Assessing the EU biofuel land use change effects: estimates with the MIRAGE-BioF model and uncertainty

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Abstract

Evaluation of indirect land use changes (ILUC) due to biofuels has been very controversial over the past few years, as doubt has arisen about the potential benefits of growing crops for use as a substitute for fossil fuels. In this paper, we present an overview of a CGE modelling approach, based on the MIRAGE-BioF model. Our framework brings new innovative features that strengthen the relevance of the methodology. In particular, a more detailed and consistent database has been developed to represent the sectors and substitution mechanism at play. Moreover, the model used has been improved in several important ways to better reproduce agricultural supply function and land use change. However, we also emphasize the critical uncertainties that prevent us from being able to provide a precise two-digit figure on the extent of land use change and associated emissions. We illustrate these efforts with the case of EU biofuel mandates implications. We show that emissions from the current national targets in the EU could lead to an indirect effect of land use expansion ranging from 1 ha per TJ consumed to 12 ha per TJ with a median value of 3.4 ha per TJ. The associated emissions in a 20-year period would range from 10 gCO2/MJ to 115 gCO2/MJ, with a median value of 38 gCO2/MJ. These results seriously question the sustainability of the current EU biofuels policy and emphasize the even more dramatic effect of a biodiesel-oriented EU biofuel program, found to emit two times more than an EU ethanol-oriented program.

Keywords: Biofuels, Indirect Land Use Change, Computable General Equilibrium, EU agricultural policies.

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1. Introduction

The potential positive environmental impacts of first generation biofuels is currently under intense scrutiny. Indeed, the debate on indirect land use change (ILUC), which was exacerbated by the articles of Searchinger et al. (2008) and Fargione et al. (2008), has seriously questioned the principle that biofuel policies would lead to greenhouse gas (GHGs) savings as long as land use diversion effects are taken into account. Growing biofuel crops would lead to displacement of production historically dedicated to food and feed needs in other regions and would drive massive natural land conversion to cropland. This relocation of production under intense agricultural management could release significant new volumes of carbon into the atmosphere and could negate the carbon benefits associated with biofuel programs. This issue has become a more significant concern following policymakers' decision to consider calculations of these effects in United States (USA) or European Union (EU) legislation as a complement to the reduction of the usual life cycle assessment (LCA) of different biofuels pathways.

As a consequence, a large number of studies were commissioned to investigate the possible range of ILUC "coefficients." The first integrated assessments were realized by US research teams for the California Air Resource Board (CARB) and the US Environmental Protection Agency (US EPA) using a computable general equilibrium approach (GTAP model, Purdue University) and an integrated framework centred on two partial equilibrium models (FASOM and CARD-FAPRI), respectively. On the EU side, different methodologies were also applied, the results of most having been released in the first semester of 2010 (partial equilibrium with AGLINK-COSIMO (OECD) and computable general equilibrium with MIRAGE-BioF (IFPRI)).

This paper provides a clear description of how land use is represented in the MIRAGE-BioF computable general equilibrium model. Providing details about the data and methodology used, we illustrate why such models are relevant for understanding the implications of biofuels policies and, among other aspects, land use competition and environmental impacts related to land use change.[1] We

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[1] It is worth noting that using a global model where all markets are cleared simultaneously does not allow computing the "indirect land use" effect of a policy versus a "direct" effect. If this discrimination can make sense

illustrate our setting with simulations of EU biofuel policy. As the future composition of the ambitious EU biofuels mandate in terms of fuel type and feedstock use may still evolve, comparing different scenarios is of particular interest. Until recently, biodiesel has been used as the main fossil fuel substitute (80 percent in 2009), while the ethanol market is still underdeveloped. We show that in the case of the EU, this orientation could be more costly in terms of land use change and associated carbon emissions.[2]

Using a CGE model to study such issues, however, presents significant challenges since it requires dealing with some inherent limitations of the approach. First, CGE models are in general highly aggregated in sectors and regions, whereas tracking land use change requires a good geographical resolution and disaggregation of crops and technological pathways to correctly represent the substitution effects. Second, as change in these models is driven by relative prices and calibration based on value shares, physical units are not represented traditionally and results, expressed in percentage change on volume index, can be inconsistent when entering into detailed sectors with homogenous goods. In this analysis, physical linkages (crushing ratio, yield per hectare, energy content of one liter of biodiesel vs ethanol) and appropriate rates of substitution through price levels are precisely reproduced. Third, the key production factor, land, is traditionally treated as any other factor without paying particular attention to the specific nature of this input or to its supply and substitution elasticities. However, supply and demand elasticities used in CGE models for agricultural sectors are usually significantly larger compared with their PE equivalent, even when focused on the long term. Therefore, price fluctuations are limited, whereas in the case of biofuels and their land use effects, the distribution of effects between increased acreage, reduced demand, and yield intensification is strongly determined by the calibration assumptions on price elasticities.

The structure of the paper falls as follows. In section 2, we present the modified global Input/Output database used for our CGE, which significantly corrects usual flaws and lack of details found in

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in a causal analysis or in a policy debate, it is purely artificial in a general equilibrium perspective: the modeling approach used in this article determines the net land use changes of the policy studied.

[2] However, it is important to keep in mind that this article is not aimed to provide an exhaustive emission analysis of the biofuel mandate. We focus on land use emissions and its uncertainties and do not look at the emissions related to the production of crops (energy, fertilizers) or to the processing of biofuels.

commonly used databases in agricultural CGEs. Section 3 presents the modeling structure and the underlying behavioral assumptions. In section 4, we stress some interesting qualitative learning from a central scenario and discuss the role of uncertainty on some parameters. In section 5, we discuss the role of some important specifications that play a critical role in the results. We conclude with section 6 concerning the potential consequences of different EU policy options.

2. 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 (Hertel et al. 2010; Banse et al. 2008; Kretschmer et al. 2009), even though modelers have developed various techniques to cope with the absence of the biofuel sectors in the commercial version of the database (see Kretschmer et al. 2009 for an overview of the different approaches used). In this section, we explain why usual the 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 (Narayanan and Walmsley 2008). 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. More details on the methodology and the full list of sectors are provided in Appendix 1 and 2.

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, 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 versus durum wheat or gasoline versus 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:

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

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 to 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 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 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).

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 cost structure of vegetal oils, and the cost structure of new sectors such as ethanol in the European Union. Table 1 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. India and 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 2 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 1** provides an example for the ethanol supply chain implemented in the data based on a unique ethanol price per liter on the European market.

[Insert Table 1, Table 2 and Figure 1]

Several other databases have been associated to 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 2. More details on the incorporation of these databases in the model are provided in Valin et al. (2010).

3. 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.

3.1 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. 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 account 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 projection 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 bioethanol 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 works based on generic CGE applications based on standardized sector descriptions.

3.2 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.

3.3 Land use substitution and expansion

Among other factors, land was subject to a specific decomposition. In most CGEs,[3] 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 use. 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.[4] . The nesting is illustrated in Figure 2. 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 can optionally be extended to include pasture land and managed forest land with additional levels (“constrained pasture and forest” closure).

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. Second, transformation elasticities are endogenously

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[3] A notable exception is the approach proposed by Gurgel et al. (2008) with the EPPA model where an approach using pure conversion cost is developed. However, this type of model does not enter into description of substitution at the crop level.

[4] 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

calibrated to fit at the regional level land supply elasticities from the FAPRI elasticity database, which ensures consistency with aggregated regional observation on agricultural system responses. Although a two-tier structure is not flexible enough to fit all the heterogeneity of values displayed in FAPRI dataset, the calibration allowed to obtain land supply elasticity response close to FAPRI figures, as displayed in Figure 6.

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. In most standard agricultural CGE approaches, cropland, pasture, and forest are substituted through a CET function on a value basis, which introduces many problems relative to the mapping between physical land units and land rent information. By default, we will represent cropland expansion into new land such as pasture, forests, savannah, or other natural cultivable land through a specific elasticity calibrated on a few references from the literature (OECD, 2001; Barr et al., 2010; Roberts and Schlenker, 2010). The value of this elasticity decreases linearly depending on the distance to the limit of cultivable land according to the IIASA GAEZ database.[5] 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. That is why we conduct a sensitivity analysis on this parameter in the next subsection. With this design, it is important to note that expansion of cropland is not restricted by an increase in forestry or animal products; production of forest and pasture is possible without retroaction on cropland. Level of expansion into pasture, forest, or other land cover is therefore determined by historical share and is fully transparent. This assumption is convenient to precisely track the expansion of cropland independently from what occurs in a non-crop system and to accurately measure effects of co-products. A coefficient of marginal productivity is also be applied to this new land to reflect the fact that expansion can occur in land of different quality from the land already used. In section 5.3, we will change this assumption and see what occurs if pressure from cattle and forest activities is added in the competition for land.

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

4. Land use change from three potential scenarios for EU biofuels policies

4.1. Description of baseline and scenarios

We illustrate the effect of the previous setting and calibration with an evaluation of the impact of different biofuel policies scenarios in the European Union. These three scenarios are implemented on a baseline starting in 2004 and going through 2020, which is the final year for the EU directive target of incorporation of renewable energy in European road transportation fuel. The level of sectoral and geographical disaggregation used in the simulations are displayed in Appendix 2.

In our baseline, we consider a global adoption of biofuel targets across major world economies, according to existing programs and to announced future commitments from major countries. The US program is continued under the Renewable Fuel Standard, requiring incorporation of 36 billion gallons in 2022, with no more than 15 billion gallons from corn ethanol, at least 1 billion gallons of biodiesel, and some imports of sugar cane, considered an advanced biofuel, to compensate for the slow emergence of second generation fuels. However, we consider that trade policies with respect to ethanol remain at *status quo* and that, consequently, the share of sugar cane ethanol in US consumption remains minor. Japan and Korea develop biofuel programs up to 5 percent of their consumption of transportation fuel. Brazil follows its ethanol program with a share of 35 percent of incorporation.[6]. ASEAN countries and Argentina are also supposed to reach a 5 percent mandate by 2020, which seems in line with recent observations of the rapidly growing biofuel industries in these regions. We finally consider a similar target for China, although recent developments in Chinese policy suggest some deviation from the initial objectives if high food prices are maintained.[7] These biofuel programs are implemented through incorporation mandates, while other countries adapt their energy consumption according to oil price evolution. We suppose a linear increase in oil prices along

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[6] The Brazilian policy on ethanol does not involve a mandatory incorporation so high. Thanks to a large, and growing, fleet of flex fuel cars, the Brazilian consumption is not driven anymore by policies but by the relative prices between ethanol and conventional gasoline. However, due to the role of the national oil company PETROBRAS in the fuel market, we consider that the EU policy will not displace Brazilian own consumption and that the blending rate will be stabilized by Brazilian national actors. The average blending rate of 35 percent used here is lower bound of UNICA recent projections about domestic consumptions. See Al Riffai, Dimaranan and Laborde, 2010b, for a discussion of Brazilian policies and alternative consumption level.

[7] We do not incorporate the Indian biofuels target of 20% blending rate by 2020 due to the uncertainty commitments and the official objective of using marginal land and new crops (Jatropha, Sweet Sorghum) not included in our model.

the baseline from the base year 2004 (US$40) to the projected long term price forecasts from International Energy Agency with US$110 by 2020 for a business-as-usual scenario (WEO 2010).

In the European Union, the reference case is supposed to be a moderate biofuel policy with a stabilization of incorporation at 2008 levels, which represents 3.3 percent of total fuel consumption. Trade policies are mainly supposed unchanged. The only notable intervention is the end of biodiesel imports from the United States, for which we consider that EU countervailing and antidumping measures, modeled as a prohibitive tariff, are maintained after their implementation in 2009.

Three scenarios are modeled with respect to the baseline:

1) Our main central scenario on EU biofuel policies is based on the current 27 National Renewable Energy Action Plans (NREAP, called therein NAP) implemented as a transposition of the EU directive in the different Member States (see Laborde, 2011). At the EU aggregated level, it represents an overall target of 7.7 percent of biofuel incorporation (27.5 Mtoe) in 2020, with a share of 72 percent of biodiesel and 28 percent of bioethanol.

This central scenario is completed by two other scenarios aimed at disentangling the composition effect between ethanol and biodiesel impact:

2) A scenario of 7.7 percent fully based on the addition of biodiesel only (“BIOD”)
3) A scenario where the same target is reached through an increase in ethanol consumption (“ETHA”).

4.2. Results

European consumption mandates participate and increase the development of the biofuel industry along the baseline. Ethanol and biodiesel sectors expand from an initial value of around 40 Mtoe in 2008 up to 111 Mtoe globally in 2020, EU program included. In our results, displayed in Table 3, the central scenario leads to a higher consumption of biodiesel according to the National Action Plans, with 85 percent of biodiesel being produced domestically (even if some feedstock products are imported) and the rest being provided by Malaysia and Indonesia (1.7 Mtoe) and Argentina (1.7

Mtoe). In addition, Malaysia and Indonesia becomes leading exporters in the pure biodiesel scenario, with 2.5 Mtoe of exports, i.e. around 3.2 billion liters of palm oil based biodiesel (in addition to palm oil imports). In the European Union, this type of biodiesel is balanced with other feedstock use, as illustrated by Figure 5, which shows the production mix between crops. On the ethanol side, in spite of the EU protection level, the incorporation target relies much more on imports, representing more than half of all consumption, thanks to the low production costs of Brazilian sugar cane ethanol. Brazil indeed provides most of the 5 Mtoe of ethanol imported to the EU in addition to exports in the direction of other regions in the baseline. At the same time, expansion of EU domestic production is considerable to satisfy the large ethanol demand, as the sector is to grow by a factor of 10. However, in the situation of the central scenario “NAP,” the contribution of Brazilian exports is reduced to 1.9 Mtoe, which then represents 3.7 billion liters (around 20 percent more than the record total exports of the country observed in statistics for the year 2006).

[Insert Table 3 and Figure 5]

This rapid and large contribution of South American and East Asian exports to the EU program does not mean that all land use effects are to take place in these regions. Indeed, significant trade repercussions also occur on the feedstock side, as illustrated by Table 4. Producing biodiesel for the central scenario requires significant increase in imports of all type of vegetable oils. The EU transforms all its production of rapeseed oil and relies more on imports, whereas large quantities of palm oil and soybean oil are provided by trade partners. A more ethanol-oriented policy appears less critical on the cereal trade balance in absolute; under an assumption of sufficient yield increase, exports are significantly reduced under an ethanol scenario. Interestingly enough, the exports of cereals also increase with the level of incorporation of biodiesel, as oil meals produced during the crushing can be used as feed input into the livestock sector.

[Insert Table 4]

Increase of production worldwide to provide for the new biofuel demand in the shocks triggers extensive and intensive margin response in the agrosystem. Yields tend to increase with a contribution from investment and other factors mobilization, as well as from the addition of more input such as fertilizers and pesticides. These source are, however, less significant in the reaction of agricultural production than land use expansion, as illustrated in Figure 4.

[Insert Figure 4]

This consequently leads to a significant change in land use across regions, due to requirements of crops to be processed as biofuels or directly exported, in order to be transformed elsewhere or to replace other diverted crops. We find that the fulfillment of the National Action Plans would require 2.7 million ha of converted land for growing new crops, whereas very small expansion would occur in the EU, most of the domestic effect being driven by crop substitutions on existing cropland (Table 5). The first source of land cover converted to cropland would be savannah and grasslands (accounting for almost half of converted land), whereas primary forest, pasture, and other mixed land covers would come as secondary sources. Because of the carbon contained in the biomass and soil, this expansion leads to a large amount of carbon emissions. In addition, expansion of palm oil plantation in South East Asia is also particularly significant in the case of scenarios with biodiesel, which releases additional quantities of carbon from peatlands. In total, the “NAP” scenario is found to have emittedaround 491 Mt CO2 in the atmosphere by 2020; biodiesel contributes significantly to this number. Indeed, the “BIOD” scenario is associated with 639 Mt CO2, whereas the “ETHA” scenario is two times more sober, with 316 Mt CO2.

[Insert Table 5]

These levels of emissions can be compared with the quantity of energy produced with the biofuel feedstocks. A good way to conduct the comparison is to decompose the overall ILUC effect, expressed as gCO2 / MJ of biofuel (also known as ILUC factor) in several intermediate factors, as proposed in Plevin et al. (2010). These authors introduce the notion of net displacement factor (NDF), defined as the quantity of cropland expansion divided by the area of grown feedstocks used to produce the fuel. The relation behind the decomposition follows:

$$\begin{aligned}\textit{ILUC factor (gCO2 / MJ)} &= \textit{NDF (ha / ha)} * \textit{EF (tCO2 / ha)} \\ &\quad / \, [\, \textit{Crop yield (GJ / ha / yr)} * \textit{Project period (years)} \,] * 1000 \textit{ (gCO2 / MJ per tCO2 / GJ)}\end{aligned}$$

We use a project period of 20 years, as suggested in preparatory works by the European Commission of calculation of ILUC. The ILUC factor and its decomposition are detailed in Table 6. The “NAP” scenario leads to an average emission of 39 gCO2/MJ, which represents around 40 percent of the fossil fuel emissions (value). The role of biodiesel is illustrated by the results of the decomposition in the two scenarios. Using only biodiesel would raise the coefficient to 51 g CO2/MJ, whereas the ethanol scenario is closer to 25 gCO2/MJ.

Interestingly enough, it appears that the difference of results between ethanol and biodiesel is not significantly driven by the NDF, which is in fact of similar magnitude for the three cases (0.19 for ethanol, 0.20 for “NAP,” and 0.22 for biodiesel). The average value of emission factors (EF) is not more explicative, as these factors do not appear to diverge by more than a few percent. The real meaningful value is indeed the average energy yield of crops used in each of the scenarios. In the case of the ethanol scenario, the use of high yielded crops like sugar cane significantly pushes up the total yield of 80 GJ per ha. In comparison, the “BIOD” scenario cannot produce more than 38 GJ / ha with its mix of rapeseed, soybean, and palm oils.

[Insert Table 6]

The value of NDF can appear counter-intuitively low. However, as explained by Plevin et al. (2010), this indicator mixes several effects: intensification response, co-products effect, change in demand, and declining marginal production yield; the first three clearly mitigate land use expansion. A fifth factor could be added with the geographical and cross sectoral composition effect on yield due to reallocation of production in different regions of the world. Lastly, demand displacement, allowed by elastic demand (final and intermediate), help to supply the biofuels sectors without additional production. Indeed, demand for biofuels puts pressure on the markets, raises prices, and diverts some products usually used as food, feed, or processed products by various industries. Table 7 displays the distribution of the change on each market between supply and demand and illustrates how some diversion helps to limit the extra production required. For example, the increase in sugar price following the demand for ethanol processing leads to a decrease in refined sugar use and frees one-third of the total sugar supply for biofuel production. In addition, this table strongly illustrates the significant cross-sectoral effect of co-products. Production of cereals finally diminish in the "NAP" scenario because they are replaced by rape meals, and more indirectly by soy meals, which frees some land to grow other crops in the EU and in America. This contribution of co-products will be more precisely investigated in the next section.

[Insert Table 7]

4.3. Sensitivity Analysis

The previous section clearly illustrated the variability between results associated to different shocks through deterministic scenarios. However, this 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 factors. This was already emphasized in Hertel et al. (2010) and very clearly illustrated by the paper on uncertainty from Plevin et al. (2010). In this section, we therefore investigate intervals of confidence around our initial estimates by running many alternative runs, combining in a systematic approach all possible bounds for our parameters.

However, we will especially focus on the uncertainty on the Net Displacement Factor (NDF) because while the other sources identified in Plevin et al. (2010) have been extensively discussed there, the NDF remains a shadowy area determined by the agro-economic models.

We identified six biophysical and behavioral parameters that are generally considered important for the determination of this NDF variance. They directly affect the source of supply of crops and biofuels. Of course, demand parameters also play a critical role in how the additional demand of crops for biofuels is split between demand displacement and increased supply. The parameters considered for the sensitivity analysis are:

1) Elasticity of endogenous yield response
2) Elasticity of land substitution between highly substitutable crops
3) Elasticity of land substitution between other crops
4) Elasticity of land expansion into other land covers
5) Elasticity of Armington (between domestic production and imports and between imports)
6) Marginal yield return on cultivated land

The elasticities chosen for this systematic sensitivity analysis are considered to be correlated across regions and sectors. They therefore correspond to an overall measurement uncertainty rather than to variability between regions or sectors. For most parameters, we change its value from 50 percent to 200 percent from its initial magnitude. Trying to derive a corridor of boundary values, we only looked at combination of value bounds, which represented $2^6 = 64$ simulations to test. The different parameters that we tested, as well as the range of values used, are summarized in Table 8.

[Insert Table 8]

The results on the sensitivity analysis clearly illustrate the large interval of uncertainty concerning estimates of ILUC factors (Figure 8). Values range from 10 gCO2/MJ up to 116 gCO2/MJ for the central scenario, with a median at 37.7 gCO2/MJ and a higher mean at 46.8 gCO2/MJ. Interestingly enough, NDF ranges are wide from 0.06 to 0.46 but are quite homogenous across the three scenarios. The difference is driven on the one side by the crop energy yields, where ethanol shows great performance with a mix containing a share of high yield sugar beet ethanol production and sugar cane ethanol imports. On the other side, the emission factor associated to land use change is slightly higher on average in the case of ethanol policy because of the stimulation of Brazil land use change for sugar cane and possible repercussions in terms of deforestation. However, it is biodiesel policies that show the most extreme values for emissions. This corresponds to cases where imports of biodiesel or vegetable oil from Malaysia and Indonesia lead to conversion of peatlands that represent very dense carbon stocks.

[Insert Figure 8]

This test of parameter ranges clearly illustrates the potentially high effects of land use change emissions related to biofuel policies on the one side and the imprecision of measurements for such an effect. In fact, this type of analysis allows for testing uncertainty depending on parameter values only. Another source of uncertainty comes from the specifications of our model that we are now going to examine to illustrate the role of different market drivers affecting land use change.

5. Fuel vs Feed vs Food: Domino effects on the Demand side

Indirect land use change is based on the idea that displaced production should be grown elsewhere. This could at first approach gives the intuition that the Net Displacement Factor relative to this production should be close to 1, and even greater if marginal lands are less productive.

However, as Plevin et al. (2010) clearly emphasize, three other factors in addition to the marginal yield come into play to limit this displacement: change in demand, co-products, and intensification. The authors therefore assume that a plausible range for NDF would be between 0.25 and 0.85, on the basis of the few studies they reviewed. Our own range of NDF values pushes for a range merely around their lower bound, and possibly even lower. Indeed, price increases provide significant incentives on the production and also on the demand side. In this section, we focus on the latter by looking at how displacement of the demand for land directly (pasture) or indirectly (crops) is affected by the response of final consumers and intermediate sectors, particularly the livestock industry, to the price changes. We discuss the role of food disappearance and the substitution pattern in the feed, looking at both the issue of co-products and the intensification consequences of the demand for pasture land.

5.1. Disappearing food?

As illustrated in Table 9, a significant portion of food is diverted following food price increases in order to replace a portion of the production allocated to biofuels. Although the competition for land leads to an overall decrease in wheat production, prices for cereals increase in our central “NAP” scenario; this has some impact in some parts of the world. In total, 917,000 tons of wheat and 934,000 tons of corn are diverted from the food market in our scenario. Most of this is provided from three regions: Asia (565,000 tons), Middle-East and North Africa (464,000 tons), and Sub-Saharan Africa (309,000 tons) because these regions are the most dependent on imports from world markets, and from the EU exports in particular, and their demand is more sensitive to a change in price.[8] Despite the fall in demand, we still have significant increases in the prices on oilseeds (except for soybeans) and vegetal oils (above 30 percent), meaning that consumers (households and firms) will be at the same time deprived of a part of their normal consumption and will have to redirect a part of their expenditures from other goods to these.

[Insert Table 9]

This effect occurs in the cereals market but is also visible in the meat market, which is influenced by the change in the price of feed. As a consequence of increases in the price of cereal feed and decreases in income due to oil price contraction, demand for cattle meat decreased by 0.7 percent in Middle-East and North-Africa and by the same amount for pig and chicken meat. In Sub-Saharan Africa, the demand for pigs and poultry decreased by 1.4 percent. Indeed, the share of cereals is low in the feed ratio of cattle bred in these regions, and the excess of soybean meals is even lower than production costs.

The contribution of food effects on the carbon balance is illustrated in Table 9. Overall, the effects of maintaining the consumption of food constant increase the effects by 58 percent (scenario “CST

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[8] In MIRAGE, price and income elasticities for household demands are calibrated from USDA dataset. As a matter of fact, price elasticity for wheat in Sub Saharan Africa, MENA and Asia are three to ten times higher than those of developed countries.

FOOD").[9] The lack of new supply from demand change indeed requires an expansion of land use, although some more intensification allows to partly compensate for the extra pressure. The food demand effects can be decomposed into two components: assuming that crop consumption for food is not affected ("CST CROP") or assuming that meat consumption for food is constant ("CST MEAT"). It appears that although meat production consumes a significant portion of crop production, the first scenario changes the results much more than the second (+18.8 gCO2/MJ in for crops, versus +0.6 gCO2/MJ for meat). This mainly comes from the fact that the price of meat is much less affected by the price increases in crops and, therefore, the quantity of change in demand to compensate remains low. Secondly, significant crops substitution can occur to more efficiently distribute crops within feed and allows for compensation for the additional pressure on feed input.

5.2. Role of co-products (disappearing feed)

Co-products have also been shown to be a significant source of attenuation of effects (Searchinger et al., 2008). Some papers have used applied models to test how supplying additional dried distillers' grains with solubles (DDGS) could save some land by substituting other type of feed, such as oilseed meals made from low yield soybean (Taheripour et al., 2010; Hertel et al., 2010). However, the case of corn grain is easier to apprehend, as grain distiller side products have a low price and are by-products in the pure sense: the demand for DDGS can hardly drive new transformation of corn.

The case of biodiesel co-products is significantly different and of significant importance for the consideration of the biofuel policy in the EU. Oilseeds are crushed to produce vegetable oil and protein meals, and the latter usually have more commercial value. Therefore, accounting for meals as by-products is not appropriate, as meals could be produced even without the extra demand for vegetable oil transformed into biodiesel.

In our model, the modelling of these aspects is reproduced by an explicit representation of the co-products, which are produced in fixed proportions in volume, with flexible prices summing to the crushing production price. The market for the product and its co-product are therefore simulateneously

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[9] This is implemented in the model through a state subsidy that compensates for the price change for final consumers and also for food industries relying structurally on food intermediates (Sugar, MeatDairy and OthFood sectors). Substitution of vegetable oil by consumers and industries remains however unconstrained.

balanced, and the model determines endogenously if the demand for the product or its coproduct drives an extra demand for new production. Co-products are inserted in the feed composition by substituting with other protein meals, and they substitute on a protein content ratio, as prices have been equalized per quantity of protein content in the data. The protein feed group is then considered as a substitute for other feed.

In order to test the role of co-products in our model, we ran alternative scenarios where we removed the effect of biofuel co-products as a substitute in feed.[10] We consider a scenario where grains are transformed into ethanol without producing DDGS ("NO DDGS"), another where oilseed crushing leads to sales of vegetable oil only ("NO MEAL"), and a last one where both joint productions are removed ("NO CPT"). The results are displayed in Table 9.

We find that co-products have significant effects on the displacement of land. When compared with our central "NAP" scenario, removing oil cakes increases the NDF by 16.6 percent, while removing DDGS increases it by 11.1 percent. This larger contribution of oil cakes is partly due to the significantly higher share of biodiesel co-products used in our scenario. The combined effect of removing all co-products increases the NDF by 25.6 percent, which means that according to our calculation, the savings resulting from co-products for the central EU scenario would be around 20.4 percent. These results are close to the estimate of Taheripour et al. (2010), who found a decrease of 21.2 percent of cropland expansion due to by-product incorporation in their model when modelling the impact of US and EU biofuel mandates.

5.3. Role of Pasture land

In all the previous simulations, we have been considering that cropland expansion could be done with some constraints, but independently from evolution of other land use activities. However, if some grassland is available for expansion in regions such as Sub-Saharan Africa or Latin America (Bouwman et al. 2005), cropland expansion in some regions could compete with livestock production

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[10] This was achieved technically by diverting the meals and DDGS output from livestock to the manufacturing sector, where it was substitutable with ordinary other processed input. Therefore, the price dynamics on ethanol and vegetable oil remains a joint-production one.

and forestry output if the land resources are scarce. We therefore distinguish between two different approaches to pasture and forested activities representation:

a) "Free Intensified pasture and forest": This has been the assumption used so far. Cropland can expand into other land types following historic observations an,d if necessary, intensification is assumed to follow the previous trends to free the available land required for this new cropland.

b) "Competing pasture and forest": In this design, pasture and forest land are considered as direct factors necessary for livestock and wood production. Therefore, increasing production puts a higher pressure on available land and can compete with cropland expansion. Projections on land used for cropland expansion can consequently depart from preceding observations, either because pasture and forest land would be less accessible if the demand for their products increased, because of either increasing meat or wood prices, or because a decrease in the associated demand would free more land from pasture and managed forests.

In this latter design, substitution between cropland, pasture, and managed forests is implemented using nested low elasticity CETs and calibrated to obtain the same value of elasticity of cropland expansion at the base year.

The results of switching from assumption "Intensification" to "Competition" can be seen in Table 9 with the "NAP" and "CTL FRS COMP" scenarios, respectively. As cropland expansion is calibrated on similar elasticities, results differ little, with the new competition introducing a slight increase in NDF (+7 percent); however, one can note the increase in the average land emission factor that denotes a shift in the place of expansion of cropland in most regions.

The way closure affects cropland expansion is interestingly illustrated by the situation in Brazil (Figure 7). When pressure from pasture is introduced, regions that are characterized by higher use of pasture for cattle (AEZ5 and AEZ6, corresponding respectively to Brazil Cerrado Central and Central-West zone and the Amazon Basin area) undergo a reduced expansion with comparison with historical observation, since cropland will expand into pasture.

[Insert Figure 7]

5.4. Testing the possibility of higher NDF: a worst case scenario

In all the variation of modeling specifications that we tested, we obtained Net Displacement Factor reaching a maximum of 0.3. We have, however, previously illustrated in section 4.3 how different parameters could lead to much higher coefficients. Theoretically, a NDF could be as high as 1 or even higher if marginal yields are low, corresponding to a situation where one hectare of new energy crops would require one additional hectare of cropland. In order to provide a counterfactual to our previous scenarios, where co-products, demand diversion, and yield response play a significant role, we run an addition set of specifications where we disable most of these sources of market supply through diversion and substitutions. In this additional scenario, we combine the removal of co-product from scenario “NO CPT” with the fixation of food consumption from scenario “CST FOOD.” We additionally neutralize the endogenous yield effect and prevent all forms of substitution within feed in livestock.

The cumulated effects of these restrictions significantly boost the results obtained so far and illustrate the significant contribution of all these aspects, as suggested by Plevin et al. (2010). Indeed, the results of this scenario “HIGH NDF,” presented in Table 9, are three times higher than the previous ones. Interestingly enough, the crop energy yield have increased by 31 percent at 60.9 GJ/ha, indicating a composition effect with more contribution from efficient crops, in particular sugar cane. However, the NDF is increasing drastically up to 0.83, which leads to an ILUC factor of 116 gCO2/MJ. This value corresponds to a situation where indirect land use emissions would be greater than emission from use of usual fossil fuel in road transportations over a 20-year period.

6. Conclusion

This paper aims to describe the different channels driving land use changes in a global multi-sectoral CGE and to provide an illustration of land use change driven by EU biofuel policies, in particular the implementation of current National Renewable Energy Action Plans. The model presented, MIRAGE-BioF, benefits from specific development on the data side, as well as on the modelling side, that makes it particularly suitable to study such policies. Applied to the assessment of the EU biofuel policy, if current targets are followed, we confirm that emissions driven by land use changes would most likely be significant (38 gCO2 for our median case) and require some attention. Indeed, through direct and indirect effects on the commodity markets, the increased demand for energy crops in the EU will lead to land use changes all over the world: considering the present restriction on pasture conversion and the already large use of set-aside land for bioenergy crops, we find that future needs would make most of the global cropland expansion take place outside of Europe, in Latin America, Eastern Europe and Russia, and Sub-Saharan Africa.

The EU policy differs significantly from other biofuel mandates around the world due to the diversity of feedstocks involved and the large share —78 percent—of biodiesel. It affects both the cereals and the vegetable oil markets, linking the EU biofuel demand to potentially high carbon stock regions (e.g. peatlands in South-East Asia). By looking at alternative composition mixes for the future EU biofuels consumption (current targets, only biodiesel, only ethanol), we confirm previous results (Al Riffai et al. 2010; Britz and Hertel 2010) that ethanol and biodiesel demands have quite different effects, biodiesel releasing twice as much CO2 due to land use changes as ethanol.

However, significant uncertainty exists for measuring such effects, driven by behavioural parameters, confidence intervals, and some modelling specifications. Parameter values and modelling assumptions affect the distribution of effects between, on the supply side land, allocation decisions for crops, marginal yields, and intensification or expansion possibilities and, on the demand side, the final consumption and the inputs demand of downstream sectors, in particular the feed and land demand of the livestock sectors. Performing sensitivity analysis on these key parameters, we show that the emissions can vary from 10 to more than 115 gCO2/MJ and that additional land requirements would represent 1 to possibly more than 12 ha per TJ with a median value of 3.4 ha per TJ. If this degree of uncertainty does not invalidate the approach, it calls for flexible and well-designed mechanisms on the policy side to address the issue, as well as further future research efforts, in particular reinvestment in econometric estimation.

Overall, our results display low bounds estimates of possible effects of biofuel policies, although the ILUC factors are sufficiently high to seriously question the sustainability of current policy orientations. These low values in comparison with some other evaluations (Searchinger et al. 2008; Plevin et al. 2010) may come partly from lower default coefficients on carbon stock, whose uncertainty has not been explored here (Plevin et al. (2010) show that we could have used average emission factors at least twice as high). Another, much more structure-related reason is the low value of net displacement factor, resulting notably in a decrease in demand accompanying food price increases. As various crops used for biofuels have surged to historic heights several times in recent years, a limited land use change effect could imply a dangerous trade-off with food security in the short run, as long as yield response is not yet effective. Considered from this perspective, it is not assured that assumption of low indirect land use change emissions would guarantee satisfying policy implications.

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Table 1: 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

Table 2: 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

Table 3: Production, consumption and trade of biofuels in different regions (Mtoe)

	Production				Consumption				Net trade			
	2008	2020			2008	2020			2008	2020		
	REF	NAP	BIOD	ETHA	REF	NAP	BIOD	ETHA	REF	NAP	BIOD	ETHA
Biodiesel												
Argentina	0.2	1.8	2.1	0.8	0.1	0.1	0.1	0.1	0.1	1.7	2.0	0.7
Brazil	0.3	1.5	1.1	2.5	0.3	1.5	1.1	2.5	0.0	0.0	0.0	0.0
EU27	7.1	16.2	20.5	7.5	8.7	19.6	25.1	8.6	-1.6	-3.4	-4.6	-1.2
IndoMalay	0.3	4.8	5.6	3.5	0.2	3.1	3.1	3.0	0.1	1.7	2.5	0.4
USA	1.7	0.8	0.7	1.2	0.3	0.8	0.6	1.2	1.4	0.0	0.0	0.0
RoWorld	0.1	0.4	0.3	0.5	0.1	0.4	0.3	0.5	0.0	0.0	0.0	0.0
World	**9.6**	**25.5**	**30.3**	**16.0**	**9.6**	**25.5**	**30.3**	**16.0**	**0.0**	**0.0**	**0.0**	**0.0**
Ethanol												
Brazil	12.1	29.1	28.5	30.3	10.9	20.0	20.7	18.7	1.2	9.2	7.9	11.6
China	1.8	13.8	13.8	13.8	1.8	13.8	13.8	13.8	0.0	0.0	0.0	0.0
EU27	1.2	5.5	1.3	13.5	1.8	7.4	1.7	18.4	-0.6	-1.9	-0.4	-5.0
JPNKOR	0.0	0.0	0.0	0.0	0.0	6.7	6.7	6.7	0.0	-6.7	-6.7	-6.7
USA	14.1	33.3	33.3	33.2	14.6	34.0	34.2	33.6	-0.5	-0.8	-0.9	-0.4
RoWorld	1.3	4.2	4.2	4.3	1.4	4.0	4.1	3.9	0.0	0.2	0.1	0.4
World	**30.4**	**85.9**	**81.2**	**95.1**	**30.4**	**85.9**	**81.2**	**95.1**	**0.0**	**0.0**	**0.0**	**0.0**

Source: MIRAGE-BioF Simulations

Note: Changes between 2008 REF and scenarios in 2020 incorporate elements of the dynamic baseline. For instance the large growth in production of Ethanol at the world level is related to growing production and demand in non EU regions during the baseline.

Table 4: Production, biofuel use and EU trade of different feedstocks (1000 MT)

	EU27 production				Use for biofuel				Net trade			
	2020	Delta 2020			2020	Delta 2020			2020	Delta 2020		
	REF	NAP	BIOD	ETHA	REF	NAP	BIOD	ETHA	REF	NAP	BIOD	ETHA
Wheat	150345	-519	-1206	1021	2023	6506	-290	21602	6633	-2176	2791	-12816
Maize	72103	-171	-444	543	1994	6261	-366	22959	-12284	-4146	2589	-20265
Sugar beet	157013	2818	87	4598	14005	23365	-1205	45959	-344	-601	77	-1507
OilPalm	25	15	26	0	633	2191	3711	-111	-2998	-2485	-4053	107
OilRape	7270	1711	2470	-330	6062	2336	3279	-419	-52	-278	-380	33
OilSoyb	3050	1191	2114	-333	2155	3407	5532	-491	-543	-2086	-3267	203
OilSunf	3072	783	1207	-115	670	1427	2246	-132	-843	-628	-977	57

Source: MIRAGE-BioF Simulations

Table 5: Area expansion under the scenarios and associated emissions

	2008	2020			2020		
	Initial area	Area increase (1000 ha)			Carbon emissions		
	(1,000,000 ha)	NAP	BIOD	ETHA	(MtCO2)		
EU27							
Cropland	*93*	72	80	67			
Pasture	*68*	-35	-39	-33	6.3	7.1	5.8
SavnGrasslnd	*20*	-30	-33	-28			
Other	*50*	1	0	1			
Forest_managed	*151*	-8	-9	-8	1.9	2.1	1.8
Forest_primary	*7*	0	0	0	0.0	0.0	0.0
World							
Cropland	*1,239*	2708	3694	1547			
Pasture	*990*	-357	-490	-199	240.4	330.9	130.9
SavnGrasslnd	*3,364*	-1278	-1763	-696			
Other	*3,111*	-569	-806	-279			
Forest_managed	*1,150*	-127	-187	-45	34.3	51.1	11.2
Forest_primary	*2,772*	-378	-448	-329	178.5	198.9	176.0
Peatlands		(-33	-51	2)	37.4	58.5	-2.2
TOTAL					**490.6**	**639.4**	**315.9**

Source: MIRAGE-BioF Simulations

Table 6: Decomposition of ILUC effect for the three main scenarios

	NAP	BIOD	ETHA
Crop energy yield (GJ/ha)	47	38	80
NDF	0.20	0.22	0.19
ILUC yield (ha/TJ)	4.3	5.9	2.4
Average emission factor (tCO2/ha)	181.2	173.1	204.2
ILUC emissions 20 years (gCO2/MJ)	**38.6**	**51.0**	**24.8**

Source: MIRAGE-BioF Simulations

Table 7: Market balance in the "NAP" scenario for most agricultural goods (1000 MT) and price changes

	Biofuel shock demand	**Extra supply**	**Final demand diversion**	**Livestock demand diversion**	**Other demand diversion**	***World prices (producer) changes***
Wheat	6842	-2490	917	8086	328	*2.2%*
Maize	9722	-2368	934	10734	423	*2.0%*
Sugar_cb	54668	28902	428	29	25308	*10.3%*
Rice	-	-553	86	185	282	*0.1%*
OthCrop	-	-218	178	33	6	*-0.1%*
VegFruits	-	-1424	854	266	304	*0.0%*
Soybeans	-	7392	53	1430	-8875	*14.9%*
Sunflower	-	1652	6	1051	-2710	*32.3%*
Rapeseed	-	2572	16	884	-3473	*34.8%*
PalmFruit	-	3519	345	921	-4785	*37.0%*
OthOilSds	-	208	-85	-46	-76	*0.6%*
OilPalm	3586	1174	817	0	1594	*29.7%*
OilRape	2263	930	496	0	838	*36.9%*
OilSoyb	3633	1929	544	0	1160	*33.0%*
OilSunf	1377	1141	175	0	62	*32.9%*
DDGSWheat	-	2630	0	-2630	0	
DDGSMaize	-	4995	0	-4995	0	
DDGSBeet	-	1385	0	-1385	0	
MealPalm	-	13	0	-13	0	
MealRape	-	1364	0	-1364	0	
MealSoyb	-	8367	0	-8367	0	
MealSunf	-	684	0	-684	0	

Source: MIRAGE-BioF Simulations

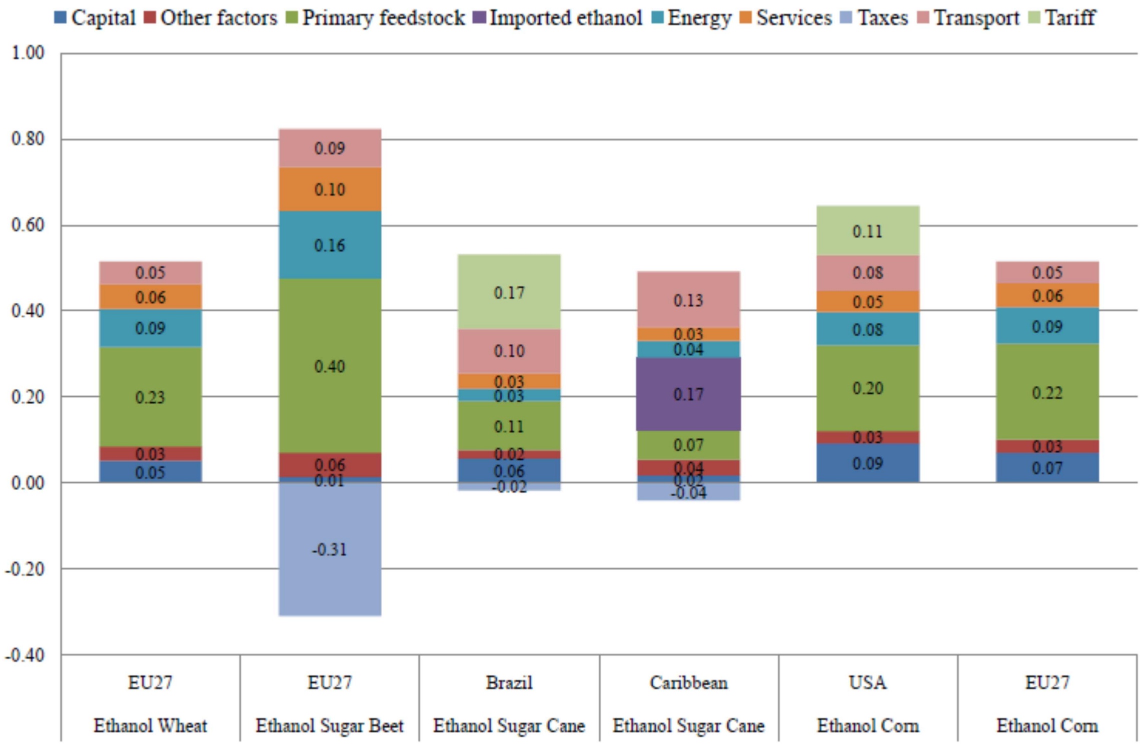
Table 8: Effect tested in the sensitivity analysis and relative parameters varied

Effect to test	Target parameter	Initial range	Source	Lower bound	Upper bound
Endogenous yield response	Elasticity of substitution between land and other inputs	Yield elasticity in the 0.1-0.3 range for most crops	CARB (2011), Huang and Khanna (2010)	/ 2	x 2
Land substitution between highly substitutable crops	Elasticity of substitution at higher level of CET nesting	Land supply elasticity in the 0.2-0.5 range for most crops	FAPRI elasticity database	/ 2	x 2
Land substitution between other crops	Elasticity of substitution at intermediate level of CET nesting	Land supply elasticity around 0.1	OECD (2001)	/ 2	x 2
Land expansion into other land covers	Elasticity of land expansion	From 0.01 to 0.05	Barr et al. (2010), Roberts and Schlenkers (2010), OECD (2001)	/ 2	x 2
Armington effect	Armington elasticity	From 0.9 to 17.4	Hertel (2007)	/ 2	x 2
Marginal yield return on new cultivatedland	Marginal yield return coefficient	0.75 for all	CARB (2011)	0.5	1

Table 9: Summary table with different alternative scenarios on mandate and on model specifications

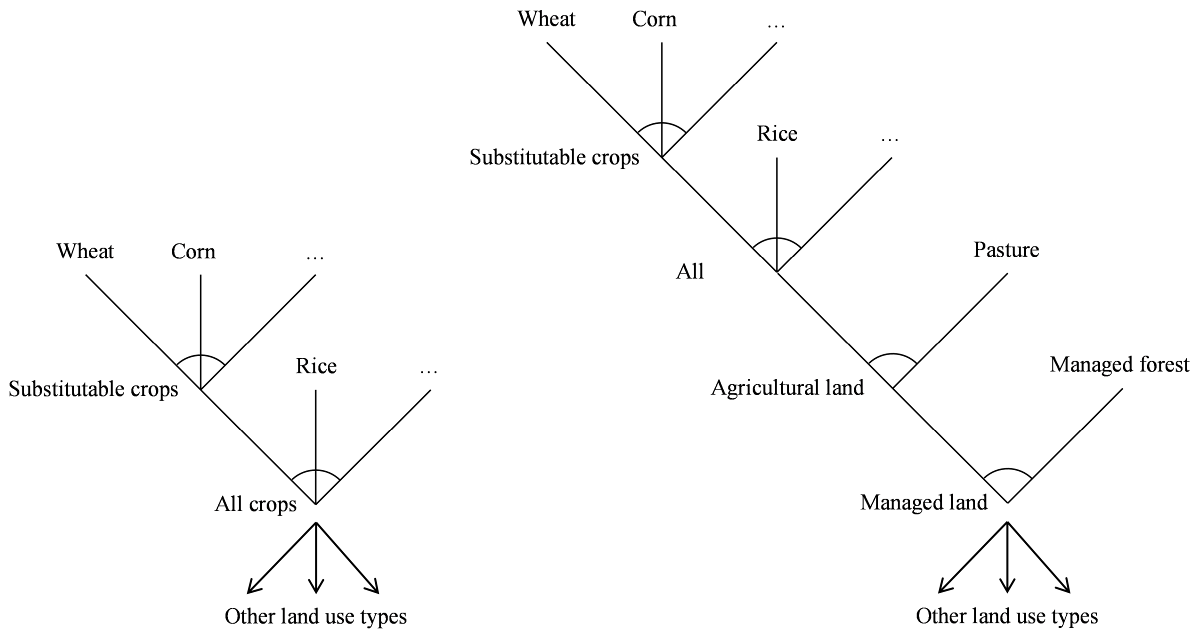
	NAP	BIOD	ETHA	NO MEAL	NO DDGS	NO CPT	CST CROP	CST MEAT	CST FOOD	CTL & FOR COMP	HIGH NDF
Crop energy yield (GJ/ha)	46.6	37.7	80.0	45.9	48.9	47.1	45.2	46.6	45.2	48.9	60.9
NDF	0.199	0.222	0.194	0.232	0.221	0.250	0.296	0.203	0.307	0.213	0.828
ILUC yield (ha/TJ)	4.3	5.9	2.4	5.0	4.5	5.3	6.5	4.4	6.8	4.4	13.6
Avg. emission factor (tCO2/ha)	181.2	173.1	204.2	178.9	183.8	180.6	181.4	180.0	179.6	192.9	170.8
ILUC factor 20 yrs (gCO2/MJ)	**38.6**	**51.0**	**24.8**	**45.2**	**41.6**	**48.0**	**59.4**	**39.2**	**61.0**	**42.0**	**116.1**

Source: MIRAGE-BioF Simulations



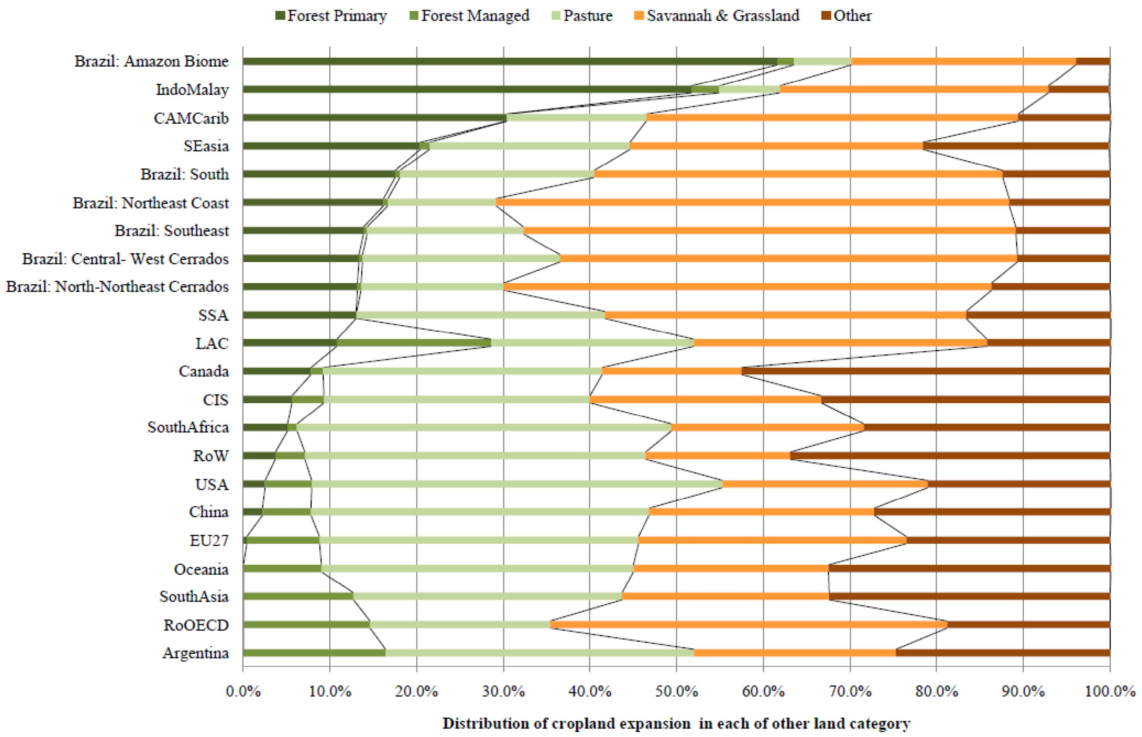
Source: MIRAGE-BioF Database

Figure 1. 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 price in the EU.



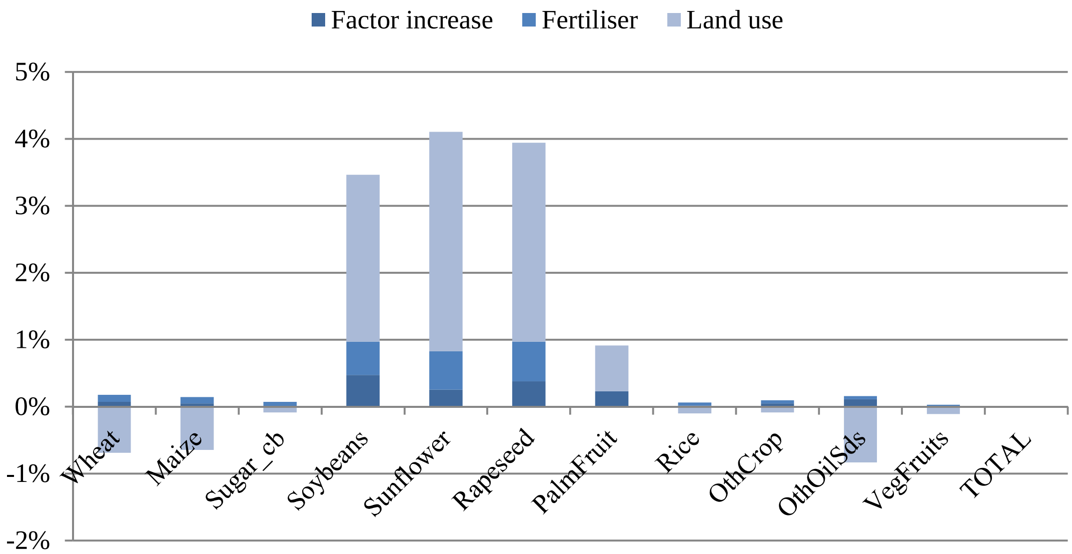
Unconstrained pasture and forestry **Constrained pasture and forestry**

Figure 2: Nesting of CET functions and expansion patterns in the two representation of land use substitution and expansion. “Unconstrained pasture and forestry”, composed of two nested CET functions, is the default representation and assumes fixed share of expansion into pasture, managed forest and other land use types. “Constrained pasture and forestry” is composed of four nested CET and expansion into pasture and managed forest is endogenously determined depending on demand for cattle and wood.



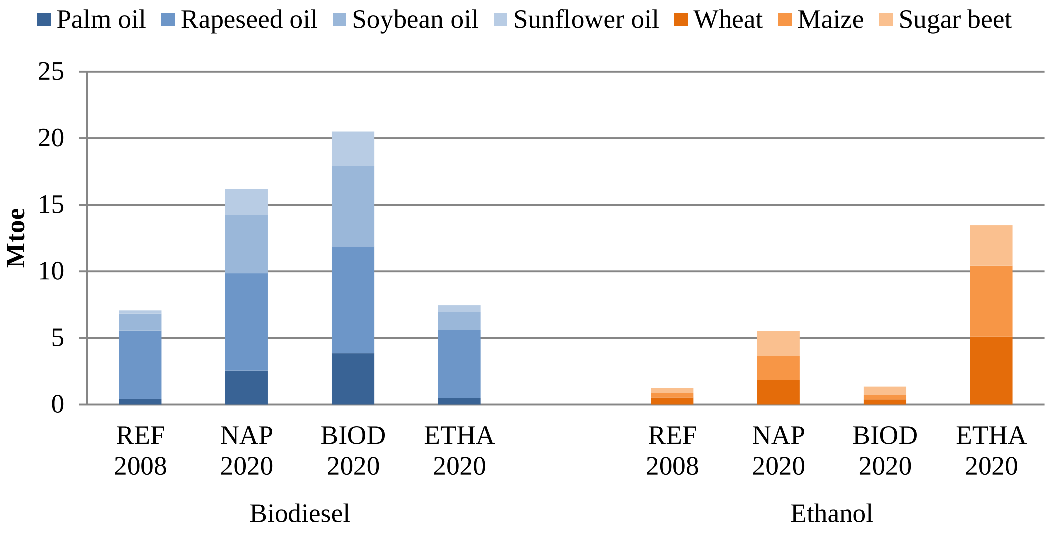
Source: EPA for raw data.

Figure 3. Distribution of cropland expansion across land use type categories for regions in the model. Brazil has been decomposed among six regions corresponding to different AEZ zones explicitly represented in the model in order to better track expansion effect of sugar cane. To map land use categories, some change to raw Winrock data are made: forest category is split within primary and managed forest, grassland category is split between pasture and natural grassland, wetland and barren are merged with others, and mixed are distributed between all land use categories. Note that when cropland substitution is measured endogenously with forest managed and pasture, expansion shares are only used in the model for primary forests, savannah and grassland and other, after a rescaling to 100%.



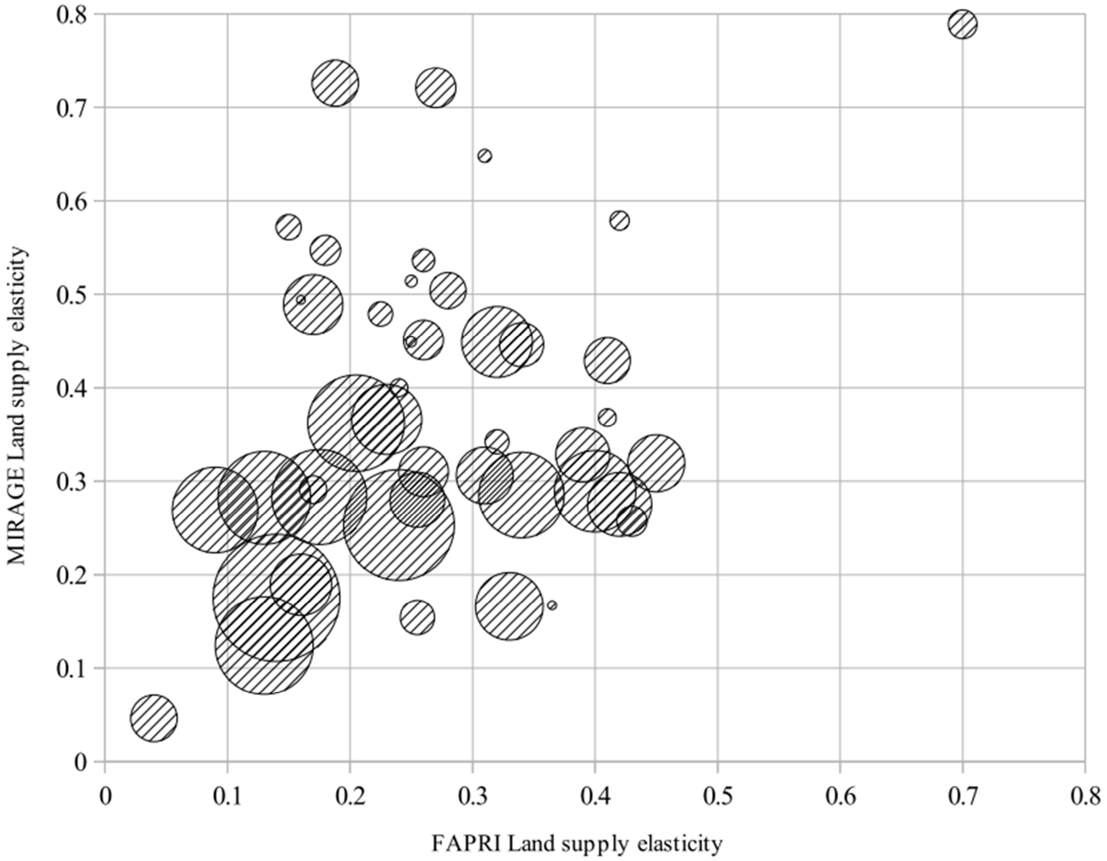
Source: MIRAGE-BioF Simulations

Figure 4. Increase in production at the world level in the “NAP” scenario, decomposed by source of growth: land expansion, fertilizers increaser and other factor increase.



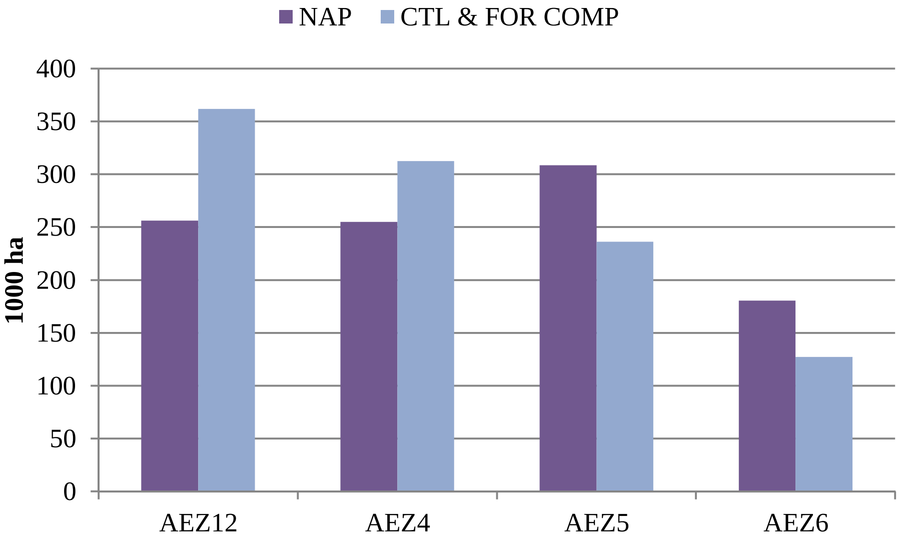
Source: MIRAGE-BioF Simulations

Figure 5. Composition of European Union biofuel production according to the different feedstock for each scenario of the mandate.



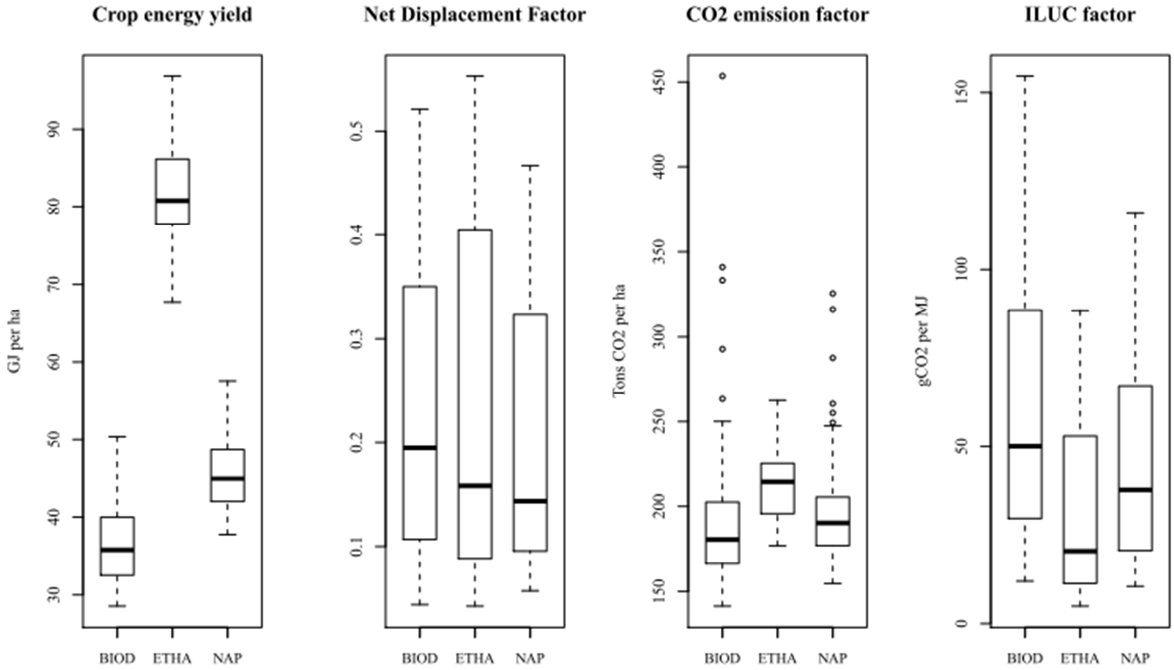
Source: MIRAGE-BioF Model, FAPRI elasticity database

Figure 6. Calibrated land supply elasticities for crops and regions in the model compared with FAPRI elasticities. Crops represented are wheat, maize, soybeans, rapeseed, sunflower, other oilseeds for regions where FAPRI elasticities wer available. Circle areas are proportional to the harvested area for the corresponding crop x region couple.



Source: MIRAGE-BioF Simulations

Figure 7. Cropland expansion in Brazil in different agroecological zones, according to two land use closure. The two closures tested are “Intensified pasture and forests” (default assumption in all scenarios, included the central scenario “NAP”) and “Competing pasture and forests” (“CTL & FOR COMP” scenario based on NAP other assumptions).



Source: MIRAGE-BioF Simulations

Figure 8. Decomposition of the different components of ILUC factor effect in our sensitivity analysis. ILUC factor can be computed in function of the three other parameters according to the formula from section 4.2.

APPENDIX 1: List of sectors and regions in the model

Table A 1. List of the 43 sectors in the model

#	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 coproducts.
Source: MIRAGE-BioF Nomenclature

Table A 2. List of the 11 regions represented in the model.

#	Region	Description	#	Region	Description
1	**Argentina**	**Argentina**	**8**	**EU27**	**European Union (27 members)**
2	**Asia**	Rest of South and South-East Asia	**9**	**IndoMalay**	**Indonesia and Malaysia**
3	**Brazil**	**Brazil**	10	JPNKOR	Japan and Republic of Korea
4	**CAMCarib**	**Central America and Caribbean**	11	LAC	Other Latin America countries
5	Canada	Canada	12	Oceania	Australia, New-Zealand and Pacific Islands
6	China	China	**13**	**SSA**	**Sub Saharan Africa**
7	**CISRoEur**	**CIS countries and Rest of Europe**	**14**	**USA**	**United States of America**

Note: Regions in bold are regions whose representation is of particular importance for representation of the impact of EU biofuel policies.
Source: MIRAGE-BioF Nomenclature

APPENDIX 2: Construction of the MIRAGE-BioF database from GTAP7 and FAOSTAT

The MIRAGE-BioF model required for a more precise study of agricultural and energy dynamics the development of a new database, based on the GTAP data but overcoming some of its main limitations to address the topic.

The GTAP datasets combine domestic input-output matrices, which provide details on the intersectoral linkages within each region, and international datasets on macroeconomic aggregates, bilateral trade, protection and energy. We started from the latest available database, GTAP 7, which describes global economic activity for the 2004 reference year in an aggregation of 113 regions and 57 sectors (Narayanan and Walmsley, 2008).

However, after some first tests, we found that an approach based on pure splitting in a top-down settings –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. [11] We therefore developed an original and specific procedure to generate a database that is consistent in 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.

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[11] 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.

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, the different by-products. Finally, rates of profits are computed based on the difference between production costs, subsidies and output prices.

5) For Steps 2, 3, and 4, the value of inputs is deducted from the relevant sectors (other food 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 in value often generates inconsistencies in the physical linkage that 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 this 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 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 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 are 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).

APPENDIX 3: Emission factors related to land use conversion used in our framework

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 stock in 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					