefore the difference between cropland and exploited land represents the amount of cropland released by pasture and managed forest.

Combining land use changes and carbon stocks, we can compute the LUC coefficient of the policy displayed in Figure 10. The land use emissions, computed over a 20 year period,[20] remain large, with a coefficient of 38.4 grCO2eq/MJ without trade liberalization and 39.9 with trade liberalization. This difference is explained by the larger amount of land needed under free trade. The figure also shows the result for a half additional mandate that confirms our previous results. Non-linearity appears and is driven by the mix of ethanol/biodiesel. Since we implement the additional mandate and the change in composition linearly, the marginal composition of the first half mandate is 55 percent biodiesel/45 percent ethanol vs. 65/35 in the full additional mandate. This is driven by the requested catching-up of ethanol consumption at the beginning. Indeed, ethanol feedstocks have a lower LUC effect than the biodiesel feedstocks (see next section).

[20] The 20 years period is chosen to be consistent with the RED directive. It implies that total land use related emissions are divided by 20.

Figure 10 LUC emission coefficients (grCO2/MJ), annualized over 20 years



Source: Mirage-Biof Simulations

Figure 11 displays the source of CO2 emissions. Due to the share of biodiesel and vegetable oils in the additional mandate, the peatland emissions represent one-third of total emissions, when representing only one-fourth of the global land use change.[21] All vegetable oil markets being strongly integrated, palm oil plays an important role as a direct feedstock (and has been consumed as biodiesel after being processed in the EU or in Indonesia/Malaysia) or as a replacement for other oils displaced from other uses. Primary forest plays a minimal role in overall emissions since direct deforestation will be limited. However, the competition between cropland versus managed forest (or replanted forest) and pasture–savannah - including the Brazilian Cerrado - type environment (releasing carbon from the soil) will be strong.

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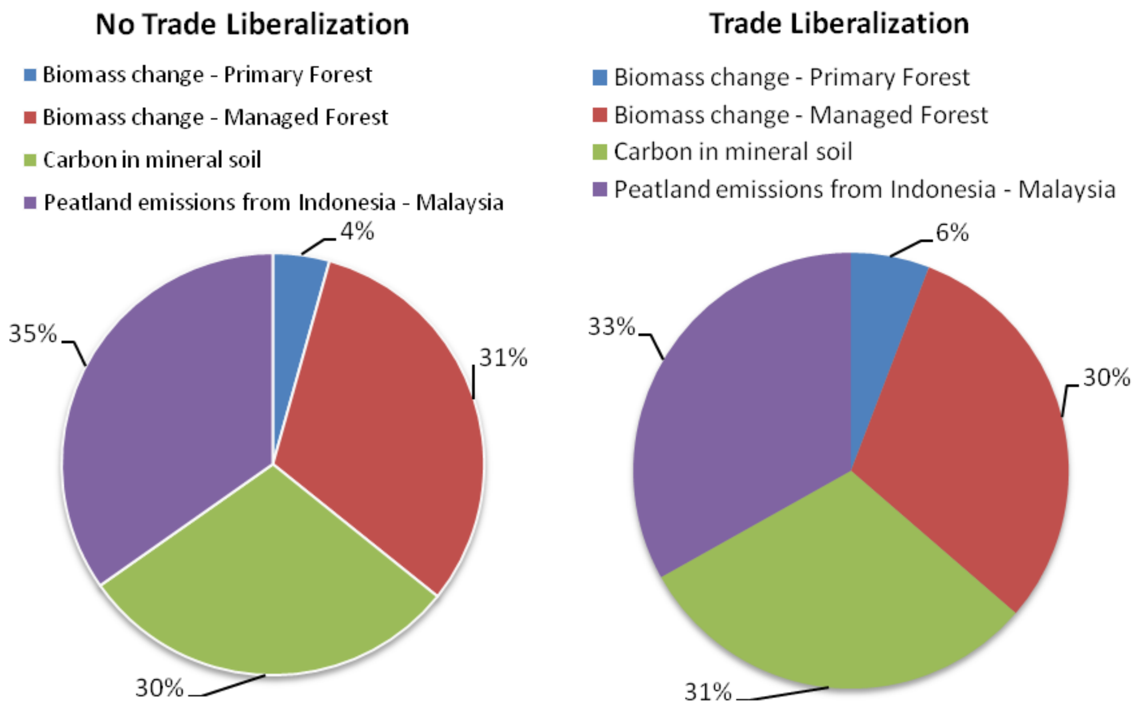
[21] Palm production in South East Asia represents 25 percent of net total cropland expansion in our simulation. We assume that 30 percent of palm extension is done on peatlands. Emissions from peatlands have been adjusted upwards compared to the previous report (from 19 to 55 t CO2eq/ha yr). However, uncertainty remains. Recent research (Page, S. E., Morrison, R., Malins, C., Hooijer, A., Rieley, J. O. & Jauhiainen, J. 2011 suggests that it could even be higher, at around 86 t CO2eq/ha/yr with emissions annalised over 50 years after conversion. Annualizing over 20 years will lead to a value of 106 t CO2eq/ha/yr. In this case the LUC results reported for oilseeds will increase significantly. For example for palm oil, the central average estimated indirect land use change emissions could increase to 84.6 grCO2/MJ.

Figure 11 Source of emissions



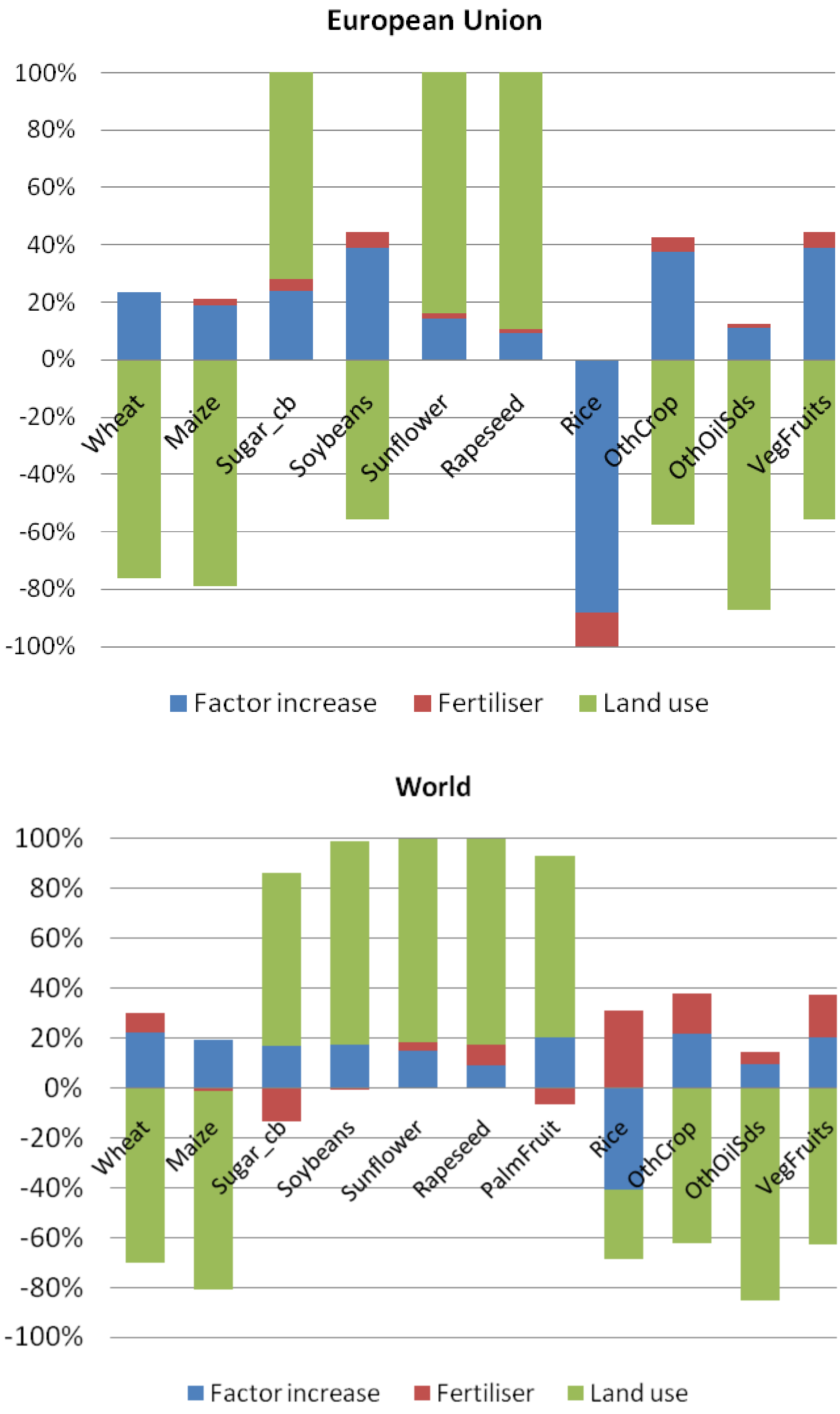
Source: Mirage-Biof Simulations

Figure 12 discusses the relative role of intensification and extensification in our results. In absolute terms, land use effects dominate. More than 80 percent of increased production of key oilseeds and sugar crops comes from additional land. For other crops, for which most area decreased, the production level tries to be stabilized through higher yield. At the world level, due to initial lower fertilizer use rates, more intensification can be achieved through additional fertilizer, while such a result is very difficult to achieve in the EU (especially for cereals, for which we have already reached maximal level of inputs in the baseline).

Figure 13 translates the relative yield increases in production as a change in tons per ha for the world average. It can be compared to values of Table 2; it appears that the intensification effect, even if it is critical in mitigating the demand of land use for biofuel feedstocks and for avoiding demand reduction of other crops when land is displaced, does not lead to incredible yield increases. Cereals can represent an increase of 0.32 percent of yield in the EU for corn, 0.25 percent for wheat, up to 4 percent for sugar beet yield (that has been reduced in the baseline with the deregulation of the sugar market), and 1.4 percent for rapeseed.

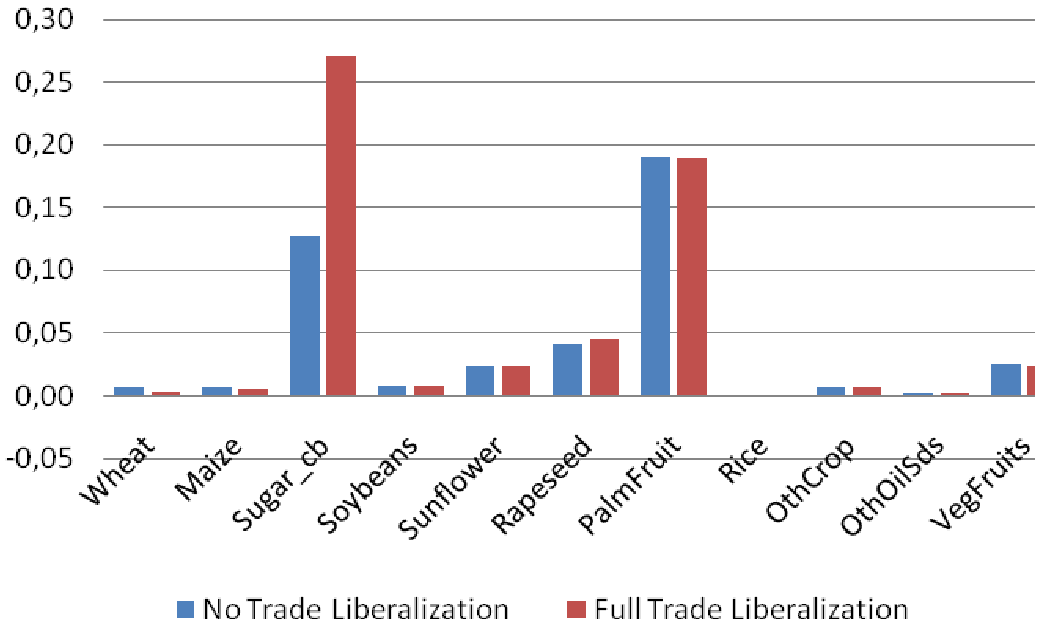
At the world level, increase in yields is not only driven by changes in factor and fertilizer (intensification), but also through the composition effect of land use. Reduced area of maize (-0.1 percent, -4,000 ha in the no trade liberalization scenario) in the EU, with an average 1.8 tons by ha, and increased area in Brazil (+1.1 percent, +300,000 ha), with an average yield of 3.5 tons by ha, leads to an automatic increase in world average yields.

Figure 12 Intensification and Extensification drivers. Normalized effects: Additional Mandate, Trade Policy Status Quo



Source: Mirage-Biof Simulations

Figure 13 Effects on average World Yield. Changes compared to the baseline. Tons by Ha



Source: Mirage-Biof Simulations

Applying direct savings coefficients (assuming improved 2020 technology and the respect of EC emissions criteria, see Table 9 for precise values and Appendix VI) to the different source of biofuels, we establish the carbon balance sheet displayed in Table 8. With a 20 year amortizing period for carbon released from land use,[22] land use emissions represent two-thirds of total direct savings. Net emission savings are limited to 21 percent of the fossil fuel reference or 19 grCO2eq/MJ.[23] We assume that all pathways will qualify to the EC sustainability scheme that requires direct savings of at least -45g/MJ or 50 percent of fossil fuel emissions (with a reference of 90g/MJ). Under 2020 improved technologies, i.e. new plants, this assumption appears to be challenging only for the soybean pathway. The EC sustainability scheme may also has impact on the LUC effects, as it may put constraints on the mix of feedstocks that are used as well as their origin, but we do not model this potential effect explicitly. At the same time, we also need to keep in mind that our study does not include other source of emissions e.g. fertilizers (a more limited issue, see Appendix VI), or the overall leakage effects on the oil markets i.e. the fossil fuel consumption saved by the EU will be consumed by other countries.

[22] It is important to keep in mind that the choice of 20 years for the amortization of LUC related emissions is arbitrary but consistent with the RED framework. In addition, the temporal emission profile is strongly asymmetric since the CO2 release due to LUC effects will take place in the next decade, before 2020, when most emission reductions driven by direct savings will take place in the second half of the decade and after 2020.

[23] Exact values give slightly higher net saving emissions for the trade liberalization case with 19grCO2eq by MJ compared to the trade policy status quo (18.3 grCO2eq).

Table 8 Carbon balance sheet for the additional mandate of the NREAPs

	No Trade Liberalization, Additional Mandate	Full Trade Liberalization, Additional Mandate	No Trade Liberalization, Half additional Mandate	Full Trade Liberalization, Half Additional Mandate
Annual LUC emissions (grCO2eq/MJ, 20 years)	38	40	33	36
Annual direct savings (improved technology in 2020) (grCO2/MJ of EU Consumption)	57	59	57	63
Net Emission Savings (grCO2/MJ of EU Consumption)	19	19	24	27

Source: Mirage-Biof Simulations

Note: Direct savings coefficients are based on the EU impact assessment and discussed in Appendix VI. the LUC emission coefficient is estimated on the amount of additional biofuels needed to reach the NREAPs from the baseline and is discounted by 20 years. Net emissions are computed under the assumption of no leakage effects on the energy market.

This later effect can be quite large but depends drastically of how oil producers will decide to stabilize their prices by reducing their own production. In these conditions, the net emissions balance of biofuels is even more uncertain to assess. For the sake of illustration, the current model that does not assume strategic stabilization of oil prices, and was not developed to focus on the fossil fuel sector, finds that the world price of oil will decrease by 0.94 percent. Under this result, we find a global leakage effect through the road transportation sector (a subset of oil usage) of 30 percent, meaning that the additional 15.5 Mtoe of biofuel consumed within the European Union leads to a reduction in fossil fuel for road transportation of only 11.3 Mtoe at the world level. The domestic leakage effect within the EU being negative in the sense that fossil fuel consumption for road transportation drops by 15.9 Mtoe, more than the biofuel consumption, due to the price increase at the pump led by the mandatory blending policy.

Another limitation related to the use of the existing direct savings coefficients is the accounting of CO2 uptake and loss related to diverted agricultural production (EEA, 2011). Indeed, our LUC coefficient computations focus on the emissions driven directly or indirectly by the expansion of cropland has a reaction of the biofuel additional mandate. Nevertheless, as shown in Table 6 the policy leads to a decrease of the biomass production in several agricultural sectors (e,g, vegetables, other crops, even cereals). This displacement effect reduces the land use emissions but also implies that a share of the emissions saved by the use of biomass in road transportation is achieved by a reduction in emissions by other biomass consumers (food consumers, cotton consumers…). In simpler terms, if one hectare of wheat was used initially to provide input for the food sector and is now used to provide feedstocks for an ethanol sector, the accounting system discusses in this section will record no LUC emissions, but a direct saving effect through the replacement of fossil fuel by biofuel even if the same amount of CO2 captured has been captured by the biomass before and after the policy.

Trade liberalization, even if it released more CO2 from land use, increases the share of low emissions produced sugar cane ethanol (large direct savings coefficients) and remains a valuable option, including from an economic point of view since sugar cane ethanol is a more efficient product. A key element in comparing the net emissions between the two trade policy alternatives is the share of beet ethanol (largest net savings among EU feedstocks, see next section) in the EU domestic production of ethanol. Indeed, only sugar beet pathway can compete with sugar cane in terms of direct savings. The half additional mandate target, with the larger marginal ethanol component, allows net savings of up to 27 grCOeq/MJ when free trade is implemented. In addition, trade liberalization will also reduce the cost of implementing the mandate since imported ethanol will be less expensive than domestic production. It will lead to a more efficient outcome for each ton of CO2 saved.

Appendix V provides a detailed comparison with the previous assessment of EU policy by Al Riffai, Dimaranan, and Laborde (2010), which includes an average LUC emissions factor of 17grCO2eq/MJ for the full additional mandate under trade policy status quo and about 10 percent more under trade liberalization. However, the scenario was quite different: 55/45 percent of biodiesel/ethanol and a 5.6 percent mandate instead of 8.7 percent. In addition, peatland emissions were largely underestimated compare to current values. The last replacement ratio for co-products has been updated. Our new results (38 grCO2eq/Mj and 40 under trade liberalization) are largely higher than the previous values. The main explanation for this is the structure of the mandate and the ratio of ethanol/biodiesel. Using a ratio similar to the previous study with the current model and parameter values, we find LUC emission coefficients of about 20grCO2 for such a “virtual” mandate, which is very close to previous estimates. Current values are still larger, due in large part to the increased emissions of peatlands and the more inelastic food demand.

4.2 Crop specific results

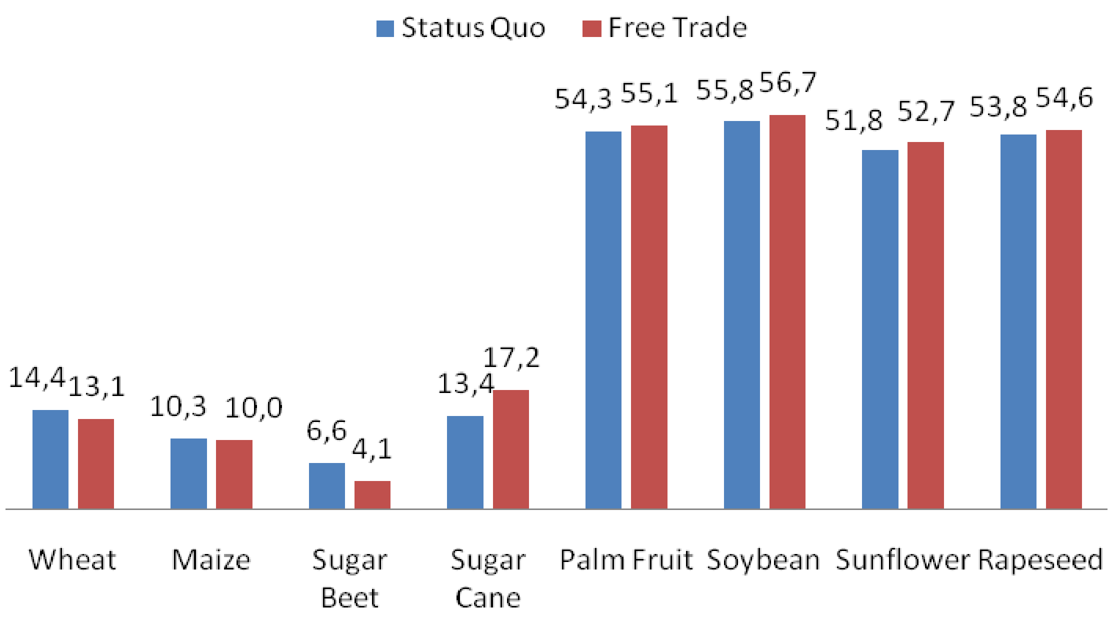
In the previous section, we have estimated the impact of the EU mandate by increasing the size of the mandate for ethanol and biodiesel, letting the model defining which crop mix will be used to fulfill the policy commitments. We have computed the average LUC effects of this policy. As a matter of fact, we have even found that the relative competition for cropland between rapeseed and wheat can even decrease the total of land allocated to wheat while wheat demand for ethanol has increased. In this section, we estimate crop-specific LUC effects by applying the methodology described in 2.1, i,e, increasing the blending rate in the EU by 0.5 percentage points (from 8.2 percent to 8.7 percent) and restraining the additional biofuel supply to be provided by only one type of feedstock at a time. Thanks to this procedure, we can focus on land use emissions. Following this, we decompose the results by source of main explanations (intensification, role of livestocks, carbon stock values).

4.2.1 LUC emission coefficients

Figure 14 provides the LUC emission coefficients for each crop and the different trade policy options. There are large differences between the LUC effects of biodiesel feedstock, ranging between 52 and 57 grCO2eq/MJ and ethanol crops between 4 and 17 grCO2eq/MJ. Biodiesel feedstocks have larger LUC effects, but vegetable oils are better integrated markets, which explains the smaller difference in the range of LUC effects (only 20 percent difference between the lowest and the highest value) compared to ethanol LUCs for which the difference between the lowest and the highest values is four-fold. This is due to very high Armington substitution elasticities used in this study in terms of production (origin) for vegetable oils and the substitution between different oils in the demand system. Nevertheless, Armington elasticities are also very high for cereals, which means that the important link here is through substitution of vegetable oils in the intermediate (for biofuels or other sectors) or final demand.

For ethanol, where there is a large difference in terms of the LUC emission effects of different feedstocks, sugar beet has the lowest land use emission coefficients, whereas sugar cane has the highest. Among vegetable oil, sunflower appears to be the best feedstock in terms of the LUC emissions, compared to soybean which has the highest LUC emission coefficient. By placing greater pressure on sugar cane ethanol and less on other ethanol feedstocks, trade liberalization pushes the coefficient of sugar cane upward (due to small non-linearity of the model).

Figure 14 LUC emission coefficients (grCO2eq/MJ) by feedstock estimated at the mandate level and alternative trade policy options



Source: Mirage-Biof Simulations

Table 9 combines the LUC coefficients with values for direct saving coefficients. Net savings are achieved by all ethanol crops assuming 2020 efficient technologies, only wheat does not reach a 50 percent of net saving coefficient against fossil fuel over a 20 year period. Table 9 displays results for both trade policy scenarios. The key results are not altered and only the ranking between sugar beet and sugar cane is modified depending on the relative pressure put on the two crops. Regarding the trade liberalization scenario, we should make three remarks: first, average direct savings by crop are still dependent of the place of processing of biofuels and is influenced by the trade pattern. However for each specific crop, the available technology among the key processors and exporters are assumed to be similar.[24] Second, trade policy scenario influences mainly the relative feedstock contributions (e.g. wheat ethanol vs sugar cane ethanol) and through this channel the emission balances. For a given feedstock, both the land use effect but the direct savings are quite stable to trade policy options (multilateral liberalization, not bilateral agreements that will potentially biased the land use towards some regions) considered in this report. Put it differently, biofuels trade policy has more impact on the type of feedstock used to produce the biofuels consumed in the EU than on the crop-specific coefficient. Last, even if for a given crop, land use effects will vary significantly from one country to another, we do not compute LUC coefficient by crop and country. Two reasons justify this choice. First, country specific LUC coefficient will be quite difficult to use in a policy context since it will lead to strong discrimination among countries and will lead to conflictual situations in a WTO context, in particular when the degree of uncertainty of LUC computation is very large when we reach this level (crop/country). Second, due to high degree of substitution across origins for one product (e.g. US corn and South Africa corn, or Australian wheat and Ukrainian wheat etc), the leakage effect at a product level will be very large, meaning that the global effects of displacing one unit of crop *x* from country a will be very close to those of taking it from country *b*.

[24]This situation involves an underlying assumption that main producers will still implement similar efforts to process biofuels in an efficient way and that, for one feedstock, some countries/producers supply the markets with clean technologies when others will use obsolete/emissions intensive technologies for the biofuel consumed in the baseline.

Table 9 LUC emissions, Direct savings and Net emissions (grCO2eq/MJ) of EU Consumption, 20 years

		No change in trade regime		Free trade in biofuels	
	Direct Savings (Improved in 2020)	*LUC emissions*	*Net Savings*	*LUC emissions*	*Net Savings*
Bioethanol					
Wheat	57	**14**	*43*	**13**	*44*
Maize	58	**10**	*48*	**10**	*48*
Sugar Beet	63	**7**	*56*	**4**	*59*
Sugar Cane	70	**13**	*57*	**17**	*53*
Biodiesel					
Palm Fruit	58	**54**	*4*	**55**	*3*
Soybean	45	**56**	*-11*	**57**	*-12*
Sunflower	58	**52**	*6*	**53**	*5*
Rapeseed	50	**54**	*-4*	**55**	*-5*

Source: Mirage-Biof Simulations, JRC-COWI and EC Impact Assessment for direct savings values.

Note: For direct savings, values are explained in Appendix VI. For wheat, it implies the full adoption of "natural gas as process fuel in CHP plant" pathway and for palm oil the "*methane capture at mill*" technology. In the case of soybean, the minimal threshold of 50 percent is assumed even if no pathway reach this value yet.

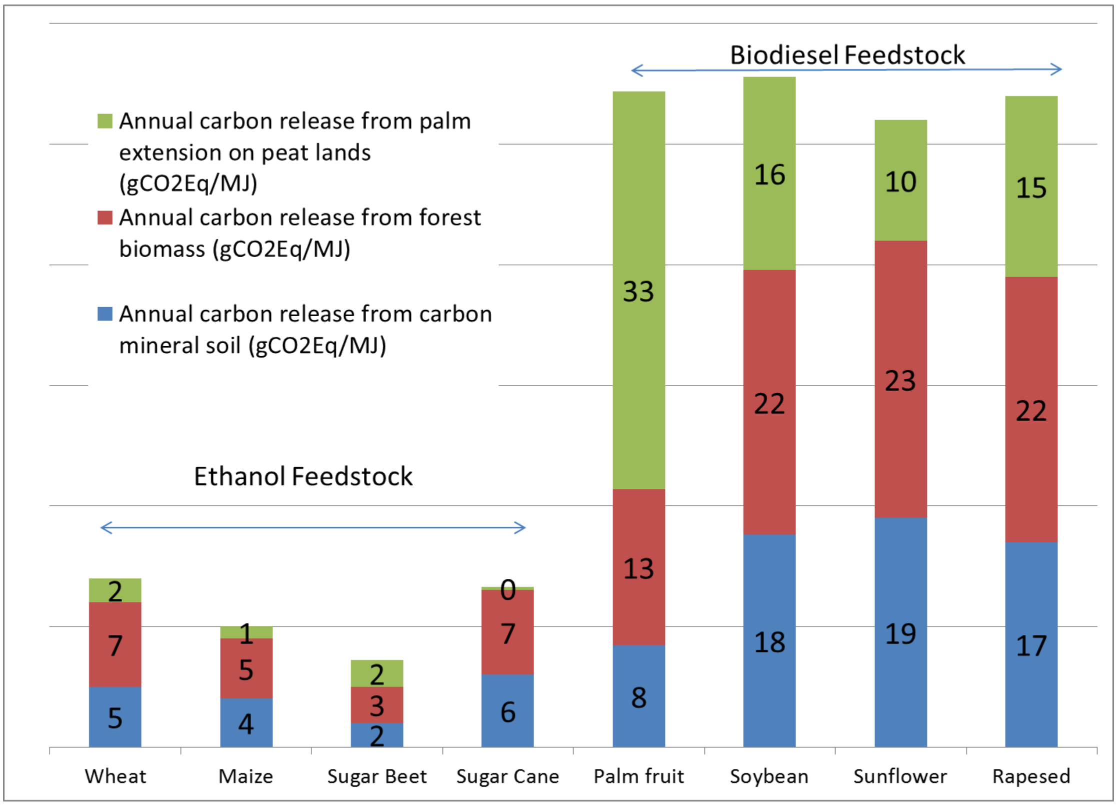
The case of sugar cane is important to discuss. Even if land use effects are larger than for other ethanol feedstocks[25] and affect a sub-region with potentially high-value carbon stocks through indirect channels, the net effects are very favorable to this feedstock. Indeed, sugar cane processing technology is the most efficient in terms of energy consumption since it releases electricity (co-generation). This illustrates a key element of comparing feedstocks: co- and by-products of cereals or oilseeds are aimed to save land (by replacing a feed demand) and therefore deliver a shadow credit to the LUC computation in our model. Sugar cane is completely different since, with co-generation, electricity is the co-product of ethanol production and saves CO2 not through the land market, but directly through the energy market. Therefore, sugar cane is not benefiting from a LUC reduction to its co-product in our framework.

[25] We use quite large elasticity of expansion for Brazil, compared to the US and the EU (i.e. four times larger), that does not strongly constrain land expansion in this region. Current policy reforms in Brazil on the forest code will provide an important signal about how the enforcement and protection of forest will take place in the future. Potentially, it can confirm the recent trend that has shown a massive slowdown of deforestation and improved land use management. This trend is poorly reflected in the elasticity of this study, reflecting the average behavior of the last decade with episodes of high and low deforestation rates. In such a case (enforceability of conservation law in the future), the sugar cane LUC effects will be reduced in significant proportion. Lastly, we also assume that marginal yields on new land for Brazil are only 75 percent of the average level, while this value can be closer to one after several years of good agronomic practices in the case of sugar cane, for instance. In addition, our assumption about how the Brazilian livestock industry can move for more intensive production system – in order to use release pasture land for crop production – remains conservative.

The LUC coefficient of biodiesel crops are quite large compared to ethanol ones. We discuss the role of peatlands in the next paragraph and more in depth explanations among the different crops in the next subsection. However, we need to discuss a key consequence of Table 9. It appears that biodiesel crops will generate low emissions savings or even positive emissions by MJ of biofuel as soon as we consider the LUC values displayed here combined with direct saving coefficients and a 20 year amortization period. Among biodiesel feedstocks, only sunflower oil and palm oil generate direct savings, but sunflower remains the most costly biodiesel feedstock and that for palm oil it requires that all the additional production is produced in installations equipped with methane capture facilities. Therefore, in order to achieve net emission savings it is critical that the processing of biodiesel technology improves and that direct savings increase. For instance, with a 66 percent direct savings (60gr/MJ), the biodiesel pathway may contribute to emissions reduction, considering the average LUC values displayed in Table 9.

The most important source of LUC emissions is peatland for oilseeds, in which case palm oil plays a critical role, contributing up to 70 percent (Figure 15). This is consistent with Figure 11, in which peatland emissions represent one-third of total emissions as a result of the share of biodiesel and vegetable oils in the mandate. Even for cereals, the indirect effect of palm production is not negligible (more than 10 percent of emissions for wheat/maize). Indeed, the DDGS also replaces meals from conventional oilseeds and reduces their production. At the same time, palm oil production will increase to stabilize the oil market.

Figure 15 Crop specific LUC emission. Breakdown by source of emissions



Source: Mirage-Biof Simulations

Figure 16 displays the "weak" non-linearity. We measure the LUC coefficient at two points during the implementation of the additional mandate (final point and intermediate point). The non-linearity is weak since we do not investigate the alternative size of demand increases for one feedstock (1 /5/10 Mtoe provided with one crop) but only look at the same shock at different points of the overall crop demand. It will display stronger effects but may not be reasonable with the overall inertia of the full mandate. The non-linearity is small but important, especially for rapeseed (8 percent higher when the reference value consumption level of the additional mandate is doubled) which is already the tensest market. For sugar, on the other hand, non-linearity is almost non-existent along the mandate path[26].

There is a combination of several factors that drive nonlinearity:

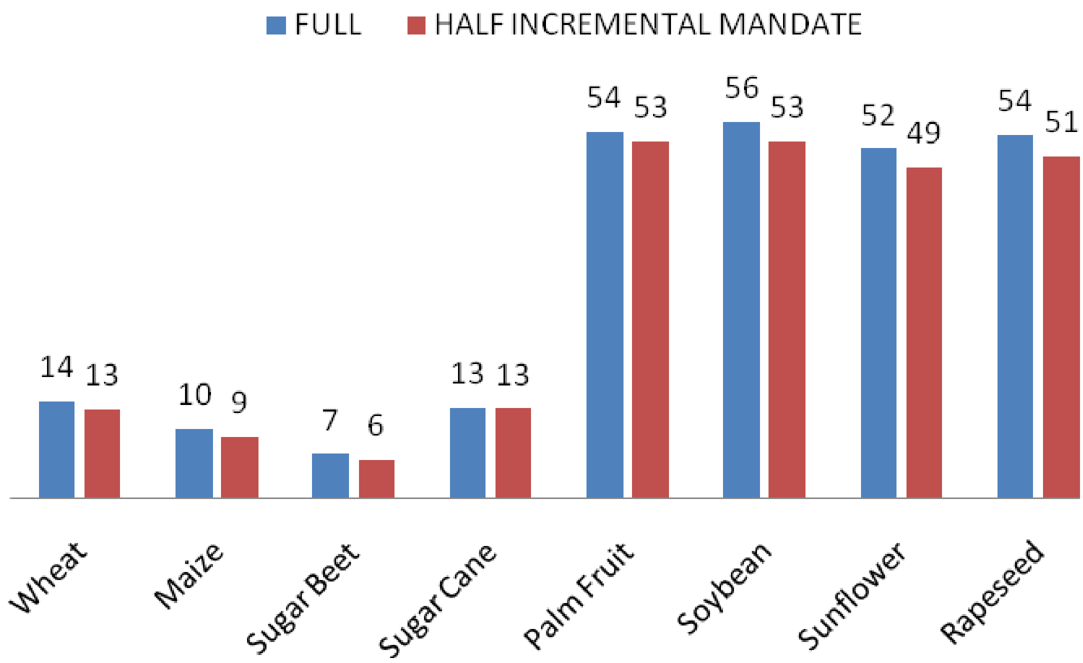
- The capacity to substitute one type of land for another. This is represented by the concavity of the CET function in the land use module. From the modeling point of view, the CET framework is not completely satisfactory, but it remains the mainstream approach used in the literature. However, in reality, farmers continue to have diversified production, even if the price of one commodity dominates the others; this

[26] But as shown with the trade liberalization scenario, non linearity can be quite important for this crop too when the total amount of a specific feedstock (sugar cane or sugar beet) is changed significantly.

needs to be taken into account. For example, although the wheat price is high, not all land in Europe is shifted to wheat. There are many possible reasons for this: farmers' desire for diversification, 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 easily shift "some" units of land to the expanding crops, they will not do it in a linear way. They will eventually stop converting; if they want to produce more of one crop, they will go for "new" land while keeping their other production at a certain level. This 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).

- 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 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.

Figure 16 Potential non-linearity in crop specific LUC emission coefficients. grCO2eq/MJ. No trade liberalization case.



Source: Mirage-Biof Simulations

Note: We estimate the crop-specific LUC emission coefficients at the end of the mandate and at a mid-point of the additional mandate.

4.2.2 Explaining the differences

This subsection discusses the different mechanisms that explain key difference among crops. Box 3 provides the insights behind the key differences between biodiesel and ethanol results. There are three main channels that explain the large differences of LUC effects among crops discussed earlier:

First, as the biofuels drive up the demand for feedstocks, it is important to know how much of this demand is met by additional production and how much is displaced from other uses. This is important for two key reasons: *i*) additional feedstock production affects the way in which land is used and *ii*) displacement of biofuels feedstocks from other uses represents a political economy issue embodied in the fuel vs. food and fuel vs. feed debate.

Second, additional feedstock production to meet the new demand can come from yield increase intensification or land expansion. When additional land is required to grow a particular feedstock, this land is either taken away from other crops or other productive uses (forestry or pasture) or is expanded by acquiring new land.

Third, when land for feedstock production is expanded in pristine environments (or even managed forest/pasture) it will have different consequences for different regions depending on their carbon stocks. Then, different feedstocks will have different implications for different regions.

Table 10 Ratio Additional Supply/Biofuel demand. Percent.

Sugar Beet	94.40
Sugar Cane	98.30
Maize	56.69
Wheat	51.38
Palm Fruit	96.6
Rapeseed	78.2
Soybeans	40.3
Sunflower	71.0

Source: Mirage-Biof Simulations

Table 10 provides the replacement ratio of different crops between the biofuels consumption and additional supply. Some results at the crop level are very consistent with the additional mandate balance sheet analysis provided earlier in Table 6 (except for wheat and corn where the competition for land with oilseeds in the overall additional mandate scenario was leading to a decrease in supply). For sugar beet and sugar cane, the displacement of traditional sugar demand is limited. The increased demand for sugar cane and sugar beet as a result of higher ethanol consumption in the EU is almost completely met by additional supply (98 percent in the case of sugar cane and 94 percent in the case of sugar beet). Palm fruit represents a similar case. As palm fruit mainly produces palm oil, any displacement of palm oil as a result of the increased demand for biodiesel production will have to be met by an additional supply of palm oil, the most competitive vegetable oil.

For other oilseeds, the direct replacement ratio is lower for rapeseed (80 percent), sunflower (70 percent), and soybean (40 percent). This, however, does not mean that soybean oil disappears without being replaced. Instead, soybean oil is replaced by palm oil. This replacement explains why soybean noted the largest peatland effects in Figure 15 compared to rapeseed and.

The situation is different for wheat and maize, however, where the direct replacement ratio is low, between 50–60 percent. In addition, these two crops are not replaced by other crops but are mainly taken away from the livestock sector and are largely replaced by their by-products (maintaining protein supply at a reasonable level).

There are three important conclusions to be drawn here. First, given that cereals do not need to be completely replaced, they will require less additional land. Second, sugar crops need to be completely replaced, which leads to higher LUC effects. Third, even though some vegetable oils are not replaced by their own kind, they are replaced by another vegetable oil, leading to large leakage effects on the LUC and no true “savings”.

This last remark emphasizes again the role of co-products and displacement in livestock consumption. As shown in Table 11, additional maize-based ethanol reduces the consumption of maize and wheat (and some soybean meal) from the livestock sector; this consumption is replaced by Corn DDGS. Wheat-based ethanol follows a very similar pattern. Biodiesel rapeseed displaces maize and wheat, as well as some oilseeds that are replaced by both rapeseed meal and soybean meal (for each ton of rapeseed meal, 0.6 additional soybean meal is used). Indeed, the displacement of rapeseed oil is linked to more soybean oil production, and more meals of both types are absorbed by the livestock industry. The picture is different for soybean where soybean first displaced maize and wheat that are all mainly replaced by soymeal. Effects through other meals are less significant (only 0.1 additional ton of rapeseed meal for each ton of soybean meal). This asymmetry behind soybean and rapeseed is quite interesting. If rapeseed oil is replaced first by soybean oil for food use, leading to a complementarity in the meal availability, the soybean market reacts differently. Soybean oil is replaced by palm oil, and the link with other meals is weaker.

Table 11 Evolution of Livestock consumption of feedstocks. Selected Crop specific scenarios (60GJ incremental demand of biofuel in the EU). Tons.

	Ethanol Maize	Ethanol Wheat	Biodiesel Rapeseed	Biodiesel Soybean
Maize	-2693	-213	-2000	-4431
Wheat	-333	-2799	-2228	-1740
Palm Fruit	-1	-2	-81	-110
Rapeseed	-4	-5	-465	-126
Soybeans	11	12	-810	-2747
Sunflower	-6	-6	-126	-131
DDGS	3485	2419	1	-32
Meal-Palm	1	1	23	29
Meal-Rape	-37	-78	3841	813
Meal-Soyb	-187	-105	2431	8954
Meal-Sunf	-1	-5	253	272
Other Crops	174	411	-154	-834

Source: Mirage-Biof Simulations

Now that we have looked at the demand response, consider the supply response.

Table 12 looks at extensification vs. intensification for different crops. In the EU, the supply increase for the main feedstock in each crop-specific scenario is driven by land extension (more than 85 percent). Fertilizer also plays a minor role, increasing production by 2 percent in the best case (sugar beet, sunflower and soybean); the remaining intensification is driven by factor-driven intensification (more physical and immaterial capital by unit of land). At the world level, the supply response is more diverse. For palm fruit, 90 percent is driven by land increases, whereas this number is only 66 percent for wheat. However, the reader should be cautious with interpretation of this table. Indeed, it combines changes in yield driven by intensification and global composition effects with relocation of production in regions with lower/higher yield and lower/higher fertilizer application rates. For instance, the expansion of palm fruit in Africa, where fertilizer use is much lower than in the South East Asia, leads to a decrease of average fertilizer input per ton of palm fruit and a decline in average yield at the world level (attributed to this reduction of average fertilizer use). Similarly, as we will see, the marginal expansion of wheat occurs foremost in Europe, leading to an important average yield effect in marginal wheat production, the latter driven by the high level of fertilizer use in the EU compared to the rest of the world.

Table 12 Intensification vs Extensification. Decomposition of supply changes (Normalized to 100). Crop simulations.

Feedstock:	**Palm fruit**		**Rapeseed**		**Soybean**		**Sunflower**	
	EU27	*World*	*EU27*	*World*	*EU27*	*World*	*EU27*	*World*
Factor increase		25	8	8	12	14	12	15
Fertilizer		-15	1	6	2	-2	2	2
Land use		90	91	86	87	88	86	83
Feedstock:	**Sugar Beet**		**Sugar Cane**		**Maize**		**Wheat**	
	EU27	*World*	*EU27*	*World*	*EU27*	*World*	*EU27*	*World*
Factor increase	12			14	11	12	12	11
Fertilizer	2			12	1	6	0	23
Land use*	86			74	88	82	88	66

Source: Mirage-Biof Simulations

Note: This table shows the decomposition of the source of increases in production. Negative figures for fertilizers can occur due to regional composition effects. For instance, if at the world level, the extension of production occurs mainly in regions with low fertilizer rate, the “world average” fertilizer use per unit of output decreases and the contribution of fertilizer to the average supply is negative.

Due to the sensitivity of the role of increased yield in the LUC assessment, we propose another way to look at the intensification/extensification debate. This approach is given by Table 13 where we provide the marginal yield on new area that the different feedstocks have to achieve to provide the same LUC effects discussed above, considering **no** yield increase in all existing production of this feedstock. As it appears, the levels of yield are relatively strong but not unreachable. These yields level are particularly high for cereals (maize and wheat) and contribute, with the demand effects, to the low LUC for these crops.

Incidentally, this result raises the following questions: where will the land extension take place for these crops and can agronomics (water, temperature, land quality) deliver such an outcome easily?

Table 13 Marginal Yield assuming NO intensification. Tons/Ha world average

Biodiesel_PalmFruit	22.9
Biodiesel_Rapeseed	3.4
Biodiesel_Soybean	3.4
Biodiesel_Sunflower	2.6
Ethanol_Sugar	89.8
Ethanol_Maize	9.5
Ethanol_Wheat	6.5

Source: Mirage-Biof Simulations

Our assumption on EU yields may appear very optimistic (catch-up effects of new Member states). We have tested an alternative assumption with 4.7 tons per ha in the baseline for EU wheat. In such an assumption, the wheat LUC increases by nearly 20 percent to 16grCO2eq/MJ. Despite this relatively large increase, compared to other ethanol feedstock, this change does not modify the overall assessment. The yield level is important but is not the main driver of wheat LUC since we have seen that the demand displacement for wheat plays a critical role.

Table 14 provides summary results of land use displacement (for a full picture, refer to Appendix III). First, due to different energy yields per hectare, as well as different demand displacement effects, we find different land intensity.

- Below 6 ha by TJ at the global level for sugar beet, sugar cane, and palm oil. This is due to the high yield of such crops;
- Between 6 and 8 ha by TJ for cereals. This is directly driven by the demand displacement effects;
- Between 11 and 14 Ha by TJ for non tropical oilseeds. This is a combination of lower displacement ratio and lower yield; and
- Depending of the feedstock, expansion takes place all in the EU (sugar beet), between 40 and 43 percent in the EU (rapeseed, wheat), between 30 and 36 percent (sunflower, corn), or totally outside the EU (for soybean, palm oil, and sugar cane).

Second, a different pattern appears in terms of how this additional land affects other crops. For biodiesel feedstock, we see complementarity: extension of the main feedstock does not push out other energy crops (ethanol and biodiesel feedstocks). By contrast, for ethanol crops, land substitution takes place first among such crops (one is pushing out another; between 60–35 percent of the direct extension of the main feedstock is provided by land coming from other energy crops). This is then followed by substitution with other crops, strongly mitigating the need for additional cropland. In the EU, additional cropland represents only 12 percent of additional rapeseed land; this ratio is below 5 percent for sugar beet, wheat, and ethanol. At the world level, since expansion is easier, the cropland increase represents a larger share of the direct demand for land for the main feedstock. At the world level, this ranges from 13 percent for maize and 18 percent for wheat to above 33 and 36 percent for oilseeds. The exception is oil palm since this could not expand easily in other production (50 percent).

Lastly, pasture and managed forest also provide significant amounts of land; the ratio of the additional exploited land/additional net cropland is between 0 percent (corn), 6 percent (palm fruit, wheat), and 20 percent (soybean). There is a negative effect of sugar beet. This last result is explained by a very specific behavior: the decline in pasture in Sub Saharan Africa that causes the release of more land than needed. This land is not required for agricultural production, but it is linked to an indirect effect of the scenario that leads to both import price increases (food, feed) and export price decreases (oil prices) that hurt meat demand and production in Africa, reducing the use of pasture. This result has to be considered very carefully from both the political economy point of view (reduced effect of land use by impoverishing Africa and reducing its meat production) and from our representation of Africa's livestock, which is poorly adapted (cultural role of pasture, ethnic specialization, and informal sector). It implies that for each additional ha of cropland needed for the feedstock scenario, the amount of additional exploited land is between -0.02 ha (sugar beet) or 0 ha (corn) and 0.065 ha for soybean.

Table 14 Land Use displacement summary. Value by feedstock. Ha by Tj

	Scenario Feedstock	Net Energy Crops	Net Cropland	Pasture	Net Exploited Land
Biodiesel_PalmFruit					
EU27		0.35	0.08	-0.01	0.03
World	3.89	5.74	1.97	-0.91	0.12
Biodiesel_Rapeseed					
EU27	4.42	2.94	0.51	-0.10	0.14
World	10.91	11.72	3.90	-1.39	0.64
Biodiesel_Soybean					
EU27	0.14	0.77	0.10	-0.02	0.03
World	11.61	11.41	3.86	-1.50	0.76
Biodiesel_Sunflower					
EU27	4.28	2.53	0.33	-0.06	0.09
World	13.59	12.42	4.90	-2.04	0.71
Ethanol_Beet					
EU27	5.34	2.23	0.17	-0.05	0.02
World	5.75	2.97	0.41	-0.13	-0.13
Ethanol_Cane					
EU27		0.01	0.03	-0.01	0.00
World		2.70	1.48	-0.88	0.15
Ethanol_Maize					
EU27	2.40	1.13	0.08	-0.02	0.01
World	6.52	3.69	0.88	-0.40	0.00
Ethanol_Wheat					
EU27	3.27	1.77	0.17	-0.04	0.03
World	7.64	4.99	1.39	-0.54	0.10

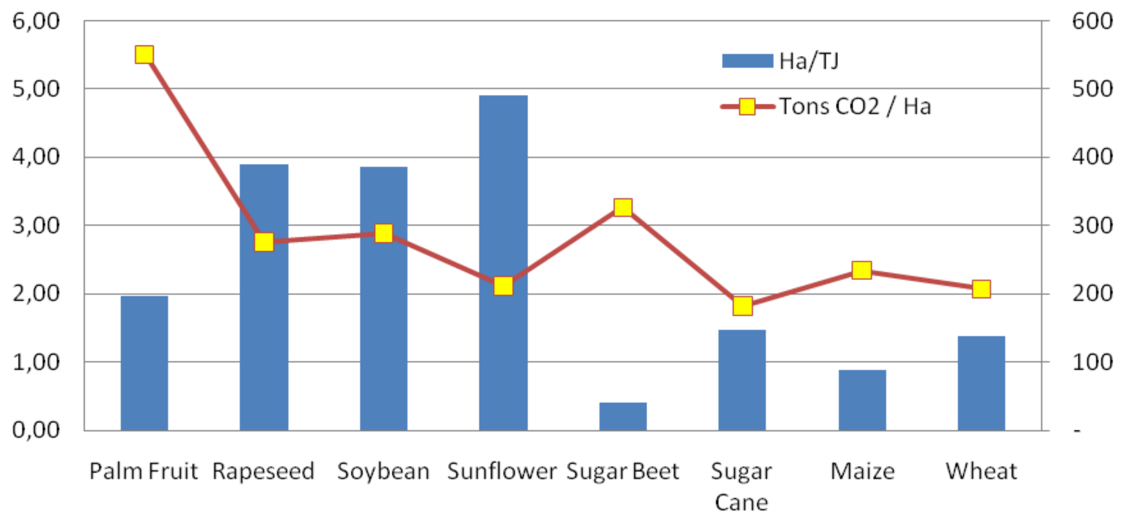
Source: Mirage-Biof Simulations

Note: The first column displays how many additional hectares of the scenario crop is needed to deliver one additional TJ of biofuels (taking into consideration the demand effect).

It should be noted here that there is a potential risk of underestimating the LUC emissions for ethanol crops in this analysis. First, regarding sugar, the reduced pasture land in Africa is relatively strong. Without it, LUC effects of sugar beet will be higher, but still lower than in the case of sugar cane. Second, regarding wheat, there is a large demand displacement effect and strong land reallocation among energy crops and other crops. Altering this assumption will increase the LUC of wheat significantly. For instance, prohibiting the displacement of non-energy cropland will increase the wheat LUC to 29 grCO2eq/MJ (changes in the demand response will be discussed in detail in the next section). Third, regarding maize, it magnifies the effects just as in the case of wheat. Large demand displacement, allowed by by-products, and even stronger crop relocation eliminate the need for extension in pristine environments and explain the very low LUC effects for corn. However, just like in the case of wheat, preventing corn from extending in non-energy crops leads to a severe increase in the LUC emission coefficient (up to 37 grCO2eq/MJ).

These remarks do not invalidate our assessment, but their goal is to stress the key mechanism that explains such results and that should be monitored closely in future years to see if the LUC values estimates presented here remain relevant.

Figure 17 More cropland or More Carbon (Ha by TJ and Tons CO2 eq by Ha of cropland)



Source: Mirage-Biof Simulations

Note : The bars (left y-axis) show the amount of additional net cropland by TJ of biofuel produced for one feedstock. The line (right x-axis) shows the average tons of CO2 equivalent by net Ha of cropland.

Figure 17 looks at the last explanation in terms of divergence of LUC emissions: land intensity vs. carbon intensity. We cross-check that the low ethanol LUC emission is mainly due to the high energy yield by Ha. Only palm oil, due to high yield, is close to ethanol level; at the same time, the average carbon stock by ha displaced is 2.5 higher, leading to a LUC emission coefficients close to the other oilseeds (which have lower carbon stocks by Ha of expansion, but need more cropland). The high carbon value of sugar beet may be intriguing, but it has an explanation. We have seen that even if additional cropland is positive, total exploited land is negative. In terms of carbon, it also implies a very specific pattern: with still cropland expansion in high-value carbon regions (Brazil through the sugar market) and land use contraction (as pasture in Sub Saharan Africa) in low carbon regions. Therefore, the carbon variation can be much larger than net hectare changes, giving this multiplicative effect on CO2/ha of cropland.

Box 3. Why Biodiesel has more adverse land use emissions than Ethanol?

A key result of this report is the apparent large gap in terms of land use emissions between biodiesel feedstocks and ethanol ones. We can present a simple analytical grid to explain this outcome.

First, for both ethanol and biodiesel we have one highly specialized feedstock with high yield (energy by ha) and no coproducts : sugar cane and palm fruit. In both cases, more biofuel means more production of the specialized feedstock and existing demand displacement is limited. However, the carbon price of each additional unit of palm oil is very large due to the nature of area affected : peatlands.

Second, ethanol and biodiesel could be produced with « polyvalent » feedstocks that generate important coproducts, in particular for the livestock industries (meals and DDGS). However, the dynamics associated to the two types of biofuels are very different. For ethanol, the key issue is to extract « energy », i.e. carbohydrate from starch, from cereals. This operation can be done by relying on existing production to some extent and the demand displacement will be more limited: the proteins are not removed from the livestock industry due to additional biofuel consumption. When additional cereals production take place to provide more inputs for the ethanol sector, the supplementary amount of DDGS will replace partially existing meals that may have high carbon values. At the opposite, the biodiesel demand is quite different in nature. It requires more vegetable oils. This additional vegetable oil has to be produced since it can not be « extracted » from an existing demand easily. The side effects, meaning more meals, are not going to save high carbon value products. It will replace cereals, for the proteins part, in the feedstuff ration but these products do not lead to significant land use gains. Indeed, they are initially produced in high yield / low carbon area (e.g. wheat or maize). Last, due to high degree of integration on the vegetable oil markets, the effects on one type of vegetable oil will still be linked to palm oil and therefore to peatland emissions

Let's compare the corn and the rapeseed situations.

- The direct effect of a new demand of rapeseed biodiesel is to increase the demand of vegetable oil. This oil has to be produced (the demand is quite inelastic). Therefore, we need to increase rapeseed production. As a matter of "fact" the model computes, Table 10, that 78 percent of the additional consumption of rapeseed needed to produce the additional oil has to come for new production. As a side product, meals also save land by displacing other feedstuffs used by the livestock sector. However meat production also absorbs this additional production of meals since it will lower the price of proteins.

- The direct effect of a new demand of ethanol has very different effects. It does not require additional production directly. It is just a matter of extracting the "energy/sugar" from existing cereals used for feed. Of course, the carbo hydrate should be replaced but it is a weaker constraint. The model predicts that only 56 percent of corn has to be additionally produced.

Forbidding yield increase (Table 13) for existing productions shows also large differences in terms of marginal yield assumed in a straightforward way. For rapeseed, the average yield for new production: 3.35ton/ha, For Corn 9.45 ton/ha. It leads to significant differences in energy yield (MJ/Ha).

The land use consequences are straightforward:

- 1MioMJ of ethanol corn requires 6.5 Ha of corn at the world level. Only 3.68 Ha of additional energy crops and only 0.87 of net cropland increase (it displaces other crops)
- 1MioMJ of Biodiesel rapeseed requires 10.9 Ha of rapeseed at the world level (50 percent more than for corn). But 11.7 Ha of additional energy crops (more than three times) and only 3.9 Ha of net cropland increase.

The five times gap between the LUC effects for corn and rapeseed could be explained easily. The net cropland ratio between the two feedstocks (0.87/3.9) captures most of the story and is largely explained the "energy crops net land changes". Due to lower yield per ha and the need to increase the production by a larger scale (less substitution effects on the demand side rapeseed start with a disadvantage (50 percent ha/MJ) compared to corn. Then the land use effect of corn is strongly absorbed by a reduction of "energy crops" (i.e. wheat, oilseeds since the DDGS will replace meals…) (6.52 Ha/MioMJ→ 3.68Ha/MioMJ). The rapeseed does not benefit from this effect: wheat production is sliced and free 3.43 ha/MioMJ) but the different other oilseeds areas increase, including those with lower yield/ha value (sunflower) to replace displaced oil. and the latter effects cancel all the land saved by other "energy crops" (in this case wheat, sugar beet, corn).

4.2.3 Additional mandate and crop LUC estimations

Combining Figure 14 with the additional mandate composition in Table 3, we can compute the additional mandate level quite accurately: 39.5 vs 38.4 grCO2/MJ. The difference is mainly driven by the non-linearity effects. Indeed, this computation has been made using the end of the mandate crop LUC emissions estimate (marginal value) when the additional mandate estimated by the overall additional mandate follows the true path of LUC estimation coefficients for each crop and considers average value (due to non-linearity the average LUC effect is smaller than the marginal LUC effect)

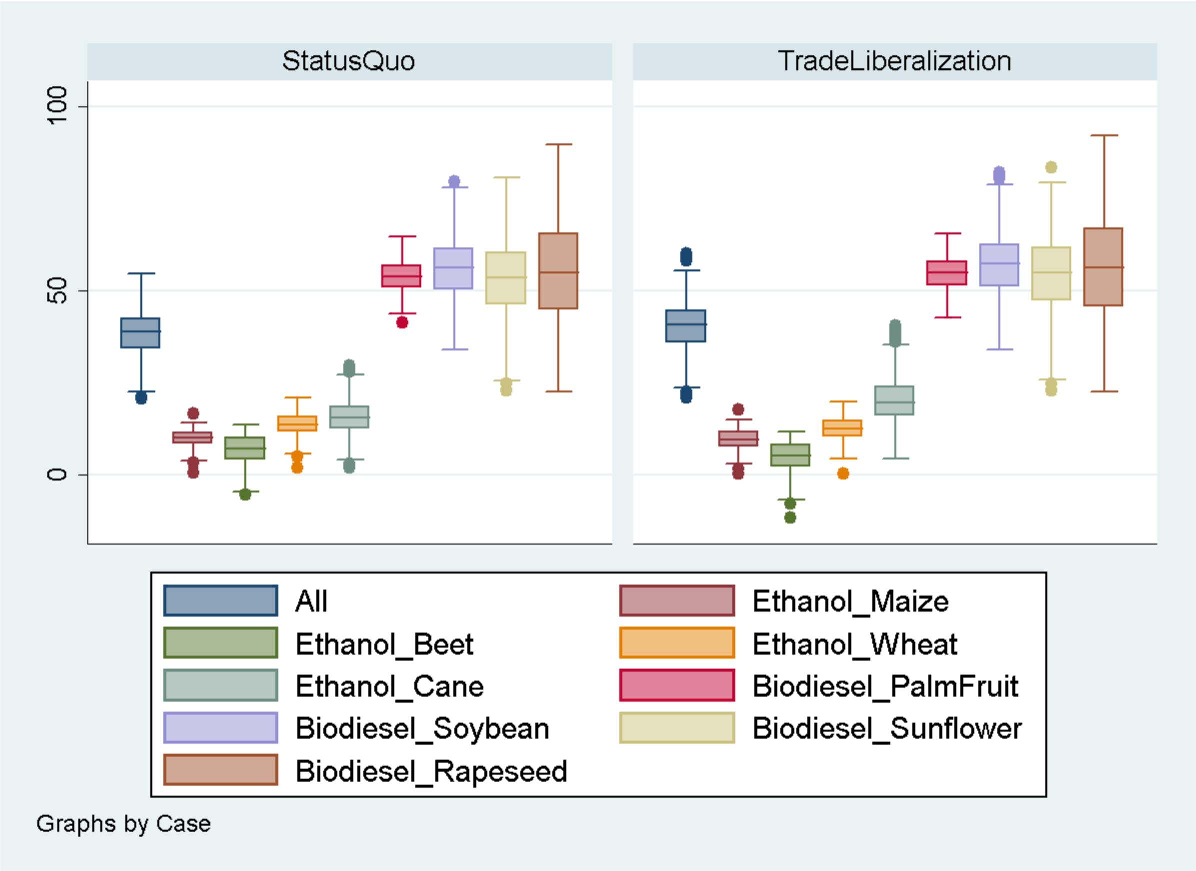
This implies that readers can compute the effects of an alternative mandate composition by changing the share and using the coefficient discussed here. However, it should be kept in mind that due to non-linearity, large changes in mandate composition have to be handled carefully (a conservative rule that overestimates emissions based on our results – Figure 16 – will be to increase the LUC emissions by 10 percent for each doubling of the share in the additional mandate)

Lastly, we need to discuss the sugar cane case. Figure 16 shows almost no non-linearity when we compare the LUC with and without trade liberalization. We have introduced this notion for this crop. First, at any point, the supply elasticity of sugar cane is among the most elastic in the mid-term: Brazil can displace pasture efficiently, large amounts of land are still available, fertilizer use in the sugar cane industry is still low, etc. Saturation effects are not expected quickly (results of Figure 16). However, when trade liberalization occurs, we consider a very large shock: the total marginal EU demand is supplied by this feedstock, and even a share of the baseline demand based on other feedstocks is redirected to this crop. This shock represents an increase of 143 percent of the initial consumption point, while the shock simulated in Figure 16 never exceeds 30 percent of the initial level.

4.3 MC analysis

Several caveats are worth noting. First, the analysis does not address all possible sources of uncertainties (e.g. demand response, carbon stock). Second, the distribution of parameters is still based on assumption rather than econometrically estimated distribution. The main property of the “central” value is to remain between the extreme values in the literature; it does not consider that it is the most probable (this is why the “uniform” distribution is used here). By statistical convergence, it is normal to find a large number of observations around this median value. This, however, should not give a wrong sense of (over)confidence. All points of the distributions should be considered seriously.

Figure 18 LUC emission coefficients, grCO2eq/MJ, Monte Carlo results



Source: Mirage-Biof Simulations

Note: The bold line within the box shows the median value, the box define the 25th-75th percentile, and the upper and lower horizontal lines describe the upper and lower adjacent limits.The dots indicate extreme values.

Figure 18, Figure 19, and Table 15 display the distribution results for the additional mandate. The range of uncertainty on the overall LUC emissions are significant: with values ranging from 24 (5th percentile) to 50 (95th percentile) and a mean of 38.4 grCO2eq/MJ. The mean and the median are quite close and still very similar to the central scenario[27] discussed in the previous section. Extreme values are not particularly high compared to those in the existing literature (see Plevin et al, 2010). This may be due to the fact that some large sources of uncertainties (e.g. CO2 stock by ha) are not covered by this analysis. It may also imply that the demand displacement effects (substitution among crops, fall in demand), which play an important role in the CGE response, are not covered in the MC analysis (a discussion on this will follow). Indeed, what we see in our results - and what is not discussed here at length - is that when parameters are very adverse to the supply side, the model still finds an equilibrium with higher prices. For instance, if land relocation is constrained, the yield increase will be stronger; if both land relocation and yield increases are more difficult, the crop price increase will deter

[27] "central scenario" refers to the use of the parameter values set used in the Sections 4.1 and 4.2 of this report.

consumption and still limit the overall LUC effect. We will discuss some worst-case scenarios in which both demand and supply are very rigid in the next section.

Concerning the distributions, we have several remarks. The medians for different crops are close to their central value, and the gap between ethanol crops and biodiesel crops appears to be quite robust to a large range of parameter values. Only the combination of the less favorable parameters for sugar cane ethanol and the most favorable for rapeseed (and to some extent for sunflower and soybean) leads to an overlap.

For ethanol, the ranking among crops is not altered with the MC analysis performed here. Maize and wheat display similar profiles around different central values and appear less uncertain than sugar cane and sugar beet. Once again, this is due to the large share of the "non" LUC effect for these crops that is absorbed by the demand displacement effect, in particular in feed and the role of co-products. This particular result is not surprising, since the MC analysis does not focus on this part of the model. Sugar beet displays a very specific distribution with a "left tail" displaying different cases of negative LUC emissions. Sugar cane is the most uncertain for two key reasons: First, out of all ethanol crops discussed here, sugar cane is the one that is most produced in developing countries. By construction of the experiment, and more dispersed parameter values for these countries, it is normal to find a more dispersed LUC coefficients for this crop. Second, within developing countries, the LUC effect of sugar ethanol will first be located in Brazil; depending on the set of parameters, sugar cane extension can lead to very low land extension (e.g. if pasture intensification takes place easily) or to large land extension with direct and indirect consequences for high carbon stock areas (Amazonia).

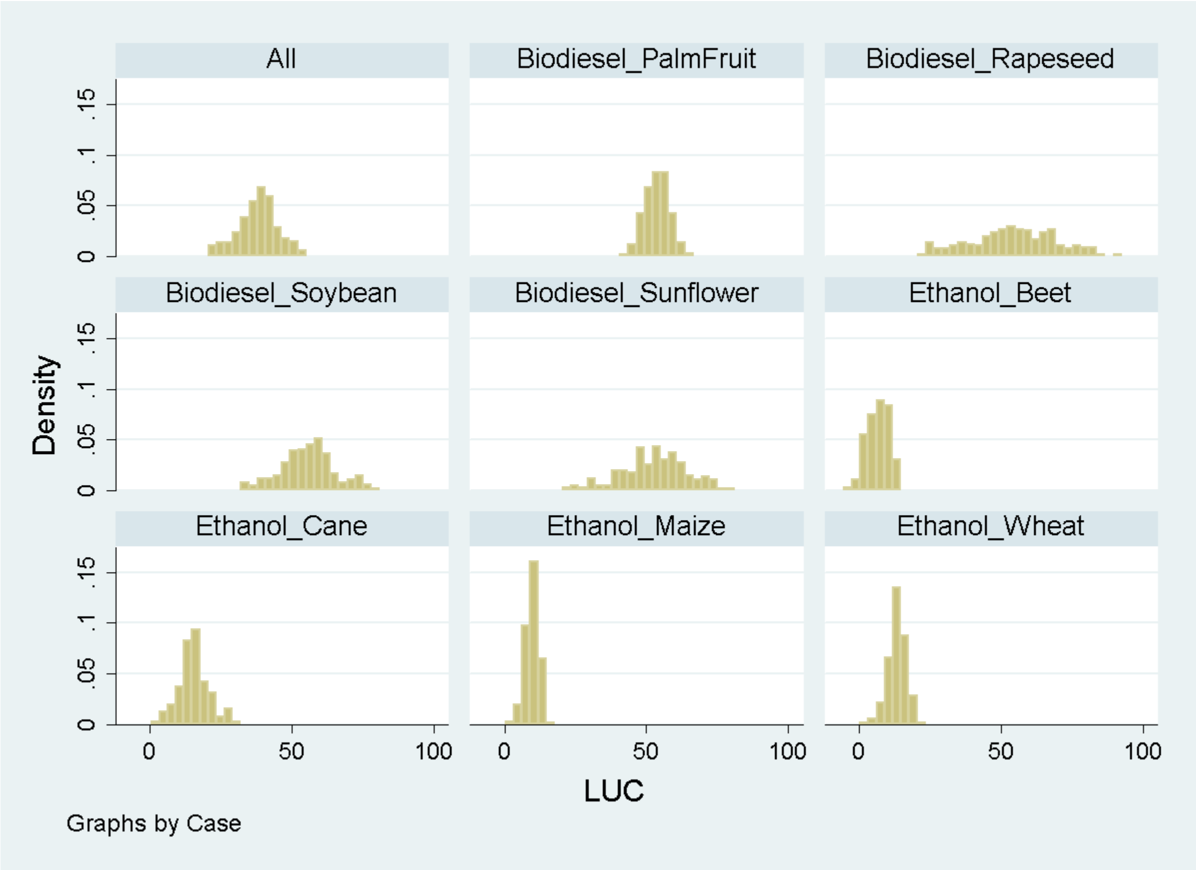
For biodiesel, the picture is slightly different. While the central and median values for different feedstocks are quite similar, the dispersion of their distribution is quite large. The standard deviation of rapeseed is nearly four times that of palm fruit. These differences are explained by structural aspects of the production of the feedstocks and the role of the geographical dispersion of land use changes. For palm oil, production in our model is less sensitive to fertilizers and intensification possibilities are limited; therefore, the elasticities affecting yield increase have very small effects on this sector. At the same time, palm oil production is concentrated in a few regions (all developing countries), so it is less affected by parameter variability than crops that are more widespread. In addition, as discussed previously, the palm oil absorbed by biofuels has to be replaced by other palm oil (very limited side effects on other vegetable oils since palm oil remains quite competitive). Therefore, palm oil LUC is weakly affected by the other vegetable oil parameter changes in the MC. At the same time, the uncertainty about how cropland can extend into pasture and/or managed land (and the related soil emissions) plays a smaller role for this crop due the region of expansion. However, a large share of palm oil emissions is driven by peat emissions, for which key parameters (share of palm plantation on peat, emissions of peatlands, see footnote 21) are not concerned by the MC analysis and will increase drastically the uncertainty for this crop.

The opposite is true for rapeseed. Its production can be more affected by the fertilizer-driven yield change parameter and its uncertainties. The marginal effect on cropland is more widely dispersed between developed and developing countries (a 25/75 ratio for rapeseed when it is around 10/90 for other oilseeds). In addition, displaced rapeseed oil is replaced by all the other types of vegetable oils. In this configuration, rapeseed is affected by global uncertainties (changes on parameters in both developed and developing countries) and changes occurring in many crops.

Trade liberalization has a limited impact on distribution. Its effects are concentrated on ethanol crops (since its main effects are on the ethanol markets), with large effects on sugar beet, sugar cane, and maize and a spread of the right tail (measured as the ratio between the 95th percentile and the median).

Indeed, trade liberalization impacts the landscape in which the ethanol demand shock takes place. With trade liberalization, sugar cane ethanol dominates the market; its production capacity is much more stressed (the reverse situation for other crops). It is important to keep in mind that the growth of the right-end tail is driven by different mechanisms (Table 15): for sugar beet, it is due to a shift of the median to lower values (as well as a reduction of the maximal values), while for sugar cane, the median increases at the same time as the last quintiles, but to a lower proportion.

Figure 19 Distribution of LUC emission coefficients (grCO2eq/MJ) based on Monte Carlo simulations. Trade policy status quo.



Source: Mirage-Biof Simulations

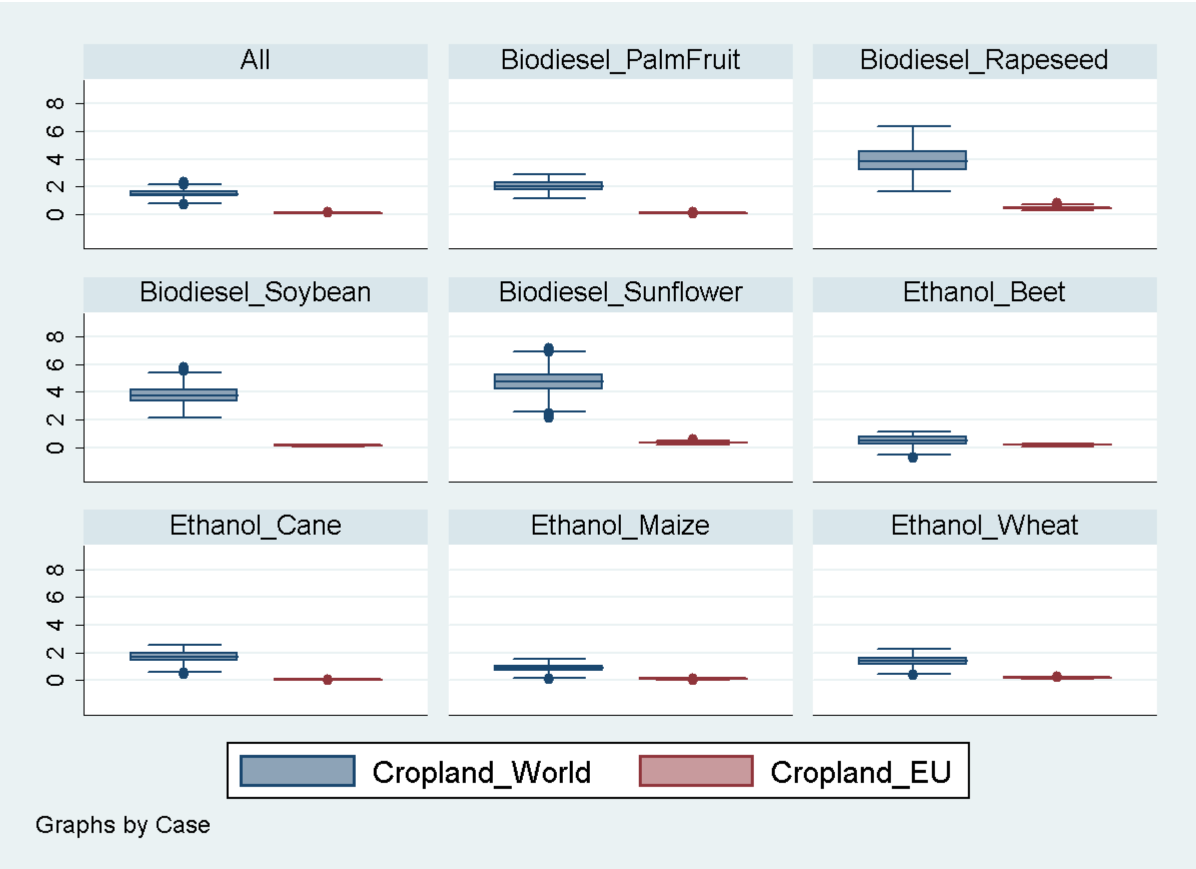
Table 15 Monte Carlo simulations Summary of the LUC emission coefficients (grCO2eq/MJ)

	Additional Mandate	**Wheat**	**Maize**	**Sugar Beet**	**Sugar Cane**	**Soybean**	**Sunflower**	**Rapeseed**	**Palm Fruit**
			Trade policy Status Quo						
Central scenario	***38.1***	***14.4***	***10.3***	***6.6***	***13.4***	***55.8***	***51.8***	***53.8***	***54.3***
Mean	38.4	13.6	9.8	7.0	15.6	55.9	52.7	54.6	53.8
Standard Deviation	*6.9*	*3.1*	*2.4*	*3.9*	*5.3*	*9.4*	*11.4*	*14.9*	*4.3*
5 percentile	24.4	8.3	6.0	0.8	6.5	38.4	30.6	28.2	47.1
Median	**38.8**	**13.8**	**10.1**	**7.2**	**15.4**	**56.3**	**53.5**	**54.9**	**54.0**
95 percentile	50.4	18.4	13.2	12.6	26.5	73.9	72.0	80.7	60.3
Max	54.5	21.1	16.7	13.7	29.8	79.6	80.8	89.8	64.6
			Trade Liberalization						
Median	40.9	12.7	9.6	5.2	19.6	57.4	54.9	56.2	55.0
95 percentile	54.1	17.1	13.8	10.6	35.4	76.3	74.7	82.5	62.2
Max	60.1	19.8	17.8	11.7	40.4	82.1	83.4	92.2	65.5

Source: Mirage-Biof Simulations

Figure 20 displays the distribution of cropland requirements in ha by TJ at the world and the EU level. It clearly appears that cropland extension uncertainty in the EU is very limited. EU capacity to intensify crop production (yield increase) or to free pasture land (livestock intensification) is limited overall; altering price sensitivity of key behaviors does not change this broad picture. The only crop for which EU cropland extension is a source of significant uncertainty is rapeseed. At the world level, uncertainties are much stronger. Most of the uncertainty affecting the LUC effects of the EU policy takes place in the rest of the world. This is an important lesson since it implies that EU policymakers will have less direct control in implementing policies aimed to reduce this uncertainty. The ranking of crop extension uncertainty follows the main conclusions of the discussion on LUC coefficient distributions. However, we notice some specificities: sunflower and rapeseed display a very similar pattern, but the right tail of cropland extension for sunflower is stronger than that for rapeseed (the reverse of what is observed on the LUC emission coefficient).

Figure 20 Uncertainty on Cropland extension in the world and in the EU (Ha by TJ). Trade policy status quo.

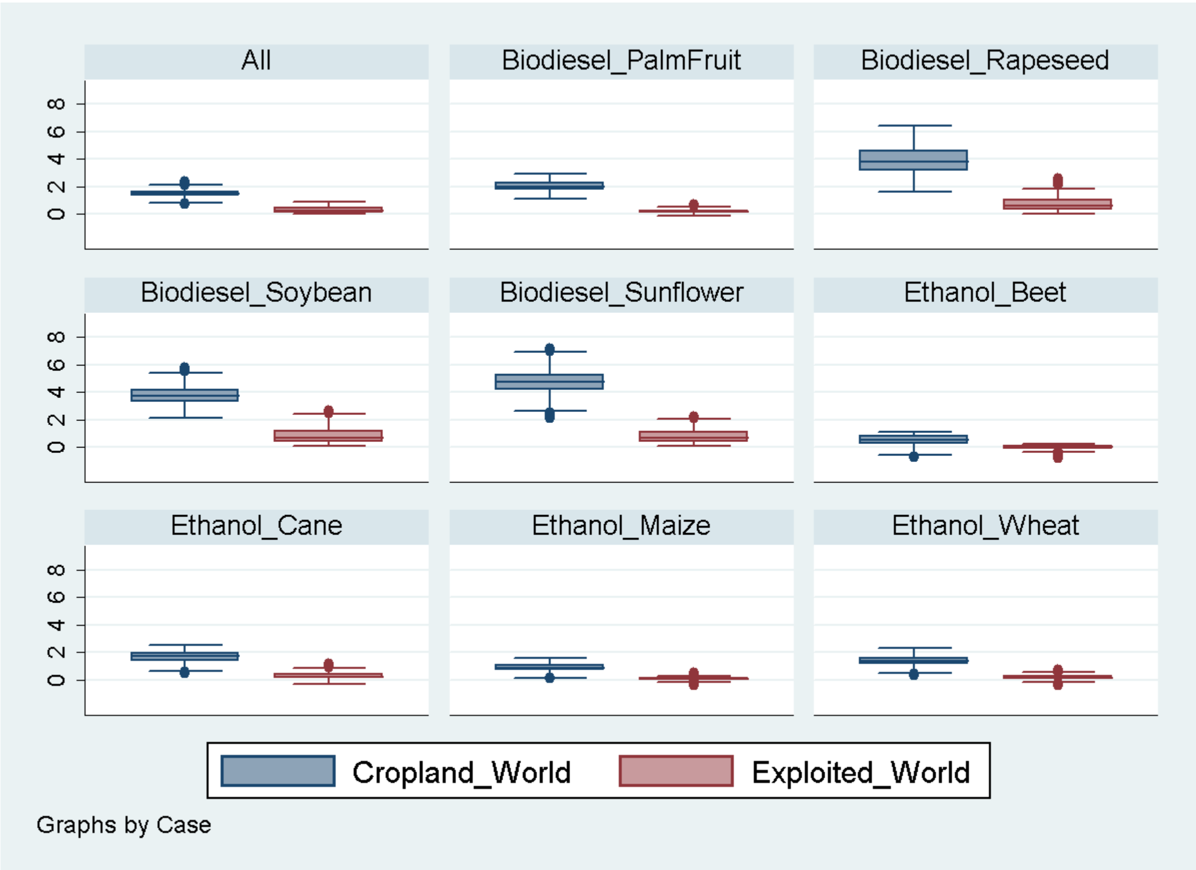


Source: Mirage-Biof Simulations

Note: The bold line within the box shows the median value, the box define the 25th-75th percentile, and the upper and lower horizontal lines describe the upper and lower adjacent limits

Figure 21 shows how uncertainties about cropland extension are tied to those about exploited land extension. In absolute terms, the distribution of exploited land is narrower than expected (lower net effects on exploited land). However, in relative terms, the exploited land distribution is much more dispersed than cropland distribution. Indeed, moving from cropland extension to net exploited land changes, consider another layer of uncertainties with the interaction between pasture land, managed forest, and croplands (two parameters of the Monte Carlo analysis impact directly this mechanism). For the additional mandate, the coefficient of variations of the exploited land increases is 3.5 times those of cropland, and the ratio 95th percentile/median twice those of cropland. These differences are magnified for several crops (nearly doubled for maize).

Figure 21 Cropland Extension vs. Exploited land extension. World Level, Ha by TJ. Trade policy status quo.



Source: Mirage-Biof Simulations

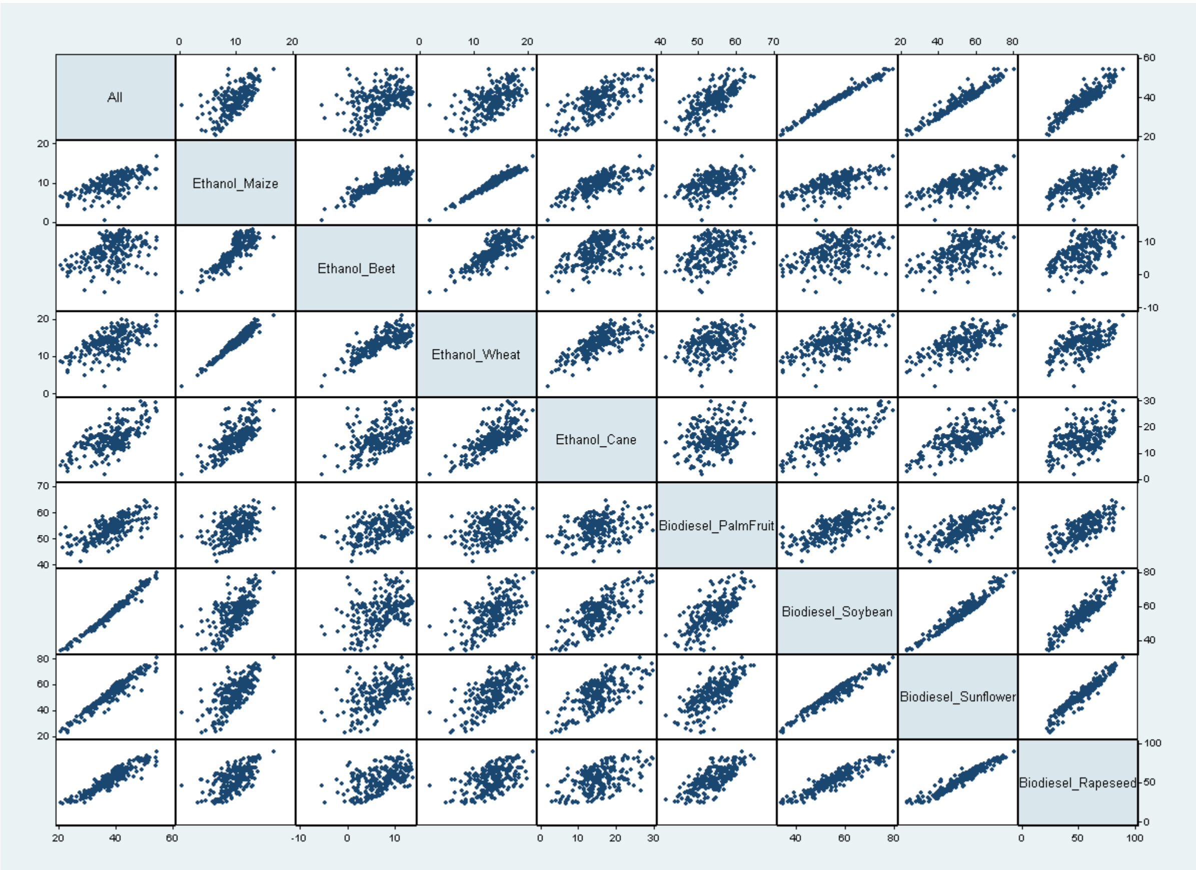
Note: The bold line within the box shows the median value, the box define the 25th-75th percentile, and the upper and lower horizontal lines describe the upper and lower adjacent limits

Finally, we briefly discuss the correlation structure among crops' LUC coefficients. By construction, since the parameters for all crops are shifted in the same way for each simulation, high correlation may be expected. However, due to different location effects (in developed or in developing countries, for which different values are used) and different exposures to key parameters (role of fertilizer use in different crops, type of AEZ where the cropland changes take place, and the possibility of competition with other uses such as pasture), we find meaningful differences.

On one hand, the additional mandate LUC is highly correlated with biodiesel feedstock-specific LUC. This shows the role of the biodiesel in the LUC effect (with a very good correlation to the soybean LUC, even if soybean remains a marginal feedstock in the mandate composition). Among vegetable oil, palm fruit is weakly correlated to other oilseeds. Even if the vegetable oil markets are quite integrated in our model and display similar LUC emissions, it appears that the land use effects of palm oil can react quite differently than the LUC effect of non-tropical oilseeds. Similarly for ethanol, wheat and corn LUC coefficients are strongly correlated; sugar beet displays similar behaviors, while sugar cane reacts quite differently.

Even if we have to be very cautious in the interpretation of these results (strongly tied to the core assumption of having the same shifter for all crops at the same time), one of the conclusions should be to maintain a diversified portfolio of tropical and non-tropical crops for each type of biofuel, knowing that the uncertainties between these two families of feedstocks may be less correlated.

Figure 22 Correlation matrix of LUC emission coefficients , grCO2eg/MJ. Trade policy Status quo.



Source: Mirage-Biof Simulations

4.4 *Alternative closures*

The previous section focused on a Monte Carlo analysis focusing on key parameters, mainly on the supply side of the model. As discussed in the first part of this chapter, we have seen that demand displacement plays a critical role in explaining the low LUC effects of key crops, in particular corn and wheat. Figure 23 looks at this issue by presenting the LUC emission coefficients assuming alternative closure on the food and feed markets. Compared to the standard closure where food and feed demand can react freely to prices, we investigate two alternatives: fixed food consumption by households and no substitution between crops and co-products. However, these approaches still allow for food adjustment. When food consumption is blocked, the intermediate consumption mix of the processing sectors can still evolve (replacement of vegetal fats by animal fats or decrease of the average contents of flour in processed food, etc.); similarly, when the crops-co-products substitution is restricted, the overall level of meat production can still adapt.

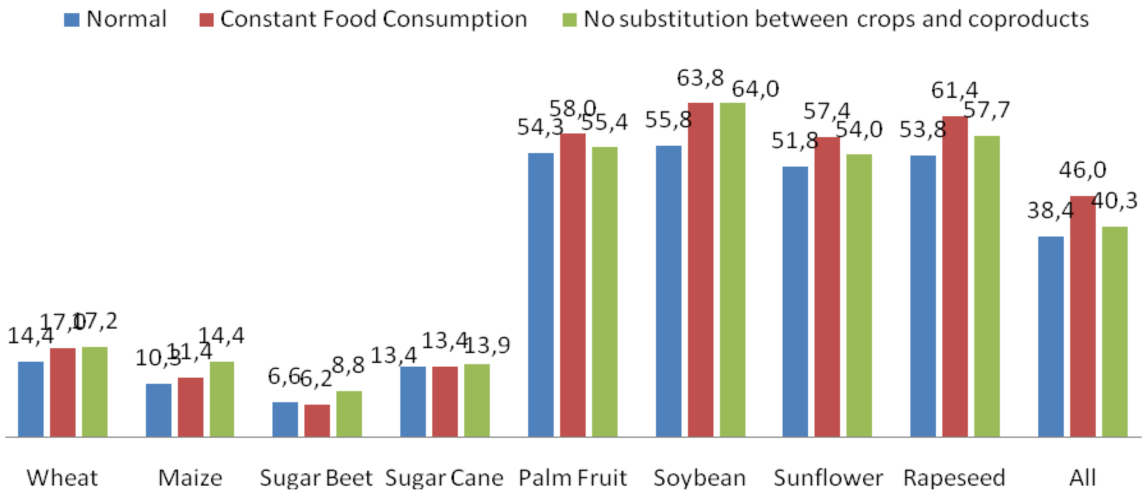
It is important to keep in mind that the two effects, looked at separately here for the sake of explanation, will have more than additive effects. For instance, for the additional mandate the 38.4 grCO2eq/MJ increases to 46 (+ 20 percent) when food consumption is constant and 40 (+5 percent) when the co-product effect is limited. The combination of both effects leads to an increase of more than 40 percent.

Overall, food consumption effects are the most important since they increase LUC effects by 20 percent on average and between 15 and 20 percent for most oilseeds. Several crops display much lower effects: sugar crops (sugar cane and sugar beet, for which the displacement effect was limited from the beginning), maize (only + 10 percent, as direct human consumption is very limited), and palm fruit (less than +10 percent, limited final consumption). Among ethanol feedstock, wheat is the most affected by this change of closure (+21 percent). Interestingly, we find a larger overall effect than the crop-weighted effect since, in the former case, it is more difficult to reallocate demand among agrifood inputs as most of the food crops faced incremental demand.

If restricting the role of co-products has more limited impacts, it should not hide a large heterogeneity of effects: + 6 percent for rapeseed vs. +16 percent for soybean (a key feedstuff) and no significant effects on palm oil. For wheat, the effects of the feed channel is as important as the food channel, and the LUC effect increases by 40 percent compared to our central scenario. For maize, where the food channel was limited, we increase the LUC effect by 40 percent.

Here also, sugar cane performs pretty well. Since its co-product (electricity from bagasse) is not used as a feedstuff, its LUC emission coefficient is not impacted by the change of closure and remains very stable.

Figure 23 Consequences of alternative closures on LUC emission coefficient (grCO2e/MJ)



Source: Mirage-Biof Simulations

Note: The "constant food consumption" closure does not maintain constant the technology of the food processing sectors. Therefore, the "food content" of processed food will change. Effects of both restrictions are not displayed on the graph. They are expected to be more than additive.

Pushing this approach to the extreme, Laborde and Valin (2011) show that a scenario close to the one looked at in this report will lead to an average LUC emission coefficient of 116grCO2eq/MJ, three times our average LUC coefficient, when no yield changes, no food consumption diminution, no change in intermediate consumption of agrofood, and no co-products effects are allowed. This shows the potentially very high value for the LUC coefficient if supply could not intensify and demand could not be displaced. Indeed, no policy is a "free lunch": the additional crop will have to deter existing consumption (social consequences) or lead to extensive production growth (very adverse LUC effects) or yield increases (an optimistic case, but with potential effects on emissions as well).

The reader may wonder why we do not systematically investigate the case in which both demand (food and feed) and supply (e.g. land reallocation) are very rigid. In such cases, we will get very high LUC emissions since the direct effects (1 ha of land used for biofuel) will be close to the net LUC effect (1 ha of cropland in addition and up to 1 ha of exploited land in addition). However, assuming that behavior will not react to prices, even for very short-term inelastic demand (such as fossil fuel), is doubtful and contrary to the philosophy of the applied CGE and a Walrasian economy. If having such values may be useful, it is obvious that no one needs a complex model to compute them.

However, the strength of the CGE approach discussed here is to be able to include political economy constraints, addressing the “no free lunch” issue explicitly. For instance, for EU policymakers, a policy leading to food consumption reduction in Africa may not be acceptable, while a similar side effect in the US will not be a political issue. Therefore, LUC effects could be computed under partial constraints (constant food consumption in Africa or developing countries only), fine-tuned to represent the relevant policy option.

5 Concluding Remarks

This section discusses the limits of the modeling tools and future research directions, and flags some issues for policymakers.

5.1 Model limitations and future research directions

Based on this research, two important comments have to be made.

First, the model has tested the limits of the CES/CET framework. Both for co-products and for land use allocation, this conventional modeling approach leads to many simplifications. For co-products, the two-level CES approach has helped to reinforce the substitution of the protein contents between meals and DDGS. Unfortunately, it has also forced simplification of the representation of substitution between proteins and carbohydrates. Similarly for land use, even if our multi-nested CET has helped to capture substitution between crops, it is not flexible enough to provide the correct full substitution matrix across crops and their yield consequences. More importantly from a long-term perspective, it is not designed to capture issues such as multi-cropping and crop rotation, both important issues for land use considerations in a dynamic approach. For both issues, two avenues of research should be investigated: more flexible functional forms or, as a proxy, a richer CES/CET nested structure with additional levels and the ability to enforce complementarity between a bundle of goods or crops to show the real constraints faced by producers.

Second, sensitivity analysis has been performed extensively on the land use side of the model, but our investigation on the demand side was quite limited (rigid food demand, changes in price elasticities of intermediate demands). However, as we have seen, a large share of additional production required for biofuels, in particular for cereals, is not replaced. In this context, we need to perform a more advanced sensitivity analysis on the demand blocks to see to what extent our uncertainty about the demand parameters, especially by other industries, will play a critical role in the assessment.

5.2 Policy issues

Even if this report will not solve uncertainties surrounding the valuation of land use changes, it can flag some important issues for policymakers.

First, it has been confirmed that emissions related to land use changes driven by biofuel policies are a serious concern. Even if for some extreme cases and for particular crops, we can find LUC coefficients close to 0 or even negative, more than 99 percent of all Monte Carlo parameter simulations show positive LUC emissions. With an average LUC emission coefficient value of about 40grCO2eq/MJ, nearly half of the potential gains of switching from fossil fuels to renewable biofuels vanish in LUC emissions, not even including emissions related to the processing of biofuels. Adding the later, even with 2020 direct saving coefficients, the net emission saving fall to 19 grCO2eq/MJ over 20 years a mere 21 percent of fossil fuel emissions.

Second, the question whether other policies should also be analyzed from a LUC perspective is also legitimate. Indeed, numerous policies (both agricultural and trade policies) have large land use consequences, and it is difficult to justify why only one policy (biofuels) has to go through the LUC analysis when GHG emissions remain a high priority in the overall EU policy. For instance, using the same methodological framework, it can be shown (Laborde 2010) that a large opening of the EU agricultural market in the Doha round may lead to larger land use emissions than the EU biofuel additional mandates. Even if the goals and global consequences of the two policies should not be compared, it remains true that overall consistency will require the same approach to be used to ensure that all EU policies will contribute to the general direction defined by the Member States and the European Commission. Additionally, policymakers who would like to introduce the LUC issue explicitly in the legislation have to consider this dilemma: "iLUC for all, iLUC for none" with potentially long-term consequences for impact assessment strategies. This argument may be used to discourage any LUC legislation in order to avoid opening Pandora's Box. However, it should not be misinterpreted. Beyond the biofuel issue, the real challenge lies in knowing if low-carbon agriculture can be implemented in the coming decades with meaningful management of scarce land resources. Indeed, with increasing demographic pressures and potential climate change effects, the question of sustainable agriculture at the global level is critical. Cropland increases 20 times more in the baseline of our model by 2020 than it does as a consequence of the EU biofuel additional mandate. This does not mean that biofuels should get a free ride on the growing emissions trend. However, in order to make sense, any LUC legislation regarding biofuels should be consistent with a broader target and systematic approach.

Third, due to the interconnection of agricultural markets, leakage effects will be large. Advanced sustainability criteria regarding biofuels will be less efficient if the other uses of key agricultural commodities remain unconstrained. We face leakages both between the biofuel market and other markets for a crop (see the role of demand displacement in our analysis) and between different feedstocks. This is strongly illustrated by our computations on land use emissions: more than 25 percent of land use emissions of soybean came from peat emissions tied to palm fruit production. Increasing only the sustainability of palm oil production for biodiesel, or only soybean production, will not properly address this issue. In this context, defining crop-specific iLUC appears to be quite challenging, both from a modeling point of view (uncertainties are still large) and from an incentive point of view: how could the soybean producers in South America be considered responsible for the governance of peat lands in South East Asia? To state it differently, if all biofuels are not equal, as confirmed in this study, it does not follow that putting a ban on one or two, or more, will solve the problem. First, if demand starts to concentrate on one or two feedstocks, strong non-linearity and market destabilization (e.g. maize in the US or rapeseed in the EU) may occur. Second, due to the land use leakage among feedstocks (with the potential exception of the sugar crops), the fact that one biofuel is bad may lead policymakers to think that all are bad and therefore to limit the consumption of all biofuels. Consequently, the strategy should be to limit the overall scope of the mandate or to increase the threshold of eligibility of direct savings for all feedstocks. The latter strategy can also be seen as the best way to force the private sector to use the most efficient technology to process biofuels for each unit of crop consumed.

Fourth, nevertheless, our evidence shows that different treatments should be used for ethanol (lower risk of large land use emissions) and biodiesel. This implies that the EU should try to get a more equilibrated ratio between biodiesel and ethanol (i.e. increase the consumption of ethanol). This may involve increasing the eligibility threshold on biodiesel, changing incentives for the car industry, and opening the EU market to foreign producers, in particular of sugar cane ethanol.

Fifth, if liberalizing the ethanol trade will help to reduce net emissions, even if land use effects can be contrasted, alternative trade policy approaches can be put on the table. Indeed, facing the risk of additional imports of feedstocks from countries with weak land use governance, the EC may want to enforce incentives through trade barriers/preferences. The measures should not be "unfairly" discriminatory and should avoid extra transaction costs, including certification costs at a firm level. The idea is to promote good governance of land resources, tackle externalities, and promote adhesion to ongoing international initiatives such as the United Nations programme on Reducing Emissions from Deforestation and Forest Degradation (UN-REDD). The GSP+ reform, linking trade preferences to implementation of international conventions (e.g. Kyoto, biodiversity) is such an example. In this context, EC trade policy should be used to provide incentives to prevent large leakage effects associated with narrow sustainability criteria. In addition, MFN based treatment could be rethought. Instead of strengthening sustainability criteria/certification for biofuels and for the feedstocks to produce them, all imports of the relevant products, whatever their uses, could be covered by the new discipline. In order to avoid restraining existing market access on EC partners and risking a WTO dispute, but also hurting existing importers, the EC could provide tariff rate quotas equal to the current level of imports that will not need to be certified, or equivalently, a number of "free" certificates based on a kind of "grandfathering" principle.

Sixth, any solution to improve yield without more emissions (e.g. no additional fertilizers) has to be favored. However, it is difficult to believe that new expenditures in agricultural R&D will deliver positive effects on land use by 2020. Utilization of existing technological packages should be privileged but may represent a challenge for existing EU regulation in terms of biotechnology. Even more important, the use of improved agricultural practices aiming to reduce emissions, e.g. low tillage may deliver quick improvements.

Seventh, and last, due to the level of uncertainties, monitoring capacities (of land use patterns) and research have to be improved and a "health check" of the biofuel policies has to be implemented. The mandate policy should be flexible enough to deal with a redirection of the policy when new information is made available, but also to tackle short-term variations of agricultural prices. Indeed, the biofuel demand, driven by a mandate, is putting an additional inelastic demand on a market (agricultural products) known for its short-term rigidity in terms of both supply and demand and, therefore, its large price fluctuations. Since a mandatory policy forbids market mechanisms to take place, the biofuel demand will increase price volatility (not discussed in this report) and will have very unintended consequences for poor consumers. Even if not related to the land use effect directly, this channel should not be neglected and must be incorporated in the development of a flexible biofuel policy.

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Appendix I. 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 51 sectors. Details are provided in Table A 1. Regional aggregation

and A 2 (Sector aggregation). The sectoral disaggregation covers agricultural feedstock crops and processing sectors, energy sectors, and other sectors that also use agricultural inputs.

Table A 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 A 2. Sectoral aggregation

#	Sector	Description	#	Sector	Description
1	Rice	Rice	**29**	**Forestry**	**Forestry**
2	**Wheat**	**Wheat**	30	Fishing	Fishing
3	**Maize**	**Maize**	31	Coal	Coal
4	**PalmFruit**	**Palm Fruit**	**32**	**Oil**	**Oil**
5	**Rapeseed**	**Rapeseed**	33	Gas	Gas
6	**Soybeans**	**Soybeans**	34	OthMin	Other minerals
7	**Sunflower**	**Sunflower**	**35**	**Ethanol**	**Ethanol - Main sector**
8	OthOilSds	Other oilseeds	**36**	**EthanolCane**	**Sugar Cane Fermentation**
9	VegFruits	Vegetable & Fruits	**37**	**EthanolBeet**	**Sugar Beet Fermentation**
10	OthCrop	Other crops	**38**	**EthanolMaize**	**Maize Fermentation**
11	**Sugar_cb**	**Sugar beet and cane**	**39**	**EthanolWheat**	**Wheat Fermentation**
12	**Cattle**	**Cattle**	40	**DDGSCane**	**Sugar Cane Bagasse**
13	**OthAnim**	**Other animals (inc. hogs and poultry)**	41	**DDGSBeet**	**Sugar Beet Pulp**
14	**CrushPalm**	**Palm Fruit processing**	42	**DDGSMaize**	**Maize DDGS**
15	**CrushRape**	**Rapeseed crushing**	**43**	**DDGSWheat**	**Wheat DDGS**
16	**CrushSoyb**	**Soybean crushing**	**44**	**Biodiesel**	**Biodiesel transformation**
17	**CrushSunf**	**Sunflower crushing**	45	Manuf	Other Manufacturing activities
18	**OilPalm**	**Palm Oil**	46	WoodPaper	Wood and Paper
19	**OilRape**	**Rapeseed Oil**	**47**	**Fuel**	**Fuel**
20	**OilSoyb**	**Soy Oil**	48	PetrNoFuel	Petroleum products, except fuel
21	**OilSunf**	**Sunflower Oil**	**49**	**Fertiliz**	**Fertilizers**
22	**MealPalm**	**Palm Fruit Fiber**	50	ElecGas	Electricity and Gas
23	**MealRape**	**Rape Meal**	51	Construction	Construction
24	**MealSoyb**	**Soybean Meal**	52	PrivServ	Private services
25	**MealSunf**	**Sunflower Meal**	53	**RoadTrans**	**Road Transportation**
26	OthFood	Other Food sectors	54	AirSeaTran	Air & Sea transportation
27	**MeatDairy**	**Meat and Dairy products**	55	PubServ	Public services
28	**Sugar**	**Sugar**			

Note: Sectors in bold represent sectors whose representation is particularly important for representation of the impact of biofuel policies. Coproducts are also represented through complementary output of vegetable oil and ethanol processing sectors, going respectively to Ethanol and Biodiesel for biofuel, and Cattle and OthAnim for co-products.
Source: MIRAGE-BioF Nomenclature

Appendix II. Carbon stocks value

Table A 3. Carbon stock in managed forests (tCO2 per ha)

	Brazil	CAM Carib	China	CIS	EU27	Indo Malay	LAC	Ro OECD	RoW	SSA	USA
Biomass_ManagedForest											
AEZ1							72		72		
AEZ2							72		72	72	
AEZ3	134						134		134	134	
AEZ4	134		134			134	134	134	134	134	
AEZ5	252		252			252	252	252	252	252	
AEZ6	354		354			354	354	354	354	354	
AEZ7			68	68			68		68		68
AEZ8			68	68			68	68	68	68	68
AEZ9			224	224	224		224	224	224	224	224
AEZ10	224		224	224	224		224	224	224	224	224
AEZ11			246	246	246		246	246	246	246	246
AEZ12	294		294	294	294		294	294	294	294	294
AEZ14			34	34	34		34	34	34		34
AEZ15			90	90	90		90	90	90		90
AEZ16			90	90	90		90	90	90		90
AEZ17							90	90			
AEZ18							90				

Table A 4. Carbon stock in primary forests (tCO2 per ha)

	Brazil	CAM Carib	China	CIS	EU27	Indo Malay	LAC	Ro OECD	RoW	SSA	USA
Biomass_PrimaryForest											
AEZ1									169		
AEZ2										169	
AEZ3	291						291			291	
AEZ4	291	291	291			291	291			291	
AEZ5	378	378	378			378	378			378	
AEZ6	708	708	708			708	708			708	
AEZ7			159	159			159				159
AEZ8			159	159				159		159	159
AEZ9			269	269			269	269		269	269
AEZ10	269		269	269	269		269	269	269	269	269
AEZ11			347	347			347			347	347
AEZ12	463	463	463	463			463		463	463	463
AEZ14			34	34				34			34
AEZ15			112	112				112			112
AEZ16			112	112				112	112		112
AEZ18							112				

Table A 5. Carbon emissions from mineral soil (tCO2 per ha)

	Brazil	CAM Carib	China	CIS	EU27	Indo Malay	LAC	Ro OECD	RoW	SSA	USA
Soil_emissions											
AEZ1	56						56	9	54	58	
AEZ2	58						56	24	57	58	
AEZ3	58						55	23	49	57	
AEZ4	57	57	49		58	46	56	18	37	56	
AEZ5	88	86	79			57	82	41	58	89	
AEZ6	113	112	95			93	101	41	99	113	
AEZ7			27	27			28	28	26	28	34
AEZ8			36	36	37		36	37	35	37	37
AEZ9			103	108	107		107	108	104	108	108
AEZ10	108		102	108	108		107	105	104	108	107
AEZ11	73		63	76	75		75	73	62	76	74
AEZ12	98	100	72	98	100		98	96	73	91	99
AEZ14			50	50	50		41	26	48		50
AEZ15			73	77	77		71	77	72		77
AEZ16			74	77	77		72	24	69		76
AEZ17			74				73	39			
AEZ18							77				

Peatland emissions are also accounted for in the case of Indonesia and Malaysia. We assume that 33 of palm oil plantation in that region expands on peatlands, accordingly to Edwards et al. (2010).

Table A 6. Carbon stock in peatlands (annual emissions, tCO2 per ha per year)

	Brazil	CAM Carib	China	CIS	EU27	Indo Malay	LAC	Ro OECD	RoW	SSA	USA
Peatland Emissions											
						55					

Appendix III. Land Displacement Matrix: Crop specific scenarios

Table A 7. Land use matrix - Biodiesel - Crop level HA by TJ

	Total exploited land	Pasture	Cropland	Maize	PalmFruit	Rapeseed	Soybeans	Sugar_cb	Sunflower	Wheat
Biodiesel_PalmFruit										
Brazil	-0.04	-0.07	0.07	-0.16	0.01	0.00	0.53	-0.04	0.00	-0.03
CIS	-0.04	-0.05	0.12	-0.04		0.02	0.03	0.00	0.48	-0.16
EU27	0.03	-0.01	0.08	-0.02		0.26	0.01	0.01	0.19	-0.09
IndoMalay	0.03	-0.13	0.51	-0.12	1.70		-0.01	-0.03		
SSA	-0.07	-0.54	0.56	-0.14	1.76	0.00	0.02	-0.01	0.09	-0.04
USA	0.08	0.00	0.10	-0.19		0.02	0.50	0.00	0.02	-0.17
World	*0.12*	*-0.91*	*1.97*	*-0.96*	*3.89*	*1.06*	*1.88*	*-0.09*	*1.08*	*-1.13*
Biodiesel_Rapeseed										
Brazil	0.01	-0.17	0.25	-0.21	0.01	0.01	0.80	-0.06	0.00	-0.03
CIS	0.05	-0.24	0.77	0.00		0.38	0.05	-0.02	0.87	0.15
EU27	0.14	-0.10	0.51	-0.49		4.42	-0.03	-0.05	0.13	-1.03
IndoMalay	0.02	-0.07	0.26	-0.05	0.80		0.01	-0.01		
SSA	-0.04	-0.40	0.42	-0.03	0.79	0.02	0.05	0.00	0.14	0.02
USA	0.11	-0.01	0.15	-0.36		0.24	0.74	0.00	0.03	-0.24
World	*0.64*	*-1.39*	*3.90*	*-1.74*	*1.71*	*10.91*	*2.86*	*-0.23*	*1.65*	*-3.44*
Biodiesel_Soybean										
Brazil	0.17	-0.48	0.86	-0.73	0.02	0.00	3.25	-0.22	0.00	-0.14
CIS	-0.01	-0.12	0.32	-0.01		0.04	0.23	0.00	0.74	-0.28
EU27	0.03	-0.02	0.10	0.03		0.50	0.14	0.04	0.31	-0.25
IndoMalay	0.02	-0.07	0.28	-0.05	0.86		0.03	-0.01		
SSA	-0.05	-0.52	0.56	-0.03	1.38	0.00	0.23	0.00	0.15	-0.03
USA	0.17	-0.01	0.25	-1.23		0.01	2.92	0.00	0.02	-0.68
World	*0.76*	*-1.50*	*3.86*	*-2.99*	*2.48*	*1.86*	*11.61*	*-0.25*	*1.70*	*-3.00*
Biodiesel_Sunflower										
Brazil	-0.05	-0.02	0.01	-0.17	0.00	0.00	0.39	-0.05	0.02	-0.02
CIS	0.29	-1.16	2.71	-0.12		0.01	0.05	-0.06	6.14	-1.16
EU27	0.09	-0.06	0.33	-0.54		-0.08	-0.04	-0.02	4.28	-1.07
IndoMalay	0.02	-0.05	0.19	-0.03	0.55		0.00	-0.01		
SSA	-0.04	-0.55	0.58	-0.11	0.77	0.00	0.03	0.00	0.98	0.00
USA	0.10	0.00	0.12	-0.16		0.02	0.32	0.00	0.28	-0.22
World	*0.71*	*-2.04*	*4.90*	*-1.51*	*1.46*	*0.81*	*1.21*	*-0.16*	*13.59*	*-2.97*

Table A8. Land use matrix - Ethanol - Crop level HA by TJ

	Total exploited land	Pasture	Cropland	Maize	PalmFruit	Rapeseed	Soybeans	Sugar_cb	Sunflower	Wheat
Ethanol_Beet										
Brazil	-0.12	0.06	-0.18	-0.05	0.00	0.00	-0.22	0.05	0.00	0.00
CIS	-0.06	-0.01	0.02	-0.01		0.01	-0.01	0.03	0.07	0.02
EU27	0.02	-0.05	0.17	-0.72		-0.72	-0.07	5.34	-0.29	-1.32
IndoMalay	0.02	-0.01	0.05	0.00	0.08		0.00	0.01		
SSA	-0.07	-0.12	0.07	-0.03	0.09	0.00	0.00	0.14	0.02	0.02
USA	0.06	0.00	0.06	0.06		0.01	-0.10	0.01	0.01	0.01
World	*-0.13*	*-0.13*	*0.41*	*-0.80*	*0.19*	*-0.54*	*-0.49*	*5.75*	*-0.13*	*-1.02*
Ethanol_Cane										
Brazil	0.14	-0.77	1.09	-0.47	0.00	0.00	-0.98	3.63	0.00	-0.06
CIS	-0.07	0.02	-0.05	-0.02		0.00	0.00	0.11	-0.02	-0.08
EU27	0.00	-0.01	0.03	0.03		-0.05	0.00	0.09	-0.02	-0.03
IndoMalay	0.02	0.00	0.03	0.00	0.02		0.00	0.01		
SSA	-0.07	-0.07	0.02	-0.03	0.02	0.00	0.00	0.15	0.00	-0.02
USA	0.07	0.00	0.07	0.07		0.00	0.00	0.02	0.00	-0.07
World	*0.15*	*-0.88*	*1.48*	*-0.49*	*0.03*	*-0.03*	*-0.86*	*4.51*	*-0.03*	*-0.43*
Ethanol_Maize										
Brazil	-0.06	-0.14	0.13	0.82	0.00	0.00	-0.49	-0.04	0.00	-0.02
CIS	-0.07	0.00	-0.02	0.31		0.00	-0.01	0.00	0.02	-0.14
EU27	0.01	-0.02	0.08	2.40		-0.38	-0.05	0.00	-0.17	-0.67
IndoMalay	0.02	-0.01	0.05	0.05	0.07		0.00	0.00		
SSA	-0.06	-0.16	0.12	0.71	0.09	0.00	-0.01	-0.01	0.01	-0.02
USA	0.07	0.00	0.09	1.12		0.00	-0.70	0.00	0.00	-0.16
World	*0.00*	*-0.40*	*0.88*	*6.52*	*0.17*	*-0.33*	*-1.46*	*-0.07*	*-0.11*	*-1.03*
Ethanol_Wheat										
Brazil	-0.09	-0.01	-0.06	0.00	0.00	0.00	-0.22	0.00	0.00	0.09
CIS	0.00	-0.11	0.29	-0.03		0.00	-0.02	-0.01	-0.06	0.78
EU27	0.03	-0.04	0.17	-0.54		-0.62	-0.06	-0.02	-0.27	3.27
IndoMalay	0.02	-0.01	0.06	0.01	0.09		0.00	0.00		
SSA	-0.06	-0.20	0.17	0.05	0.11	0.00	0.00	-0.01	0.02	0.30
USA	0.07	0.00	0.08	0.01		0.00	-0.31	0.00	0.00	0.44
World	*0.10*	*-0.54*	*1.39*	*-0.74*	*0.20*	*-0.91*	*-0.87*	*-0.06*	*-0.27*	*7.64*

Source: Mirage-Biof Simulations

Appendix IV. Detailed Methodology

This appendix details the methodology used in this report. It is based on Laborde and Valin (2011) and Al Riffai, Dimaranan, and Laborde (2010). We discuss the database, the methodology, and finally the key changes implemented between this study and Al Riffai, Dimaranan, and Laborde (2010).

An innovative database for a consistent representation of agricultural sectors in CGE

CGE models are highly dependent on a high quantity of inputs, and very few available datasets currently address this issue. As far as we know, most applied CGE approaches at the global level rely on the database provided by the GTAP Center (Narayanan and Walmsey 2009). Assessments of biofuel policies are no exception, even though modelers have developed various techniques to cope with the absence of the biofuel sectors in the commercial version of the database. In this section, we explain why usual work on data, consisting of creating new sectors by splitting aggregates through value shares, can lead to flawed analysis. We present our approach to reconstruct more reliable data for consistent modeling behaviors.

Our initial source of data has been latest available database, GTAP 7, which describes global economic activity for the 2004 reference year in an aggregation of 113 regions and 57 sectors. Due to the multiplicity of feedstocks involved in the biofuel production for the EU markets, and their different technological pathways, we decided to significantly disaggregate the GTAP sectors, starting with the oilseed production and processing sectors. 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-products of distilling and crushing activities, the fertilizer sector, and the transport fuels sector. This process did not consist of a simple disaggregation of parent sectors, but required a full rescaling of agricultural production data according to FAO statistics on quantity and prices, harmonization of prices on substitutable homogenous goods such as biofuels or vegetable oils, and bottom-up reconstruction of production costs for biofuel sectors and crushing sectors for oilseeds.

Indeed, after some initial tests, we found that an approach based on pure splitting in a top-down setting –as proposed by built-in tools in the GTAP community, such as SplitCom –lead to severe issues, in particular for critical sectors such as several feedstock crops, vegetable oils, and biofuel sectors.[28] We therefore developed an original and specific procedure to generate a database that is consistent in terms of both values and quantities. The general procedure is as follows:

1) Agricultural production value and volume are targeted to match Food and Agriculture Organisation of the United Nations (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 sectors.

3) New vegetable oil sectors are built using a bottom-up approach based on crushing equations. Value and volume of both oils and meals are consistent with the prices matrix, physical yields, and input quantities.

4) Biofuel sectors are built using a bottom-up approach to respect the production costs, input requirements, production volume, and, for the different type of ethanols, different by-products. Finally, rates of profit 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 products, vegetable oils, chemical and rubber products, fuel) in the original social accounting matrix (SAM), allowing resources and uses to be extracted from different sectors if needed (n-to-n).

At each stage, consumption data are adjusted to be consistent with production and trade flows. Targeting only value often generates inconsistencies in the physical linkage, which thereby leads to erroneous assessments (e.g. wrong yields for extracting vegetable oil).

It is important to emphasize that this procedure, even if time-consuming and delicate to operate with so many new sectors, was crucial for an adequate representation of the sectors. In particular, we were surprised and concerned to see that little attention was usually given in the literature to these aspects until now. Indeed, each step allows us to address several issues. For instance, Step 1 allows us to correct for the level of production, compared to the GTAP database wherein production targeting is done only for Organisation for Economic Co-operation and Development (OECD) countries, with some flaws, and therefore gives outdated agricultural production structure for many countries. Finally, a flexible procedure is needed (Step 5) since some of our new sectors can be constructed from among several sectors in GTAP. SplitCom allows only a 1-to-n disaggregation, which is rather restrictive for the more complex configuration that we face with the data. For instance, Brazilian ethanol trade data falls under

[28] 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.

the beverages and tobacco sector, while its production is classified under the chemical products sector. For the vegetable oils, we face similar issues since the value of the oil is in the vegetable oil sector but the value of the oil meals is generally under in the food products sector.

New sectors introduced in the database are:

- 5 crops (maize, soybeans, rapeseeds, palm fruits, sunflower). Production technology for new crops sectors was inherited from the parent GTAP sector.
- 4 vegetable oil and 4 of their co-products following information on the crushing cost structure (rapeseed oil and meal, soybean oil and meal, sunflower oil and meal, palm fruit). Value and volume of both oils and meals were made consistent with the prices matrix, the physical yields, and the inputs quantity.
- 4 ethanol processing sectors and 3 of their by-products (ethanol from wheat and their DDGS, ethanol from corn and their DDGS, ethanol from sugar cane, ethanol from sugar beet and their beet pulp). The 4 ethanol products are then considered almost perfectible substitutable inputs in a single ethanol final product.
- 3 fuel sectors (fossil fuel, biodiesel, aggregated ethanol). Biodiesel was also built with a bottom-up approach to respect the production costs, input requirements, and production volume.

The specific data sources, procedures, and assumptions made in the construction of each new sector are described in Al-Riffai, Dimaranan, and Laborde (2010, Annex I). Finally, we paid much attention to building a consistent dataset in value and in volume—thanks to a reliable price matrix. Indeed, the role of initial prices and price distortions is of crucial importance in a modeling framework using constant elasticity of substitution (CES) and constant elasticity of transformation (CET) functions. CGE models usually work on small magnitude shocks, and traditional calibration adopts a normalization of all prices in the model. Physical quantities are therefore not explicitly considered in the analysis. This approach generally makes sense when the goods represented are imperfect substitutes and/or the level of product aggregation is large. In particular, the impact of trade policies and fiscal policies can accommodate such approximations. However, agricultural and energy policies are different because the goods considered are more homogenous. Even when some products can be differentiated (soft vs. durum wheat or gasoline vs. diesel), applying CES functions to such goods assumes that the substitution occurs with a technical marginal substitution rate (TMS) between two goods A and B equal to:

$$TMS_{AB} = \frac{dq_B}{dq_A} = \frac{\partial Q/\partial q_A}{\partial Q/\partial q_B} = \frac{p_A}{p_B}$$

Where q stands for quantities, p stands for prices relative to two substitutable goods, A and B, and Q is the CES aggregated good of q_A and q_B. In a case of high substitution elasticity, prices vary little around their initial position in the CES; therefore, the TMS remains almost the same and its value equals the initial price ratio. In the case of a CGE calibrated with normalized prices, the substitution for substitutable good is consequently operated on the basis of US$1 of good A and for US$1 of good B. When comparing the change in consumption with data in physical units, the implicit conversion ratio is therefore determined by the relative prices. In the case of a homogenous good, the implicit price ratio differing from one can lead to serious misinterpretation of the results (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). That is the reason why, considering the critical role of physical linkages and substitutions in this analysis (from the crop side to the energy content of different fuels and meals), we develop a world price matrix for homogenous commodities in order to be consistent with physical quantities and international price distortions (transportation costs, tariffs, and export taxes or subsidies). The information concerning the crushing/distillation technology is summarized in Table A9.

Table A 9. Processing technology coefficients

Commodity	Vegetable Oil per ton of oilseed	Meals per ton of oilseed	DDGS or eq. by ton of feedstock	Ethanol by ton of feedstock
Rapeseed	0.35	0.5145		
Soybean	0.18	0.777		
Sunflower	0.39	0.234		
Palm Fruit	0.23	0.065		
Sugar Cane			0	0.073
Sugar Beet			0.058	0.085
Maize			0.497	0.325
Wheat			0.376	0.330

Source: MIRAGE-BioF Database, GTAP7

We bring three different examples for illustrating the importance of our treatment: changes in commodity prices and relative prices between the GTAP7 and our dataset, changes in the cost structure of vegetal oils, and the cost structure of new sectors such as ethanol in the European Union. Table A10 shows the prices in our dataset for two types of commodities: wheat and vegetal oils. In the first case, we can see that, although OECD production data are consistently adjusted in the original GTAP database, significant distortions appear for other countries (e.g. USA). In the second case, much wider discrepancies are present, probably resulting from inaccurate information in the sources provided to GTAP and various aggregation problems when building the database. Last, Table A11 displays the evolution of the cost structure for producing vegetable oils from oilseeds for key countries. As it appears, we significantly increase the link between oilseeds prices and vegetable oil prices, a key mechanism for the investigation at stake. Figure A1 provides an example for the ethanol supply chain implemented in the data based on a unique ethanol price per liter on the European market.

Table A 10. Implicit domestic price in the GTAP database and in the MIRAGE-BioF dataset (USD/ton)

	Argentina	Brazil	China	EU27	USA
Initial GTAP7 database (production value/FAO production 2004)					
Wheat	118	266	103	144	139
Vegetable oil	1231	1818	517	2826	1589
MIRAGE-BioF dataset*					
Wheat	80	137	118	144	110
Palm Oil	643	643	571	673	719
Rapeseed Oil	808	678	773	676	569
Soybean Oil	512	589	675	616	519
Sunflower Oil	582	669	594	700	590

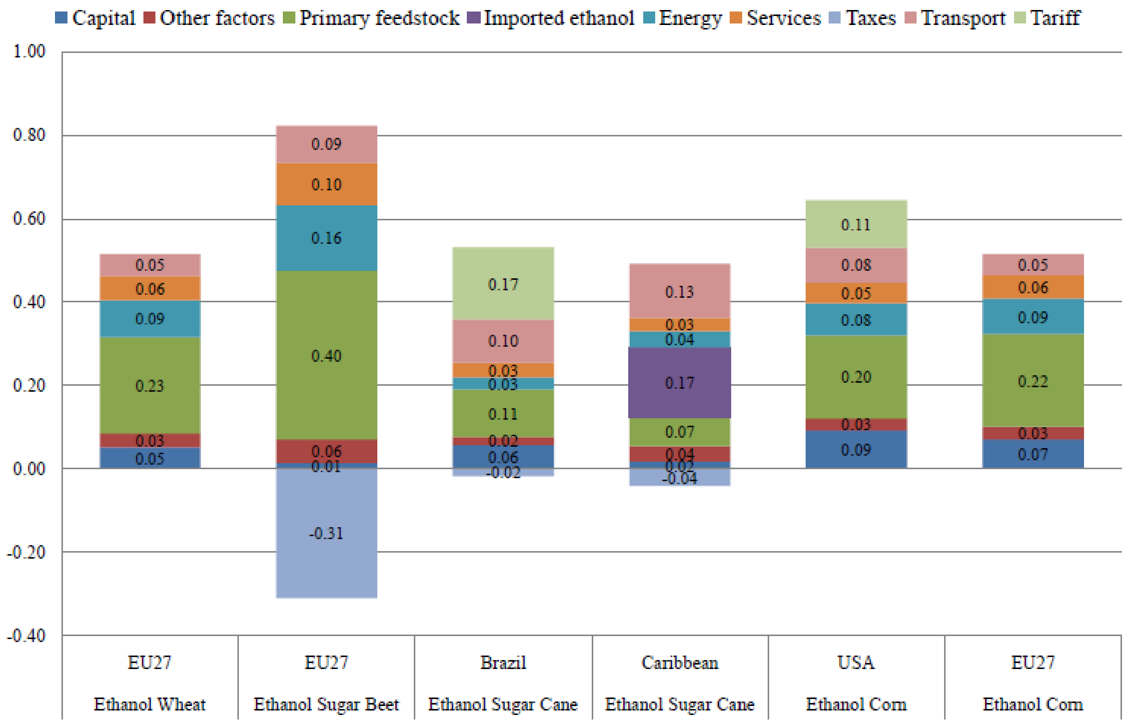
** price differences reflect transportation costs, export restrictions, tariffs…*

Source: MIRAGE-BioF Database, GTAP7, From Laborde and Valin, 2011.

Table A11. Cost share in the processing of oilseeds in the vegetable oil sector

	Argentina	Brazil	China	EU27	USA
Initial GTAP7 database					
Oilseeds	61.7	51.3	10.7	13.0	36.7
MIRAGE-BioF dataset					
Rapeseed	46.3	63.5	77.3	78.9	73.0
Soybeans	75.3	75.2	92.1	81.5	78.4
Sunflower	65.5	70.4	93.9	87.5	79.7

Source: MIRAGE-BioF Database, GTAP7, From Laborde and Valin, 2011.



Source: MIRAGE-BioF Database, From Laborde and Valin, 2011.

Figure A1. Cost structure USD per liter of ethanol supplied on the European market per country of origin and process in 2008. The ethanol market price is set to 0.514 cents per liter at EU market price, before application of fuel and value-added taxes. In the case of sugar beet ethanol, a subsidy has been calibrated to ensure the profitability of the technology based on existing regulated sugar beet prices in the EU.

Several other databases have been associated with the core Input-Output database to specifically convert changes in endowment allocations and input use into physical units. For land use, we relied on FAO for national occupation and on the M3 database (see Monfreda et al., 2008 and Lee et al., 2009) for land distribution between different agroclimatic regions. We relied on data from IIASA (Fischer et al. 2000) for land available for crop in rainfed conditions and on IPCC AFOLU guidelines (Tier 1) for computations of greenhouse gas emissions contained in biomass and in soil. Carbon stocks used for the analysis by AEZ and region is provided in Appendix II. More details on the incorporation of these databases in the model are provided in Valin et al. (2010).

MIRAGE-BioF: a model dedicated to land use and bioenergy policy analysis

In order to evaluate the impact of public policies regarding first generation biofuels, we developed an extended version of the global CGE MIRAGE, nicknamed MIRAGE-BioF, by improving the standard version in several directions. A detailed description of this version of the model is provided in Bouët et al. (2010) and in other studies (Al-Riffai, Dimaranan, and Laborde 2010a, 2010b). This section gives a quick overview of the different features, emphasizing the land market description and is based on Laborde and Valin (2011).

General features

The core structure of the MIRAGE model follows that of standard multi-country, multi-sector, recursive dynamic CGEs. Each country produces a certain quantity of goods through a nested production functions system where intermediate inputs and value added are aggregated through Leontieff technology, each of them being a CES composite of different aggregates of inputs and factors, respectively. Contrarily to standard approach, some intermediate inputs are directly combined with production factors, with some substitutability to address specific complementarity or substitutability issues. For instance, capital and energy inputs are combined together as well as feedstuff and land or fertilizer and land.

Goods are consumed by final consumers (public and private agent) and firms or are exported to foreign markets. The final consumption demand system is represented through a LES-CES that is recalibrated each year along the baseline to reproduce consistent income and price elasticities. Imported goods are differentiated from domestic goods following the Armington assumption, which allows us to distinguish different levels of market integration. Real exchange rates between regions are endogenously adjusted to maintain current accounts as a share of the world GDP. The model is recursively dynamic, and total factor productivity is adjusted along the baseline to follow GDP projections. Total factor productivity in the agricultural sector is adjusted to match yield projections of the AGLINK-COSIMO model.

In order to properly address land use change considerations, special attention has been paid to the representation of land with substitution and expansion possibilities for land use, whose setting we detail in the next subsection. Moreover, the model relies on many features specifically introduced to adequately represent the effects of biofuel policies. In particular, it includes a detailed description of the insertion of biofuel in the consumption chain, a modeling of binding incorporation mandates, and a representation of co-products production for the ethanol sector by type of pathway (wheat, corn, sugar beet) and for the four oilseed processing sectors that have been explicitly introduced (rapeseed, soybean, sunflower, and palm fruit). Particular care has been paid in the final and intermediary consumption nesting to the substitution possibilities of similar products on the one side (vegetable oils, oilseed meals, ethanol feedstocks) and to the rigidity relative to certain inputs in the production chain (vegetable oil to produce biodiesel, sugar raw products to produce refined sugar, etc). Although quite obvious in the reasoning from a bottom-up approach, this focus on the input structure requiring multi-level CES nesting structures for input, specific to many sectors, did not seem to be done in many work based on generic CGE applications based on standardized sector descriptions.

Agricultural production function

A first major improvement brought to the model was the refinement of agricultural production functions. We implemented a more precise disaggregation of factors, isolating a bundle of land and chemical fertilizer in the tree structure of factors to better control for yield response to shock in fertilizer prices and to increase in demand. This allows for precise tracking of the effect of fertilizer input, other factor inputs, and land expansion. Elasticities of fertilizer use with respect to price change are derived from the IFPRI IMPACT model (Rosegrant et al., 2008). Elasticity of other inputs constitutes the complement to match a final endogenous yield elasticity target. There is significant controversy surrounding the question of whether or not such endogenous yield should be represented. Some authors argue that such endogenous response is not established, whereas others find significant value in econometric testing for an endogenous yield response. Following the recommendation of the CARB expert group on elasticities, we assumed an average magnitude of 0.2 for such elasticity. EU27 is closer to 0.15, USA to 0.2, and developing countries to 0.3 to take into account these regions' larger intensification margins, as well as double-cropping possibilities.

Land use substitution and expansion

Among other factors, land was subject to a specific decomposition. In most CGEs, land markets are represented through constant elasticity of transformation (CET) functions. This can imply high substitution of land use between certain categories of crops depending on the value of elasticity chosen. We used a nested design to replicate substitution between cereals and oilseeds, as well as (to a lesser extent) other agricultural uses. In our nested structure, substitutable crops are therefore considered in a separate bundle from other categories of crops that are less easily substitutable (rice, vegetable and fruits, plantations). The land rent values are represented in the model through a volume of productive land equivalent based on several databases, including the GTAP-AEZ land database and the FAO PRODSTAT. Indeed, we did not follow the complete land rent allocation proposed in the GTAP framework because substituting land rent on a value basis corresponding to areas with completely different land rent yield created many conceptual problems. Therefore, our CET functions operate on land rent values that have similar yields (in dollar per hectare) within an AEZ, which ensures that our substitution occurs on a 1-to-1 technical substitution ratio and that overall land area is preserved when total land rent is fixed[29] . The nesting is illustrated in Figure A2. Crops considered as highly substitutable are wheat, corn, rapeseed, soybeans, and sunflower. Other crops are located at the lower level with less possible substitution. In order to represent pressure from uses other than cropland, the nesting structure is extended to include pasture land and managed forest land with additional levels.

[29] In order to obtain similar yield within AEZs, we rebuilt land rent values on the basis of GTAP production data for land rent at the aggregated level, and production distribution across AEZ according to the source M3 database used by GTAP, and finally mapping the aggregated harvested area with FAO data

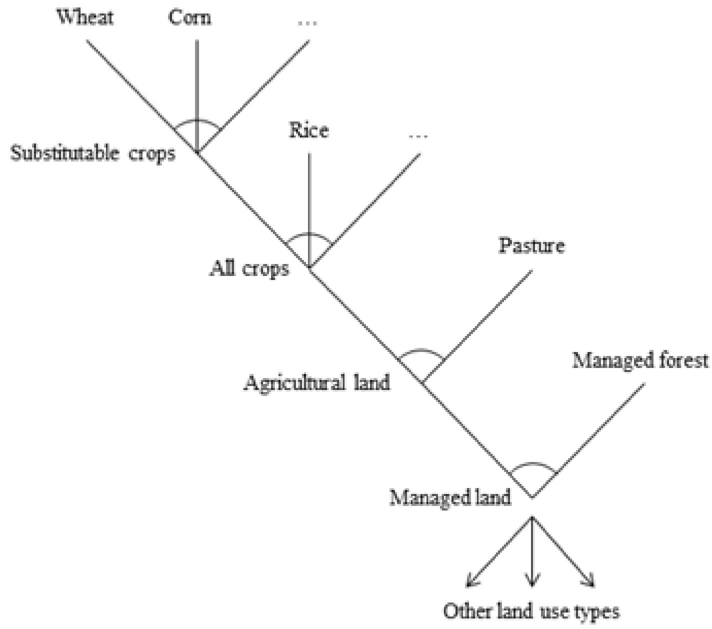


Figure A2: Nesting of CET functions and expansion patterns in the land use representations

Source : Adapted from Laborde and Valin, 2011.

In addition to the choice of this nesting structure, two specificities on the substitution characterize the model. First, each nesting structure is independent at the agro-ecological level in the different regions, which allows for more consistent description of substitution patterns between crops that follow the same agro-climatic cultivation conditions. By default, perfect substitution is assumed within each region for location of production across AEZs. However, a two-tier structure is not flexible enough to fit all the heterogeneity of values that should exist.

A second innovation introduced in the model for land use change is a mechanism that allows for land use expansion into different land cover at the level of AEZ. The extension is driven by a non constant elastic supply function. The value of this elasticity decreases linearly depending on the distance to the limit of cultivable land according to the IIASA GAEZ database.[30] It is important to recognize that such parameters are quite uncertain and that values from the literature vary and are not available for many regions. A of marginal productivity is also to be applied to this new land to reflect the fact that expansion can occur in land of different quality from the land already used.

[30] Elasticity reaches 0 when total cultivable within an AEZ is used

Appendix V. Comparing results with previous analysis

Methodological changes

The first change[31] implemented is related to the calibration of land supply and demand elasticities. Using the conventional CGE framework, demand for land and supply of land was derived from a nested CES (demand) and CET (supply) system. Elasticity of substitution and transformation were taken from the – limited – estimates in the literature. The same elasticity of substitution was assumed for all crops and all countries. Different elasticity of transformation was assumed for different groups of crops as well as for different countries. However, combined with different shares of land rent in value added and total land rent, the CES/CET framework was generating quite heterogenous land supply and demand elasticity. Indeed, elasticity of substitution/transformation and direct price elasticity are linked through the share in value of the land rents. These values were in some cases quite large and different from the existing literature regarding partial equilibrium on this issue. For instance, it was generating too much yield intensification in some cases and/or too high supply elasticity for some agricultural commodities. We have changed our calibration procedure, allowing for more heterogeneity in elasticity of substitution and transformation in order to more accurately target land price elasticity available from the literature and in particular from the FAPRI model.

Second, we have modified our treatment of co-products. While the previous study has already introduced co- and by-products of distillation and crushing processes on the supply side, the treatment of the demand for such products originating from livestock was unsatisfactory. Indeed, it has appeared that the substitution between proteins coming from meals and DDGs was too limited. Keeping a two-level nested CES in the livestock sector, we now allow for a strong substitution between DDGS and meals at a first level and between protein aggregates and other feedstuffs at a second level Table. A12 indicates the latest values used. It should be kept in mind that due to the constraint of the CES nesting, it is impossible to reproduce the same coefficients that can be used in a linear programming model for instance.

[31] This is based on a model improvement developed by Hugo Valin.

Table A 12. Updated displacement values (ton) for 1 ton of co products. EU case for two livestock sectors..

	Coproducts.									
	DDGSWheat		***DDGSMaize***		***MealRape***		***MealSoyb***		***MealSunf***	
Displaced products:	Cattle	OthAnim	Cattle	OthAnim	Cattle	OthAnim	Cattle	OthAnim	Cattle	OthAnim
Wheat	-0.07	-0.03	-0.06	-0.02	-0.07	-0.03	-0.23	-0.11	-0.05	-0.02
Maize	-0.03	-0.01	-0.02	-0.01	-0.03	-0.01	-0.10	-0.05	-0.02	-0.01
Soybeans	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rapeseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Crops	-0.05	-0.02	-0.04	-0.02	-0.05	-0.03	-0.17	-0.09	-0.04	-0.02
DDGSWheat			-0.02	-0.02	-0.02	-0.02	-0.06	-0.07	-0.01	-0.01
DDGSMaize	-0.02	-0.03			-0.03	-0.03	-0.08	-0.09	-0.02	-0.02
MealRape	-0.14	-0.16	-0.12	-0.13			-0.49	-0.59	-0.11	-0.12
MealSoyb	-0.35	-0.38	-0.29	-0.32	-0.39	-0.43			-0.26	-0.28
MealSunf	-0.04	-0.04	-0.03	-0.04	-0.04	-0.05	-0.13	-0.16		

Source: MIRAGE Biof model

Third, we have improved our data on peatland emissions. The previous report discussed two ranges of values: IPPCC (very low) and a larger but still conservative value (40grCO2eq/ha/year). Based on Edwards et al. (2010), we assume that 30 percent of palm plantation expansion in South East Asia takes place on peats and that such peats will emit 55grCO2eq/ha/year.[32] Since we do not perform sensitivity analysis on carbon stocks of different ecosystems, Appendix II provides the detailed information of what is used in the model. Plevin et al (2010) broadly discuss the uncertainty issue of computing LUC emissions and the role of carbon stock on this topic.

Concerning direct savings coefficient, we use only the default value from the directives.

Lastly, the CES-LES demand system of the dynamic model is recalibrated every year of the baseline to maintain food demand price elasticity at its original level (based on USDA). Otherwise, with economic growth, the CES-LES displayed increasing price elasticity, leading to large demand displacement by 2020 when the policy shock was introduced.

Differences in Results

In our previous assessment of EU policy (Al Riffai, Dimaranan, and Laborde, 2010), we have found an average LUC emission coefficient of 17grCO2eq/MJ for the additional mandate under trade policy status quo and about 10 percent more with trade liberalization. However, the scenario was quite different: 55/45 percent of biodiesel/ethanol and a 5.6 percent mandate

[32] In addition, we do not consider the palm tree to be a perennial crop in terms of IPCC guidelines in soil emission. This is a deviation from the EU directive on emission accounting.

instead of 8.7 percent. In addition, peat land emissions were largely underestimated compared to current values.

Our new results (38.4 grCO2eq/Mj and 40 under trade liberalization) are largely above the previous values. The main explanation is the structure of the mandate and the ratio of ethanol/biodiesel. Using a ratio similar to that in the previous study with the current model and parameter values, we find LUC emission coefficients of about 20grCO2 for such a "virtual" additional mandate, very close to previous estimates. Current values are still larger mainly due to the increased emissions of peatlands and more inelastic food demand.

At the crop level (Table A13) we see much larger differences even if some messages remain constant. Let us keep in mind that if the model and some parameters have been altered between the studies, the method used to compute the crop LUC effects is also significantly different.

We still have lower emissions for ethanol feedstocks than for biodiesel. However, the average gap has increased. Indeed, and this is the second important aspect, for nearly all crops (except palm oil due to the increase in peat emissions), the coefficients have been reduced. The soybean coefficient has been cut by half and the maize coefficient by five. However, the ranking between extreme feedstocks remains the same (sugar beet being the best and soybean oil the worst).

Table A 13. Comparing crop specific LUC emission coefficients, grCO2/MJ per annum. 20 years life cycle.

	Al-Riffai, Dimaranan and Laborde, 2010	This study
Ethanol SugarBeet	16.1	6.6
Ethanol SugarCane	17.8	13.4
Ethanol Maize	54.1	10.3
Ethanol Wheat	37.2	14.4
Palm Oil	46.4	54.3
Rapeseed Oil	53.0	53.8
Soybean Oil	74.5	55.8
Sunflower Oil	59.8	51.8

Source: Al-Riffai, Dimaranan, Laborde (2010), Table 12, including peatlands, and Author's computation

Overall, most feedstocks benefit from the higher yields in the baseline which helps to reduce the amount of land required to cope with additional crop demand. This is particularly true for cereals, and especially for maize. But the critical assumption, as discussed before, is the increased mobility of land among crops that helps wheat and maize productions in particular to expand by displacing other crops without pushing upward the total amount of cropland in large proportion.

Appendix VI. Direct saving coefficients

This report focuses on the land use effects, that is how much land is needed to produce biofuels. In order to compute the net emission balance from biofuels (direct savings minus land use emissions) we need to have direct saving coefficients. The « direct saving » coefficients give the amount of GHG saved by consuming one MJ of biofuel instead of one MJ of fossil fuel. It is based on the comparison of the GHG emitted for the production of the biofuels, without considering land use effects, through Life Cycle Analysis and the reference value of GHG emissions of the alternative fossil fuel (CO2 contents + CO2 related to the extraction/refinery process). Of course, these computations are also subject to many uncertainties (implementation of technology, source of energy used in the production of the biofuels etc.). We use values drawn from the EC impact assessment on indirect land-use change related to biofuels and bioliquids, based on the COWI-JRC computations. Original data are displayed in Table A-14 assuming an average 90.3grCO2eq per MJ of fossil fuel. The choice of the value of 90.3grCO2/MJ for the expected fossil fuel comparator follows the conclusions of the forthcoming EC Impact assessment on land use change, Annex VI and is based on the JRC.

Table A 14. COWI-JRC corrected coefficients

Biofuel chain	*Typical GHG savings 2008 [%]*	*Typical GHG savings 2020* [%]*
Wheat lignite as process fuel in CHP plant	32	44
Wheat natural gas as process fuel in conv. Boiler	45	55
Wheat natural gas as process fuel in CHP plant	54	63
Wheat straw as process fuel in a CHP plant	69	76
Sugar Cane	71	-
Corn (maize) natural gas as process fuel in CHP plant	56	64
Biodiesel Rapeseed	45	56
Biodiesel Soybean	40	48
Biodiesel Palm oil (process not specified)	36	43
Biodiesel Palm oil (methane capture at mill)	62	-
Biodiesel Sunflower	58	-
**New installations*		

Source: COWI-JRC and last column updated for a fossil fuel comparator of 90.3grCO2eq/MJ

For our computations, we assume that one value is used for each feedstock <u>and</u> that all additional biofuel production following the additional EU mandate will comply with the 50 percent threshold of GHG emissions. The latter is a constraint for soybean since by 2020 the COWI-JRC coefficients indicate a 48 percent GHG saving. When different technologies are available we keep only one. If the COWI-JRC assessment has missing values for 2020, we rely on the EC impact assessment study. For palm oil, one value is above the threshold (64 percent) and we keep the "*methane capture at mill*" technology, as the other palm oil pathway (without methane capture) will not be in compliance with the sustainability criteria in 2020. In the case of wheat, we use the "*natural gas as process fuel in CHP plant*" pathway to be consistent with the choice for corn ethanol (same technology) and acknowledging the fact that wheat ethanol will be processed with the EC. For sunflower and sugar cane, the COWI-JRC report displays value for 2008 only and following the approach of the EC impact assessment, the 2008 values have been projected until 2020 using the trend for other feedstocks. The values used are displayed in Table A-15.

Table A 15. Direct saving coefficients used in this report

Feedstock	*GHG savings [%]*	*GHG savings [grCO2eq/MJ]*
Wheat	63*	56.8
Maize	64	57.6
Sugar Beet	70**	63.2
Sugar Cane	78**	70.1
Palm Fruit	64***,**	57.8
Soybean	50****	45.2
Sunflower	64**	57.9
Rapeseed	55	50.1

Note: * since different pathways are available for wheat, we use the "natural gas as process fuel in CHP plant" to be comparable with corn based pathway and respect the 50% threshold
** value used in the EC impact assessment study. For sunflower, palm oil with methane capture and sugar cane, the value for 2020 has been projected based on the 2008 value of the COWI –JRC computations. See table A14.
*** for palm oil biodiesel, we keep the pathway "methane capture at mill" that is the best technology in the COWI-JRC computations and the only one respecting the 50% treshold.
**** minimal value EC target assumed even if no pathway appears to meet the criterion

The LCA analysis is based on observed use of fertilizer for computing emissions by MJ of biofuel from different feedstocks. However, the use of this input is endogenous to the model (yield response). As an illustration, we compute how the direct savings coefficients are impacted by changes in fertilizer use. We propose two approaches based on the world average change in fertilizer uses (and not in fertilizer contents of EU consumption)[33]. The first one assumes that the amount of fertilizer by unit of production in the baseline is identical to the RED assumption. Therefore, we only consider the marginal effects of the mandate (deviation from the baseline) in our computations. In most of the case for the central scenario, the fertilizer intensity increases but in small proportions and direct savings are noticeable reduced for rapeseed (-0.03 percent in direct savings, 0.02 grCO2equ per MJ) and sugar cane. Only for sugar cane in crop specific scenarios or under free trade that we find larger effects with a reduction of 0.13 grCO2eq per MJ of savings for this pathway.

[33] Using world average leads to an underestimation of the fertilizer response compared to an EU consumption based approach.

If we consider the changes between 2007 and 2020 of fertilizer use, per unit of output, projected by the model.[34] This later approach leads to important reduction in emissions since the fertilizer use decreases in the baseline due to two drivers. First, at the world level, the production shifts from developed countries (with high level of inputs) to emerging countries using less intensive techniques reducing the "average" use of fertilizer. Second, and mainly, the technical progress increases yield significantly in our baseline. Even without changing the amount of fertilizer per hectare, it leads mechanically to larger production per hectare and mechanically to less fertilizer by unit of production. The later effect has to be considered carefully since the production of biomass related to the yield improvement in the baseline may still require additional fertilizer. Such agronomic constraint is not included in the model. In other words, if the model captures the idea that more fertilizers lead to higher yields, yield increase driven by technological progress does not involve the needs of more inputs The consequences on direct savings are stronger than before but remains limited: direct savings increase varies from 0.03 grCO2eq for soybean (low intensity of N fertilizer for this crop) up to 0.28 grCO2eq for rapeseed.

In all cases, we do not use these figures in the report for computing net effects and keep values of Table A-15. Based on the impact discussed above, integrating the endogenous response of fertilizer will not change significantly the direct saving coefficients used.

Nevertheless, this computation remains incomplete in terms of emissions. First, we do not measure the impacts of change in fertilizer for other crops (no biofuel feedstocks) that intensify as a reaction of increased land competition. Second, we do not take into account the shift to more energy intensive production process in the farm sector following the policy shock. Indeed, as shown in Figure 12, intensification gains are only driven partially, not to say secondarily, by fertilizer increase (per unit of production). An important source of yield increase is the factor intensification, i.e. more units of labor and capital per unit of land. In this case, it can involve more mechanization, or more irrigation, per unit of crop, and therefore, more energy related emissions. This effect will reduce the GHG emissions net savings.

[34] It is important to ensure that these projections are consistent or not with the LCA underlying assumptions.