Tools and knowledge to evaluate indirect land use changes due to biomass fuel

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Abstract

The indirect land use changes (ILUC) concept refers to the displacement of crops or pastures on uncultivated land such as fallow or forest, prompted by an increase of agricultural prices due to an extension of biofuels production. Their effect on the organic carbon storage was ignored in the ecological assessment of biofuels before the articles of Searchinger et al. (2008) and Fargione et al. (2008) throw light on their potential extent. According to Searchinger et al., an increased production of ethanol in the United States should trigger massive land conversions domestically as well as in their main agricultural trading partners (Brazil, China, India), occurring a carbon debt – defined as the time necessary to reduce greenhouse gases emissions compared to fossil fuels - of 167 years in the worst scenario. This result has been highly criticised, mainly because of its pessimistic assumptions (no reaction of agricultural yields to price, land use changes scenarios based on historic data that are not realistic in projection…). Some methodological limitations have also been exhibited, and have highlighted the need to conduct further works so as to better understand the economic and agronomic reaction to a growing biofuels production. To do so, we present in this article the main numerical tools able to confirm or infirm the diagnosis of Searchinger et al. and Fargione et al.. Their results are generally more moderate, but they still find a significant contribution of ILUC to anthropogenic greenhouse gases emissions. Owing to this potential environmental impact, we analyse the methodological approaches to include ILUC effect into life cycle analysis, which provide a comprehensive environmental assessment of biofuels. According to the outcome of some of these analyses, the impact of ILUC is very variable and could have, in some cases, a decisive influence. Political decision-makers must therefore design regulatory measures to deal with this uncertainty. Some of them are presented in this paper.

Keywords : biofuels, indirect land use changes, life cycle analysis, land use modelling, iLUC factor.

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1. Introduction

An increased use of renewable energy sources is seen as a promising solution with a view to mitigating greenhouse gases emissions. In this prospect, policies are implemented in many countries to develop agricultural and industrial capacities for ethanol and biodiesel production. Biofuel production capacities have thus been growing rapidly since a couple of years : biodiesel production has risen sharply from 2000-07, with an average annual growth rate of over 30%, while global production of ethanol tripled from its 2000 level and reached 52 billions litres in 2007[2].

This large scale exploitation of biomass for energy has however been implemented in spite of some uncertainties on its effective environmental impact. So far, the principal uncertainty concerned the emissions of nitrous oxide (Dorin et al. (2009)), resulting from fertilizer use, but recent studies (Searchinger et al. (2008), Fargione et al. (2008)) highlighted an additional potential factor of emissions related to indirect land use changes. Considering that food demand is price inelastic, any increase in the production of biomass fuel will generate a rise of crop prices and create an incentive to extend cultivated areas. From there, the indirect land use changes concept refers to the displacement of crops (dedicated to food or not) or pastures on uncultivated land, such as fallow or forest, resulting from the use of feedstock for biofuels production, and generating emissions of organic carbon stored in the vegetation and the soils.

Life cycle analyses (LCA), which provide a comprehensive ecological assessment of biofuels, are generally made inside the system boundaries, focusing on the environmentally relevant physical flows of the production process. Since ILUC emissions occur outside the system boundaries via price effects, most of LCA don't include them and are therefore biased. The question is to know whether this bias is negligible or not. This issue is particularly intricate from a political point of view because two pitfalls must be avoided: either promoting a dead-end or slowing down the development of a cleaner energy. So as to throw light on the political decisions, this article aims at reviewing certainties and uncertainties about ILUC issue.

To do this, we will first give an overview of the articles of Searchinger et al. (2008) and Fargione et al. (2008) that have launched the controversy on ILUC. Their results indicate that land use effects could considerable change the environmental assessment of biofuels, but, owing to some methodological limitations, this first diagnosis has to be refined by further analyses. Our second part reviews the main numerical tools to conduct such analyses and details their findings. These results are generally more moderate than those of Searchinger et al., but they confirm that ILUC may have a significant impact

[2] Source : OECD – Biofuel an economic assessment.

on the environmental assessment of biofuels. Methodological approaches to include this impact into the LCA synthetic format are discussed in part III. As we will explain it, this impact has a potential decisive influence on the biofuels ecological footprint. As mentioned in the previous paragraph, this raises an important political problem, which incites our political decision-makers to design regulatory measures taking into account uncertainties about the mitigation potential of biofuels. Our last part gives some insights on the political options to deal with this issue.

2. To what extent does ILUC contribute to GHG emissions?

2.1. A First diagnosis: the articles from Searchinger and Fargione

This article has been among the first to raise the question of indirect land use change due to an increased production of biofuel. It introduces the concept of indirect land use changes by stating that a growing demand for biofuel can be met either by ploughing up "directly forest or grassland, which releases to the atmosphere much of the carbon previously stored in plants and soils through decomposition or fire", or diverting "existing crops or croplands into biofuels, which causes similar emissions indirectly". Prices set up the transmission channel: as land rarefaction induces higher crop prices[3], farmers tend to replace forest and grassland by feed or food.

The article provides an estimation of the emissions from ILUC for an increase in US corn ethanol of 56 billion liters above a baseline scenario up to 2016. By using the agricultural worldwide model FAPRI, they calculate that this increase would divert 12,8 millions ha of US cropland, and in turn bring 10,8 millions ha of additional land into cultivation, mainly in Brazil (2,8 mha), China (2,3 mha), India (2,3 mha) and in the United States themselves (2,2 mha). The ILUC mechanism is driven by three key factors :

- The demand for food and feed is inelastic, so it remains stable despite the prices increase due to a growing demand for corn ethanol ;
- The ethanol by-product can be used as animal feed, so new crops do not have to replace all corn diverted to ethanol;
- American agricultural exports decline sharply with the extension of corn ethanol crops, and their replacement in other countries requires more land per ton of crop because of lower yields.

To estimate greenhouse emissions, the authors assumed that the share of each ecosystem (different type of forest, savannah, grassland…) converted in the 1990s is constant and that conversion emits 25% of the carbon in soils. The results are then integrated in the full lifecycle model GREET[4] in order to compare the global emissions from corn ethanol and from fossil fuel. The article examines a second scenario, more favourable in terms of land use change and emissions due to land conversion (yield increases allow to supply 20% of the replacement grain, emissions per hectare of converted land are

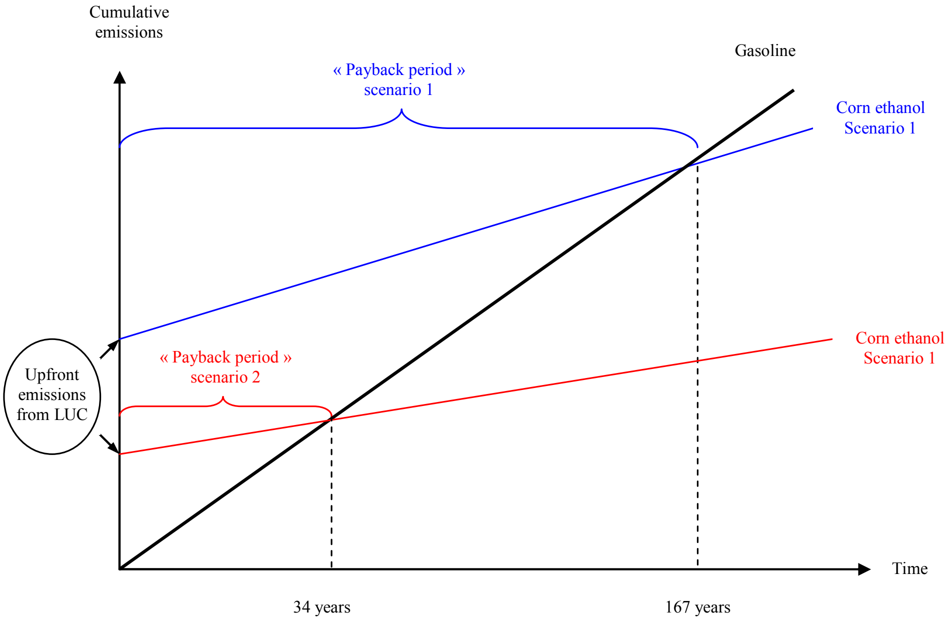
[3] The impact of biofuels on crop prices is confirmed by several studies. Baier et al. (2009) demonstrated that biofuel production generated a 14% increase of corn price and a 10% increase of soybean between 2006-2008. In comparison to other studies published on this topic, these figures constitute a low estimation of crop prices reaction to biofuel production.

[4] Greenhouse gases, Regulated Emissions, and Energy use in Transportation. This model allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle (from wells to wheel) /vehicle-cycle (through materiel recovery) basis.

only half of their initial estimate and corn ethanol reduces greenhouse gases (GHG) emissions compared with gasoline of 40% thanks to improved technology).

Fig. 1 illustrates the emissions profile of gasoline and corn ethanol in the two scenarios. The gasoline profile is characterised by regular flows of GHG emissions stemming from refining and burning of fuel, while the profile of corn ethanol is characterised by large upfront emissions caused by land use changes (through forest clearing…), followed by flows of GHG emissions lower than those from gasoline. Thus, corn ethanol progressively offsets the upfront emissions due to ILUC. The authors calculate that corn ethanol would pay back carbon emissions from land-use changes in 167 years. Surprisingly cellulosic ethanol, made from wastes that theoretically do not trigger land-use change, could exhibit a shorter but still significant pay back period of 52 years. This somewhat counter-intuitive result comes from the assumption that converting corn fields to switchgrass for ethanol would also induce soil carbon stock variations.

<u>Fig. 1</u> : emissions pathway of biofuel compared to fossil fuel

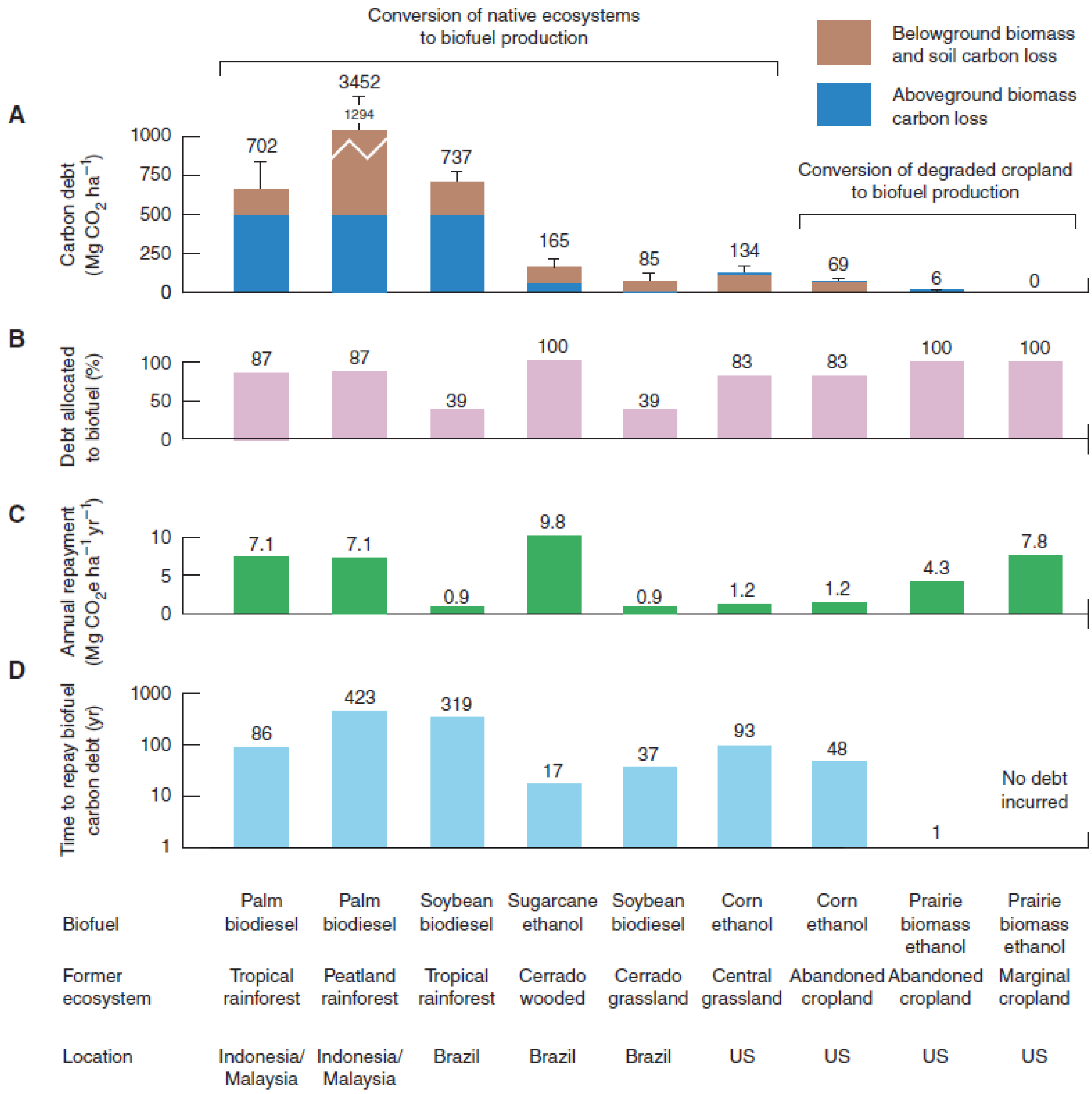


In the second scenario, the pay back period is shorter, and would last only 34 years, which means that emissions modestly increase over a 30 year period. Ethanol from Brazilian sugarcane, which has a much more favourable ecological footprint[5] than US corn ethanol, could pay back the up-front carbon emissions in 4 years if sugarcane only converts tropical grazing land. The authors conclude that "because emissions from land-use change are likely to occur indirectly, proposed environmental

[5] Based on estimated GHG reductions of 86% excluding ILUC.

criteria that focus only on direct land-use change would have little effect. […] An effective system would have to guarantee that biofuels use a feedstock, such as a waste product, or carbon-poor lands that will not trigger large emissions from land-use change".

Fig.2 : Carbon debt allocation and time to repay biofuel carbon debt for nine scenarios of biofuel production



Source : "Land clearing and Biofuel carbone debt". Fargione and al.

In counterpart to this analysis, the article from Fargione and al. calculates the biofuel carbone debt for different ecosystems in Indonesia, Malaysia, Brazil and the United-States (see fig. 2). The results reveal that land conversion due to biofuel production entails large carbon debts. The conversion of peatland or rainforest to palm biofuel generates the most important carbon debt: 423 years are needed to offset land clearing emissions. In general, the carbon debt amounts at least to 17 years for first generation biofuel. For this reason, the authors conclude that "biofuels, if produced on converted land, could, for long periods of time, be much greater net emitters of greenhouse gases than the fossil fuels that they typically displace”. On the other hand, second generation biofuels from perennials grown on degraded land or from waste biomass exhibit much better results in terms of carbon debt, and could therefore effectively help to mitigate GHG emissions.

2.2. The controversy

This first diagnosis has prompted an intense debate among the sustainable development experts community. The sharpest contestation came from Wang and Haq (2008) and from the New Fuels Alliance, a non profit-organization promoting the advantages of non-petroleum fuel production and use. Some of the main criticisms addressed to Searchinger and its co-authors are listed hereafter:

- The corn ethanol production is assumed to reach a level far above the cap established by the American in 2007 within the Energy Independence and Security Act, precisely to avoid dramatic land uses changes. Because of this unrealistic assumption, the ILUC effects could be overestimate;
- The protein content of distillers’ grains, a corn ethanol by-product, is insufficient, which tend to overestimate the displacement ratio between the two crops;
- Their prediction of future land use changes in the Brazil, China, India and the U.S. is based on historical land use changes that occurred in the 1990s. These data don’t reflect the decline of deforestation rate in Brazil and the efforts made in China to convert marginal crop land into grassland and forest, and they could therefore tend to overestimate ILUC effect;
- They don’t take into account the potential for increased efficiency in ethanol production which could result in greater emissions reductions for corn ethanol. For this reason, their assumption of a 20% reduction in GHG emissions of biofuel should be considered as a minimum ;
- Their claim that U.S. corn exports will sharply decline with a growing ethanol production is not corroborated in the facts (in 2007, corn exports have increased though a higher corn ethanol production) ;
- Finally, the study assumes that yields both in the U.S. and in the rest of the world will continue to increase at present trends based on detailed analysis. This assumption means that the yield response to agricultural price is negligible. This contradicts many biofuel proponents who claim that there is a potential yield increase which should make it possible to meet energy demand with only modest long run acreage reallocation (Korves 2007). Some countries are for instance characterised by low livestock density: Brazil counts 197 millions hectare of pasture for only 230 millions heads of livestock[6]. It would be then easy to free up new arable lands for biofuels production by increasing the number of live animals per hectare, and to raise the animal production yield beyond the current trend.

[6] Source : FA0 – 2007. The livestock volume gathers cattle, buffaloes, sheep, goats, horses.

Searchinger responded to most of the critics listed above, recalling that his paper indicated that “the emissions from land-use change per unit of ethanol would be similar regardless of the ethanol increase analyzed”, the assumption about the volume of corn ethanol production has therefore no influence on the results. He also explained that the protein content of distiller’s grain varies by the type of livestock, and that the value they retain resulted from a complex computation, which has been validated by the conclusions of the USDA about the use of distillers’ grains. He clarified the point concerning U.S. corn exports by underlining that the paper claimed a reduction of exports “compared to otherwise existing export level in 2016 if the U.S. then produced only 15 billions gallons of ethanol”. Finally, the objection related to yield hypothesis is refuted by Searchinger on the ground that this factor “would change the world with or without biofuels – in other word, [it] would change the baseline – and it is not proper to attribute to biofuels either the benefits or harms from independent factors”. Furthermore, Feng and Babcock (2009) showed that higher yields will not necessarily limit cropland expansion, because unless output prices decrease dramatically, yield enhancement increases profits on a given acre and prompts the cultivation of land of poorer quality. This assertion is corroborated by Keeney and Hertel (2008) who demonstrate, using a modified version of GTAP (see section 3.2.3 for more details), that yields increase allows U.S. agricultural export sector to regain some of their competitiveness in foreign markets and may lead to more land use.

More generally, objections have been raised against the existence of the ILUC effect itself. Observed changes in land use offer actually inconclusive results about ILUC. For instance, the rate of Brazilian Amazon deforestation peaked in 2004, and has fallen since then, yielding a negative correlation of –0.53 with soybean price during the four years since 2004. While this may appear contrary to the ILUC hypothesis, deforestation may have fallen faster without biofuels (Liska and Perrin 2009). Moreover biofuels emissions are compared to current fossil fuel emissions, although these emissions could significantly rise during the next decades. The depletion of conventional oil reserves could actually necessitate the exploitation of unconventional petroleum, such as tar sands or oil shale, which is more energy and emissions intense.

On the whole, Searchinger acknowledged that it remains some uncertainties, and that most detailed studies are needed, particularly on agricultural features and prices effect. For this reason and owing to the potential extent of ILUC emissions, this first diagnosis has to be validated by further modelling works, so as to properly guide biofuel policy development. To do so, we present in the next section, the main tools at disposal for modelling ILUC.

3. A brief review of the available land use modelling tools

3.1. Modelling challenges

GHG emissions due to indirect land use changes can be computed by multiplying the size of land conversion due to an increase of biofuels production by a GHG factor estimated for each hectare of land converted. In spite of the apparent simplicity of this calculation, the assessment of the ILUC impact on climate changes is actually of great complexity since it comes under three main disciplinary fields: economics, agronomy and climatology.

The first factor (size of land conversion) results from two driving forces, since bringing into cultivation new lands depends on economic behaviour and on agronomic parameters. Economic behaviours determine the effect of farming an additional hectare of feedstock for biofuels on agricultural prices, and from then on, the impact of an increase of agricultural prices on arable land supply. As Searchinger et al. suggested it, this impact will be all the more sizeable than the demand for food is inelastic. In the same way, the more the land supply will be elastic, and the greater the effect of biofuels on prices, the larger will be the size of land conversion.

The agronomic parameters relate to crop yields, land conversion costs and the proportion of by-products that can be used in the production process of agricultural goods. These three parameters are of great influence on land use change extent, because lower yield induce higher land displacements, while higher use of by-products tend to reduce the ILUC effect.

The second factor (GHG factor) also depends on two key elements:

- The volume of manure used in the production process causes emissions of nitrogen oxide (NO and NO2), a greenhouse gas with a high warming potential ;
- As Fargione and al. showed it, the type of land converted plays a prominent role to explain the extent of the carbon debt. Tropical rainforest or peatland rainforest store high level of carbon while the conversion of marginal croplands releases lower level of carbon in the atmosphere.

These two elements greatly vary in the different regions of the world. Each region is actually characterised by their land covers, storing more or less carbon, as well as by their technological itineraries, requiring more or less manure. For this reason, land use models shall be able to describe precisely international fluxes of agricultural goods, and to give guidelines on the geographical dimension.

Through the carbon debt and the payback period, GHG emissions profile of biofuel encompasses an important time dimension that land use models have to take into account. Parameters like carbon price or discount rate will therefore be of special interest.

The last challenge of ILUC modelling lies in the calculation of agricultural emissions. Computing net greenhouse gas effects from land conversion requires historic data about the use of every parcel. However, due to a lack of global spatial soil carbon stock data, and of its historic, and to the difficulty of modelling changes in soil carbon, calculation of agricultural emissions is generally coarse.

3.2. Existing modelling tools

3.2.1. Geographical land use models

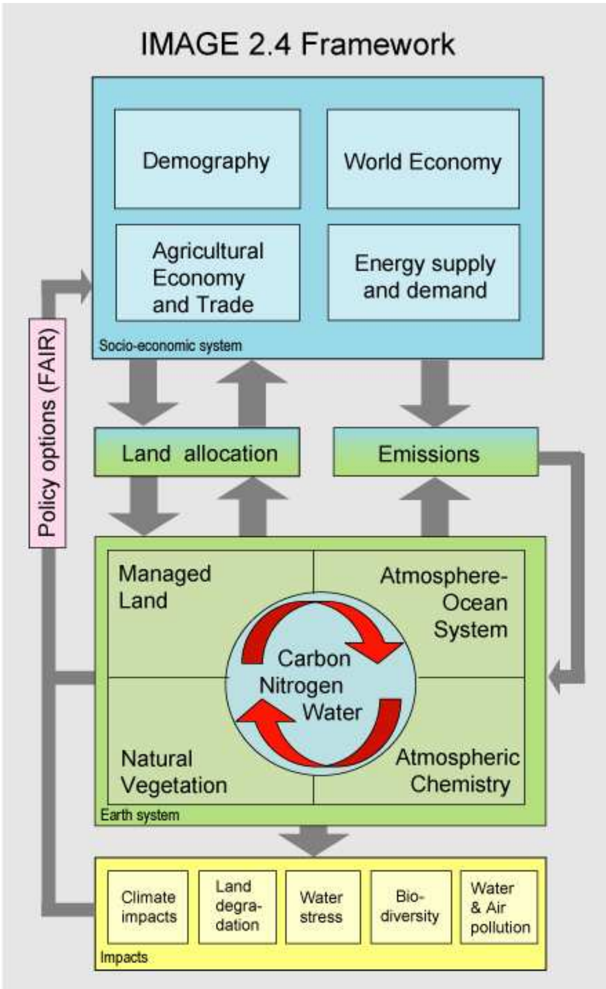
Because they are able to describe precisely the relations in land use / cover dynamics, spatially explicit land use models could be convenient to address the questions on which the previous section shed light. Geographical models are mainly small-scaled, limited to a small part of a country. Among large-scale geographical models, which are best suited to deal with the ILUC issue, Heisterman et al. (2006) distinguish between empirical-statistical models and rule-based models.

The CLUE model framework (Veldkamp and Fresco, 1996) is certainly one of the most important empirical-statistical models. The CLUE architecture is composed of several modules which estimated the most important biogeophysical and socio-economic drivers of land use through multiple regression methods:

- The demand module computes the domestic consumption and export volumes on the basis of GDP, population size (which is estimated thanks to a specific module), consumption pattern and international prices;
- From this demand on, the yield module calculates the total area needed for different land-use types;
- The area of each land-use type in a given grid cell is the result of scale-specific regression equations, where the biophysical and socio economic conditions, and the conditions at higher grid scales are the explanatory variables.

However, as Heisterman et al. notes it, “the underlying assumption of the CLUE framework is that observed spatial relations between land-use types and potential explanatory factors represent currently active processes and remain valid in the future.” For this reason, this model could not reflect correctly the ILUC effects, which are likely to change the structure of the current processes of land use allocation.

The Integrated Model to Assess the Global Environment (IMAGE) is an example of rule-based models (Alcamo et Al. 1998). IMAGE is an intermediate complexity model based on 0.5x0.5 grid cell. Allocation of land use types is driven by a causal chain, linking crop productivity, distance to existing agricultural land, distance to water bodies (population size, energy supply and demand, agricultural demand, and trade) to land use cover. Following this rule, land covers are allocated within a grid in each region of the world until the total demands, resulting from economic and demographic variables, are satisfied.



A noticeable added-value of this model lies in its precise modelling of agricultural GHG emissions, thanks to the Terrestrial Environment System (TES). The TES is a module of IMAGE devoted to the calculation of emissions from land use changes, natural ecosystems and agricultural production systems, and the exchange of CO2 between terrestrial ecosystems and the atmosphere. This module includes computation of above and below ground soil carbon stocks and emissions based on forestland conversion and agricultural land abandonment.

Overall, this kind of model allows for an accurate analysis of the spatial structure of land use, by describing notably neighbourhood effect or hierarchal organization of land. However, because of this focus on geographic features, these models don't well represent the behaviour of individuals or sectors of the economy, which are, as shown in section 3.1, of peculiar importance for the understanding of the ILUC issue. For this reason, we present in the next section land-use models including a precise description of economic features.

3.2.2. Economic land-use models

Economic land-use models can be either in partial equilibrium, taking into account only a subset of markets whereas the remaining markets are parameterized, or in general equilibrium, where all markets are modelled explicitly and are assumed to be in equilibrium in every time step. So, while computable general equilibrium models (CGE) allow for a coherent representation of the economy, partial equilibrium models (PEM) give an explicit description of supply and demand adjustments to price and optimization behaviours.

3.2.2.1. Partial equilibrium models

The Forest and Agricultural Sector optimization Model (FASOM) is an example of PEM (Adams et al. 1996). It basically aims at evaluating the welfare and market impacts of alternative policies for sequestering carbon in trees in the United States, but it has been extended to a wide range of forest and agricultural sector policies.

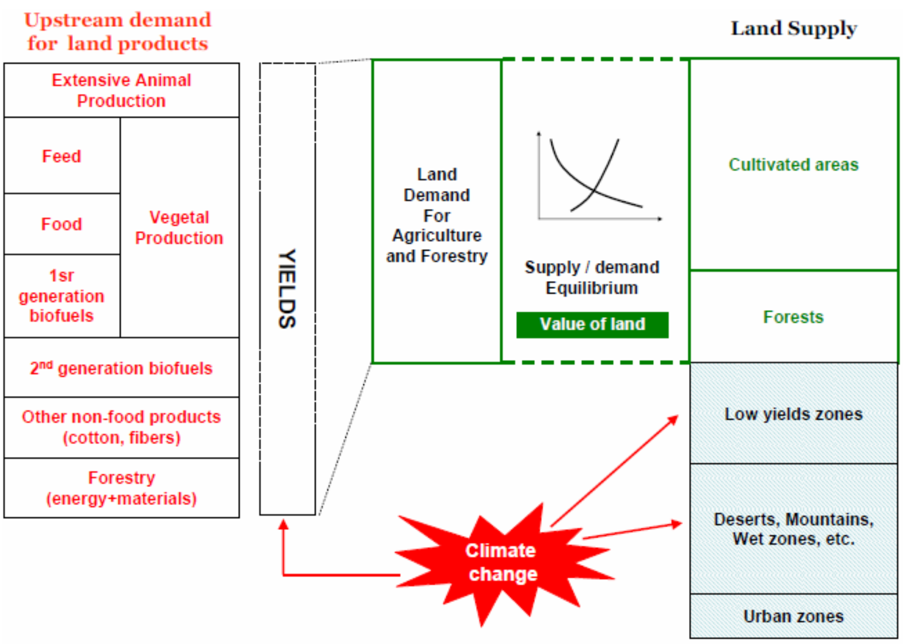
The principle of the model rests on the maximization of the net present value of the sum of the consumer and producer's surpluses, with producer's surplus interpreted as the net returns from forest and agricultural sector activities. At each period, the landowner must choose whether he wants to use his land for cultures or forest; the type of culture to be put on each surface or the type of forestry exploitation.

Unlike geographical models, prices are endogenously determined by demand functions and supply processes. United States are subdivided in 11 homogenous supply regions and a single national demand region. Supply curves for agricultural products and sequestered carbon don't result from estimations from observed historical date, but they are the outcome of competitive market forces and market adjustments. As the model's designers note it: "This approach is useful in part because FASOM will be employed to analyze conditions that fall well outside the range of historical observation".

This way of representing the supply side is of great interest in the optics of dealing with the ILUC issue. In this prospect, the representation of the forestry sector appears also to be relevant. The flow of land between agriculture and forestry is actually an endogenous element of the model, and farmers and timberland owners are supposed to be able to foresee the consequences of their behaviour, in terms of planting trees or crops, on future agricultural prices and to adapt their behaviour consequently. For these reasons, FASOM is one of the commonly used models to evaluate the effects of ILUC, as we will see it further. A version of the FASOM model, integrating the agricultural and forest sectors, is transposed to the areas of the European Union (EU FASOM), with a special focus on the carbon wells.

The NEXUS Land Use (Dorin, Brunelle (2009)), developed by the CIRED, is a world model of land allocation according to the main categories of uses: extensive livestock farming, feed cultures, vegetal production for human consumption, energy cultures of first and second generation and forestry development and other non-energy products (fibers, cotton, etc), taking into account in addition the protected natural zones, residential areas and non-exploitable zones (deserts, mountains, etc).

Fig 3 : The modelling architecture of the NEXUS Land Use



The guiding principle of the model is a supply-demand partial equilibrium of available surfaces (see fig 3). The demand for land rises from upstream needs for food calories, crop products (wood, cotton, fibers), for agrocarburants and possibly for sequestration of carbon, but several intermediate trade-off can vary significantly the demand for lands for upstream needs given the intensification of the vegetal production and the passage of an extensive to an intensive livestock farming. Food prices are not supposed to have an influence on the demand for food calories. By assumption, this demand corresponds to a basic need which must be satisfied whatever the price. The price of agricultural goods is an output of the model. It corresponds, under the terms of the ricardian theory, to the production costs on the least productive land.

Land supply depends more directly on land value, whose growth increases the potential profitability of the not exploited grounds (forests, waste lands or zones with poor yield), while being forced by the dynamic external ones with the model: climate change, turning into a desert, urban sprawl.

The resolution of the supply-demand equilibrium is done on the land value. This value is interpreted like a physical indicator of land use constraints. In this respect, as it is designed to account for the constraint on land use, the Nexus is particularly well adapted to analyse the ILUC effects.

The Kleines Land Use Model (KLUM) is a global agricultural land-allocation model (Ronnberger et al. 2006). The allocation in each spatial unit (whose size is flexible) is computed by maximising the expected profit per hectare under risk aversion, according to crop price and potential yield. Geographical location and biophysical heterogeneity of land is represented by using spatially explicit potential productivities, calculated by the crop growth model EPIC (Erosion Productivity Impact Calculator). Its basic principle is theoretically suitable to the ILUC issue because "its objective is to reproduce the key-dynamics of land allocation to capture the characteristic trait of the feed-back loop between vegetation and economy".

Thanks to its simplicity and to the use of spatially explicit potential yields in the optimisation, KLUM is a convenient tool to be coupled with CGE models or vegetation model (through exchange date on geographic and biophysical heterogeneity of land). More details on this aspect will be given in the next section.

Three other partial equilibrium land use models can be mentioned:

- Agriculture and Land Use (AgLU) focuses on "the impact of a changed climate or a climate policy on land use, carbon emissions from land use change, production of field crops, and production of biofuels", and can't be for this reason directly used to deal with the ILUC ;
- AROPAj (Jayet 2004), developed by the INRA, aims at calculating the cost of the Common Agricultural Policy and the impacts of its reforms. It also allow to analyze the linkage between agriculture and environment in the framework of climate change ;
- The International Model for Policy Analysis of Commodities and Trade (IMPACT) was essentially designed to draw global food scenarios and to analyze the food security issue (Rosegrant et al. 2008). Its originality is to connect water supply and demand to crop production, through a module dedicated to water availability: IMPACT-WATER..

3.2.2.2. Computable general equilibrium model and land use.

Computable general equilibrium model can bring additional details at the macroeconomic level, by connecting the agricultural markets to the rest of the economy. As biofuels are closely related to energy and food markets, this feature is potentially of great interest.

In addition to the fact that land is generally represented in the CGE as an homogenous good, hampering so the biophysical quality of the soil and the impact of climate, the integration of biofuels in CGE comes up against a major difficulty (Kretshmer and Peterson 2008). Unlike macro econometric models, CGEs are not estimated, but calibrated using a social accounting matrix (SAM). A SAM is a balanced matrix that summarizes all economic transactions taking place between different actors of the economy in a given period (typically one year). It is assumed that a SAM of a certain year represents an equilibrium of the economy and the model is calibrated in such a way that the SAM is a result of the optimizing behaviour of firms and consumers in the model. These SAMs are generally provided every year by the Global Trade Analysis Project (GTAP), but as regards biofuels, the data are not as precise as for the other sectors for two reasons: first, they are not represented explicitly in the SAMs, but aggregated to other sector (fossil fuels…) ; and then, bioenergy production was until recently of weak width, and primarily driven by a variety of governmental supports that are not well represented in the SAMs. For these reasons, these matrix don't give the appropriate information from which could be projected a realistic trends of biofuels projection, and they can't be used such as it is for the study of ILUC.

To solve this problem, Reilly and Paltsev (2008) present a methodology for incorporating biomass production into recursive-dynamic multi-regional CGE model: the MIT Emissions Prediction and Policy Analysis (EPPA). Like most of CGE, EPPA rests on the GTAP data set. It uses additional data for greenhouse gas and air pollutant emissions based on United States Environmental Protection Agency (EPA) inventory and projects. The GTAP data are further disaggregated to include latent technology, i.e. energy supply technologies that are existent but not active in the base year of the model, generally because they are not yet fully profitable (e.g. 2nde generation biofuel). Two technologies which use biomass are introduced: electricity production from biomass and a liquid fuel production from biomass. They are described by their cost structure (composed of capital, labor, land and intermediate inputs from other industries), and their competitiveness level with existing technologies, endogenously computed by the model, determines their market share.

Biofuels are represented in the DART model (Klepper et al. 2003) by using a comparable methodology. This model is a recursive dynamic CGE model, solving a sequence of static one-period equilibria for future time periods connected through capital accumulation and relying on GTAP 6. In this database, the refined oil products category has been disaggregated into motor gasoline and motor diesel to better account for the substitution possibilities between these two products and biofuels (Kretschmer et al. 2008). Corn production has also been separated from the "cereal grains neglected" category since corn is an important feedstock for the production of bioethanol. Bioenergy technologies are also modelled as latent technology. In this approach, technologies are described through their cost structure, including feedstock, electricity, and a value-added composite of capital and labor. Markups are also added to account for the difference between production and prices. This methodology allows for a fairly realistic representation of biofuels sector, but it can be problematic in the sense that, technologies being only "latent", there are few exchanges at the calibration year, and projection of future trends can be done only using strong assumptions. For this reason, Klepper et al. assumed that bioethanol trade only takes place between Brazil and the industrialized countries and small shares of biodiesel exports must have been included in some region of the model.

The Mirage model (Decreux and Valin, 2007), developed at CEPII for trade policy analysis, was modified to explicitly address biofuels issues and their consequences on land use changes (Valin, Dimaranan and Bouet, 2009). As the EPPA model, MIRAGE is a general equilibrium model relying on the GTAP database. From this database, six new sectors were added: the liquid biofuels sectors (ethanol and biodiesel), major feedstocks sector (maize, oilseeds used for biodiesel), the fertilizer sector, and the transport fuels sector. They were created using the SplitCom software, a windows program specifically designed for introducing new sectors in the GTAP database.

The supply side is represented by production functions (a Leontieff function of value-added and intermediate inputs for the final output, and nested CES functions for the intermediate inputs), and a representative agent forms the demand side. Unlike most of CGE, the heterogeneity of land is taken into account using agro-ecological zones (AEZ), which desegregate surfaces into homogeneous unit with respect to climatic and agronomic characteristics. As for the Mirage model, lands are differentiated by 3 different climates and 6 humidity levels.

In the modified version of MIRAGE, land use changes arise from two effects: substitution, which relates to the modification of crops distribution on existing arable land, and extension, which relates to the conversion of non-arable lands (forest…) into arable lands. The substitution effects results from optimization behaviour of producers, computed on each AEZ, while the extension effects is determined from an exogenous land evolution trend based on historical data, cropland prices and an elasticity of cropland extension. It is worth pointing out that the model reproduces non market effects, e.g. measures related to environmental protection, land management, urbanization…, using land use change patterns reported in FAO time series. The main results of this model will be presented in section 3.2.3.

Finally refinements have been brought to the GTAP model itself to improve the treatment of biofuels and accurately represent global land use. GTAP is a standard CGE static model distributed with the GTAP database of the world economy (Hertel, 1997). A variant called GTAP-E has been developed by Burniaux and Truong for the analysis of energy markets and environmental policies, with more details on substitution possibilities between energy factors and an accounting of CO2 emissions from energy consumption. GTAP-Bio (Birur, Hertel and Tyner (2008)) is a modified version of GTAP-E which incorporates the potential for biofuels to substitute for petroleum products. GTAP-EFL is a refinement of GTAP-E in terms of industrial and regional aggregation levels. Economy is modelled through representative firms and consumer. The production functions are specified via a series of nested Constant Elasticity of Substitution functions.

3.2.2.3. Coupling of models with CGE

A convenient way to overcome the problem of misrepresentation of the agricultural sector is to couple CGEs with land use models incorporating a more detailed description of land use and biofuels sectors. In such an architecture, the dedicated model computes patterns of agricultural production and land allocation. These results are taken into account by the CGE as exogenous parameters, and used to update the calibration data. In its turn, the CGE feedbacks the land use model with information on new conditions of production.

KLUM@GTAP (Ronnberger et al. 2006) is an example of land use model coupled to an extended version of the computable general equilibrium GTAP. This coupled system is composed of the global agricultural land use model KLUM – previously presented – and GTAP-EFL.

GTAP-EFL provides crop prices and management induced yield, while taking into account this information, KLUM calculates land allocation changes on country level. The relevance of the coupling was tested by comparing the results of the coupled system with those of each of its components taken separately. This analysis reveals significant differences between the simulations of KLUM@GTAP and of the models standalone, which, according to the authors, "strongly supports the hypothesis that a purely economic, partial equilibrium analysis of land use is biased; general equilibrium analysis is needed, taking into account spatial explicit details of biophysical aspects."

Overall GTAP constitutes a convenient platform to be coupled with. From a comparable methodology with that of KLUM@GTAP, the geographical model IMAGE, described previously, has been coupled to an extended version of GTAP, in the framework of the EURURALIS project (Klijn et al., 2005). The coupling of the two models is established by exchanging demand for crop and pasture land, determined by GTAP, with land allocation, as calculated by IMAGE. The LEITAP model, built by the agricultural economics institute, follows a very similar approach by coupling IMAGE and GTAP. The originality of this model rests on its land supply curve modelling, constructed with biophysical data from IMAGE. This allows introducing geographically heterogeneous information on land productivity in the agroeconomics model LEITAP.

IMACLIM-R and the Nexus Land Use provide another example of coupling procedure with a CGE. IMACLIM-R (Sassi et al. (2007)) is a multi-sector multi-region dynamic recursive growth model. The growth path is described as a sequence of static short-term equilibria, on a yearly base, articulated with dynamic equations, computed within sectoral modules and giving the new conditions for the following equilibria. In this architecture, the Nexus Land Use has vocation to supplement the set of existing sectoral modules.

A demand for agricultural and forest goods will be deduced from the economic indicators returned by IMACLIM-R (indicators of activities and signals price). The Nexus Land Use will then determine the reaction of the agricultural systems to the demand addressed to him: technical choices as regards intensification of the production, distribution of land uses between production food and non-food, etc… Taking into account these trade-offs, an equilibrium land price will reflect the relative rarefaction of the land factor, as well as the evolution of the profit of the agricultural sector, and production capacities. An estimate of the all-gas emissions of GES (in equivalent CO2) will be also developed.

The ICES model (Bosello and Roson (2007)) has been built on a comparable recursive structure with that of IMACLIM-R. It is a global CGE top down model used for the economic assessment of climate change. To study the relation between demand for land, driven by economic factor, and land availability, resulting from biophysical constraint, ICES is being coupled with the geographical model CLUE. From a vector of demands for different land uses, calculated by ICES consistently with a given social economic scenario, and given an initial land allocation, CLUE allocates the land demand. ILUC are not included for the moment in the coupling exercise, but it is expected to be introduced in future improvements.

Model cluster constitutes an alternative methodology of coupling land use models with CGE. Basically, that consists in linking a set of complementary models. The Global Biomass Optimization Model, developed by the IIASA (Havlik et al. (2009)), is an example of model cluster. It rests on the recursive dynamic structure of FASOM, which determines production and consumption levels, trade flows, and prices, following the methodology described in section 3.2.2.1.. Results are downscaled on homogenous response units (HRU), i.e. spatial units where altitude, slope and soil are assumed to be homogenous. This HRU concept assures consistency in integrating the biophysical features in the economic land use optimization model. Crop yields and soil organic carbon stock are extracted from the Environmental Policy Integrated Climate (EPIC) model according to 4 management systems. Forests are explicitly represented thanks to the Global Forestry Model (G4M). In accordance with this model, deforestation occurs if net present value of land use from agriculture – function of land price - together with the benefits of selling wood is greater then net present value of forestry – defined as the sum of stumpage wood price, multiplied by harvested wood volume minus planting costs. Final results of GLOBIOM are presented in the next section.

3.2.3. Results

In spite of the great variety of land use models, there are relatively few studies given numerical results about the extent of indirect land use changes. This section presents a non-exhaustive review of these studies.

Keeney and Hertel used the GTAP-Bio model incorporating a supply response compact module to analyse the impact of a one billion gallon increase in U.S. ethanol demand. The volume studied is thus far below the 15 billion gallon mandate of the 2007 Energy Act, but the purpose of the article is mainly to provide a "rigorous analysis of the fundamental determinant of indirect land use associated with biofuel mandates". With this intention, Keeney and Hertel computed for the coarse grain production yield and acreage response to the demand shock according to different assumptions on factor mobility: in the short run, when primary factors of production are immobile, the demand is met primarily from expanded land use (+1.23%) ; as the length of run increases and the factors become more mobile, the yields response rises rapidly, this effect lessen land use extension but not totally, and cultivated surfaces continue to grow (+1.68% with foreign yield response and +1.87% without). As mentioned in section 2.2, when yields rise, U.S. agricultural export sector regains some of its competitiveness in foreign markets which requires more acreage domestically. According to their results, the demand shock also generates land use changes in the rest of the world (ROW), whose width depends on the U.S. and foreign yield response (+0.46% without any yield responses, +0.21% with yield response in U.S. and in the ROW and +0.13% with only U.S. yield response). As in the domestic case, the impact of yield increase on foreign land use change is counterbalanced by the competitiveness effect. It remains that in the medium run (five years), yield gains are expected to reduce of nearly thirty percent the pressure on land due to a demand shock. As noticed by Keeney and Hertel, this conclusion stands in sharp contrast to assumptions made in Searchinger et al. (2008), where a twenty percent contribution of yield growth to supply replacement grains was considered as a best case.

The approach followed by the IIASA, using the GLOBIOM model doesn't concentrate on the technical features of biofuels (type, production mode, yield response…), and focus instead on institutional aspects. In this prospect, three dimensions are taken into account: the scope of the biofuels mandates (EU27 or World), and the possibility of trading biofuels and of deforesting. The simulation horizon extends from 2000 to 2020. The scenario of biofuels expansion supposes an increase of 1st generation biofuels from 20 Mtoe in 2000 to around 60 Mtoe in 2020 for the EU27, and from 40 Mtoe in 2000 to 180 Mtoe in 2020 for the World. Intermediary cases are also studied.

As far as the payback periods are concerned, two cases can be distinguished according to the combination of the different parameters:

- When deforestation is not allowed, upfront emissions from land clearing are negligible, and the payback period is close to zero. In this case, trade has few influence on the results;
- When deforestation is not constrained, introduction of trade can significantly reduce the payback period, because it offers to each country the possibility to convert marginal agricultural land in other countries rather than converting forest domestically. For this reason, payback period without trade amounts to 60 years in Europe as well as the World against about 20 years with free trade.

Outcomes of the GLOBIOM models highlight therefore the role of trade in reallocating efficiently agricultural production among available lands (i.e. lands with a carbon stock a small as possible), and reducing consequently ILUC impact in terms of GHG emissions.

This interrelation between ILUC and trade has also been tackled by Valin et al., with the help of the CGE model Mirage (see above for a detailed description). The authors study two scenarios of ethanol development with a reference situation in 2004. Under both scenarios, mandates are implemented to reach a production of 30 billions gallons (around 60 Mtoe) of ethanol production in 2022 in the US, and about 35 Mtoe in 2020 in Europe, in which 16 Mtoe must be devoted to ethanol. In the first scenario, the objectives are supposed to be reached using only domestic production (DM for domestic mandate), while in the second scenario markets are completely open to ethanol produced abroad (FTM for free trade mandate).

After computing the variation in land types area in Europe, USA, and Brazil (see Fig. 8), and in order to take into account the time path of ILUC GHG emissions, the authors calculate the payback period for ethanol, following Fargione et al. (2008).

According to their results, the payback period would approximately last 12 years in the EU and in the US by 2020. The main result is that implementing free trade reduces the ethanol payback period of 1 year by 2020 and of nearly 14 years by 2010. In spite of higher carbon release from deforestation in the free trade case, due to higher variations of forest surfaces than in the domestic mandate case (see table 1), trade liberalisation allows for using larger quantities of Brazilian ethanol sugar cane, which has a better yield than any crops used for making ethanol, and to significantly reduce carbon release from cultivation of new land.

Table 1 : Variation in land types area in Europe, USA, and Brazil (in Mha)

		2020 Ref Lev	2020 DM Lev	2020 DM Var	2020 FTM Lev	2020 FTM Var
Pasture	**EU27**	0.71	0.70	-0.45%	0.71	-0.13%
Cropland	**EU27**	1.17	1.18	0.53%	1.17	0.20%
Other	**EU27**	1.17	1.17	-0.17%	1.17	-0.07%
Forest_managed	**EU27**	1.47	1.47	-0.07%	1.47	-0.04%
Forest_primary	**EU27**	0.07	0.07		0.07	
Forest_total	**EU27**	1.55	1.54	-0.07%	1.55	-0.04%
Total exploited land	**EU27**	3.35	3.35	0.06%	3.35	0.02%
Pasture	**USA**	2.39	2.38	-0.60%	2.38	-0.47%
Cropland	**USA**	1.92	1.94	0.96%	1.94	0.76%
Other	**USA**	1.88	1.88	-0.14%	1.88	-0.11%
Forest_managed	**USA**	2.97	2.97	-0.05%	2.97	-0.04%
Forest_total	**USA**	2.97	2.97	-0.05%	2.97	-0.04%
Total exploited land	**USA**	7.28	7.28	0.03%	7.28	0.03%
Pasture	**Brazil**	1.94	1.94	-0.09%	1.93	-0.18%
Cropland	**Brazil**	0.84	0.85	0.80%	0.85	1.63%
Other	**Brazil**	1.43	1.43	-0.15%	1.43	-0.30%
Forest_managed	**Brazil**	0.19	0.19	-0.18%	0.19	-0.52%
Forest_primary	**Brazil**	4.11	4.11	-0.06%	4.11	-0.12%
Forest_total	**Brazil**	4.30	4.30	-0.07%	4.29	-0.14%
Total exploited land	**Brazil**	2.97	2.97	0.16%	2.98	0.31%

Source: Valin et al. 2009

Note: "DM" stands for Domestic mandate and "FTM" for free trade mandate.

Land use change and payback time, as computed by Valin et al. (2009), are much smaller than those calculated by Searchinger et al. (2008). Considering an ethanol production increase of around 15 billion gallons, against more than 20 billion gallons[7] for Valin et al., Searchinger et al. projected a 10.8 million ha rise of cultivated area around the world which is of much greater extent than the results presented in table 1. This difference can be explained by the fact that, contrary to Searchinger et al., Valin et al. supposed that feedstock demand is price elastic. Furthermore the methodology used, as outlined by the authors, is at its beginnings, and some factors need to be précised in order to get reliable results: the incorporation of co-products could minimize the extent of indirect effects, but this could be offset by taking into account peatland emissions and GHG emissions from fertilizers.

[7] This figure includes ethanol and biodiesel production in the U.S. and in EU27.

4. Including ILUC into life cycle analysis

4.1. LCA analysis methodology

Life cycle analysis (LCA) is increasingly used by the government to assess the environmental efficiency and define targets of new regulatory policies integrating biofuel. The European Commission Renewable Energy Sources Directive, the US Energy Independency and Security Act, the German Sustainable Biofuel Obligation Draft and the UK Renewable Transport Fuel Obligation explicitly refer to this analytical instrument.

LCA provide a comprehensive assessment of the environmental impact of a product, by computing GHG emissions at each step of the production process, from "cradle-to-grave", or in the case of biofuels, from "field-to-tank". As far as biofuels are concerned, five main production stages are generally studied (Bio Intelligence Service (2008)) :

1. The farming phase where GHG emissions stem notably from manure spreading (essentially N2O), fuel for mechanization and energy of irrigation ;
2. Biomass transport where emissions are associated with fuel combustion ;
3. The industrial phase which uses intensively energy and chemical product ;
4. Distribution involving CO2 emissions associated to transport ;
5. Tailpipe emissions.

The intergovernmental panel on climate change (IPCC) provides detail guidelines for computing GHG emissions in the Agriculture, Forestry and Other Land Use (AFOLU) sector, which covers the LCA farming phase. According to this methodology, land uses are divided into 6 categories (Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land). Each of these categories is further subdivided to include land converted from one category to another. Land conversion, occurring at the local level and at the aggregate one and whose potential environmental effect has been exhibited by some of the models previously presented, is therefore a phenomenon that has to be taken into account in the LCA.

However, a review of 60 life-cycle analysis carried out by the OECD in 2008 concludes that "most LCA on biofuel […] did not take this phenomenon into account"[8]. The article of Searchinger, presented previously, was the only noticeable example of LCA including indirect land use changes effects.

[8] Biofuel support policies an economic assessment

As recognized by the OECD review, traditional LCA, also called *attributional*, is not "designed to assess the absolute impacts of large-scale deployment of certain technology or product". This analysis actually focuses on attributing emissions to inputs that are directly used in the production process[9], such as fertilizers and pesticides, and does not include collateral effects outside the life cycle investigated. Thus, so-called *attributiona*l lifecycle assessment ignores indirect impacts of crop extension.

To extend life-cycle GHG balance of biofuels and correct this shortcoming, an approach has been proposed by the Oeko-Institut known as the iLUC factor. We present this methodology under a critical angle in section 4.3.

Besides this approach, a new lifecycle methodology has been developed named the consequential lifecycle assessment. This methodology is defined in the draft regulatory impact of the U.S. Environmental Protection Agency (EPA) in the following way: "Consequential analyses account for activities within and outside the lifecycle that are affected by an incremental change within the lifecycle of the product under investigation. In other words, consequential lifecycle analyses study the consequences of changes in production or consumption from a market-based perspective, utilizing economic modelling to identify the ultimate impacts of a decision, such as a policy or a single project." Next section presents the lifecycle analysis conducted by the EPA, on the basis of the consequential methodology.

4.2. The EPA lifecycle analysis

4.2.1. The model architecture

From the report that no single model can capture all of the complex interactions associated with estimating lifecycle GHG emissions for biofuels, the U.S. environmental protection agency (EPA) has used a set of tools to "create a more comprehensive estimate of GHG emissions", paying special attention on "significant indirect emissions such as significant emissions from land use change".

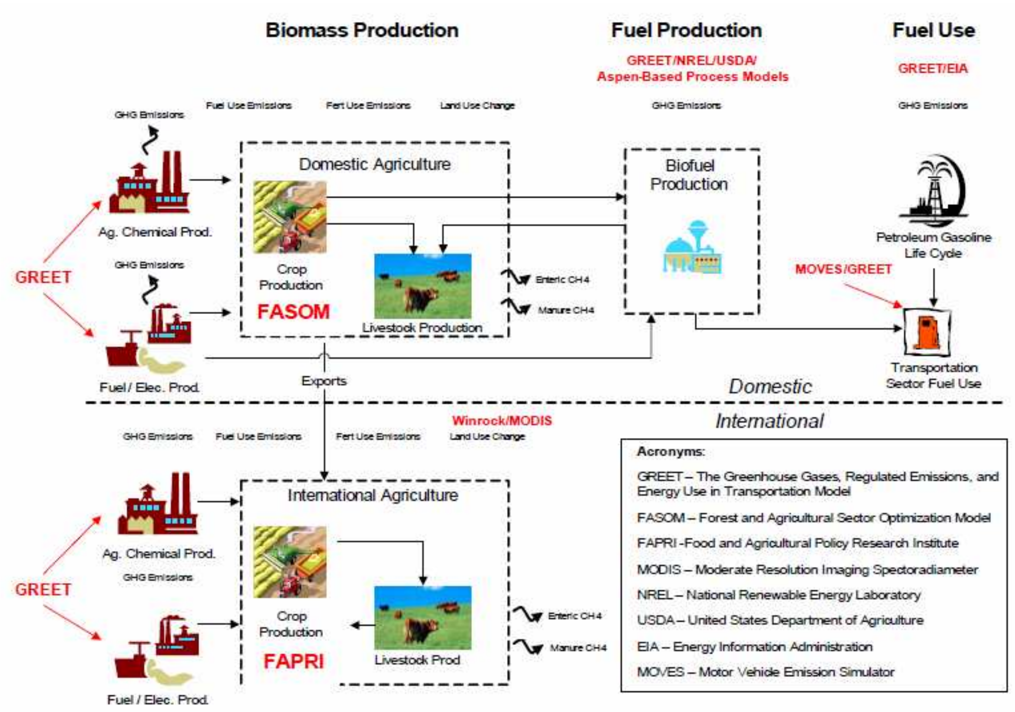
As shown on Fig 4, the LCA methodology adopted by EPA mobilised various modelling tools:

- The GREET model quantifies the emissions at each step of the biofuel production process. It provides GHG emissions resulting from the use of fertilizers, herbicides, pesticides, etc…and it take into account all kind of energy used to produce biofuel (fuel for transportation, electricity…) ;

[9] Co-products are handled by allocation using average data to determine the allocation.

- Emissions due to land use, export and livestock market changes are estimated by FASOM. This model was chosen by EPA because it covers a wide range of production possibilities and accounts for the main GHG emitted by agricultural activities ;
- While FASOM predicts land use change in the U.S. agricultural sector, FAPRI estimates land use changes in other countries due to the response of the international agricultural production to changes in commodity prices and U.S. exports. These estimates are based on historic responviness to changes in price in other countries. Using satellite data MODIS from Winrock international, FAPRI also predicts what land types will be converted into crop land in each country, and calculates GHG emissions associated with land conversions ;
- The EPA-developed Motor Vehicle Emission Simulator (MOVES) estimates vehicle tailpipe GHG emissions, and represent impact that greater renewable fuel use may have on the prices and quantities of other sources of energy, and the greenhouse gas emissions associated with these changes in the energy sector, it was projected to use the Energy Information Administration's National Energy Modeling System (NEMS).

Fig 4 : EPA analytical framework

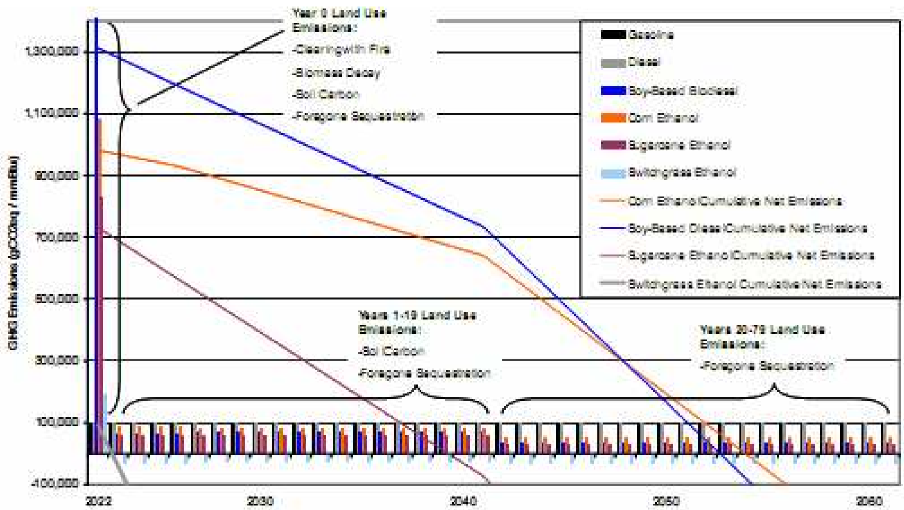


4.2.2. Results

Using the combination of models previously described, EPA estimated GHG emissions associated with land use changes that occur domestically and internationally as a result of increasing renewable fuel demand in the U.S..

As the starting point of the analysis, the report tackles the emissions time profile question. Contrary to fossil fuel, whose emissions occur in a short period of time, essentially at tailpipe stage, biofuel emissions actually spread out over time: "*The GHG emissions associated with converting land into crop production accumulate over time, with the largest releases occurring in the first few years due to clearing with fire and biomass decay. After land is converted to crop production, moderate amounts of soil carbon would continue to be released for approximately 20 years. Furthermore, when forest is cleared there would be foregone sequestration for approximately 80 years associated with the fact that the forest would have continued to grow had it not been cleared*."

Fig.5 : Annual lifecycle GHG emissions over time and payback period.

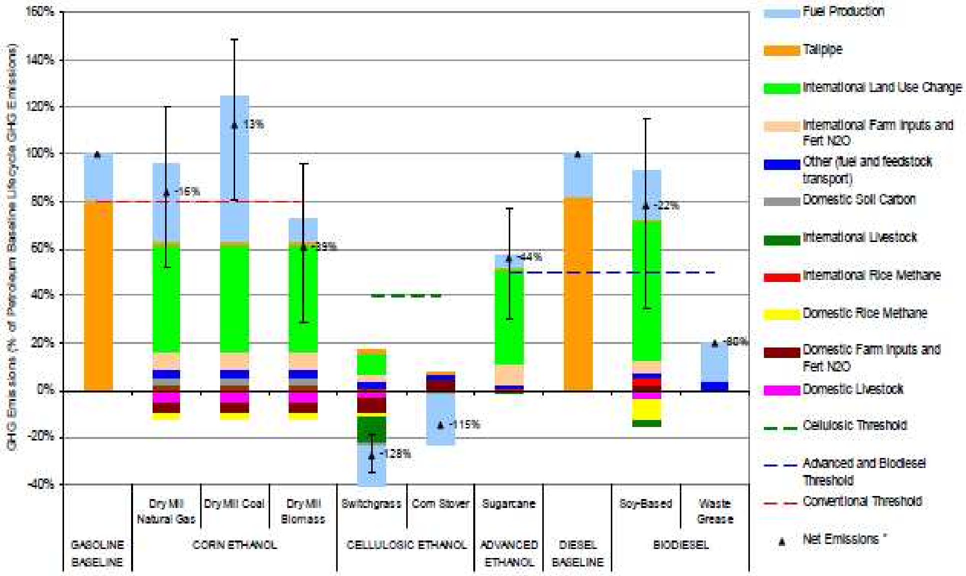


Source : United States Environmental Protection Agency

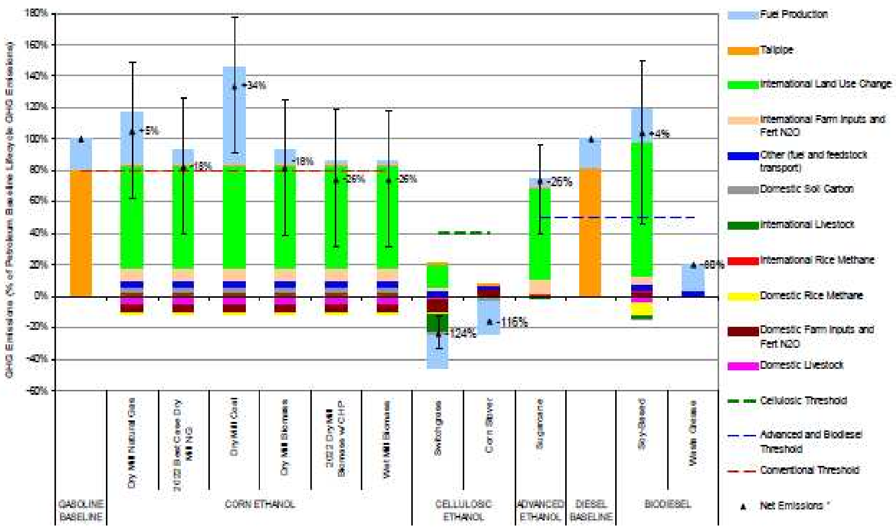
Fig. 5 presents annual emissions (stripes) and net cumulative emissions of four types of biofuel (lines) - soy based biodiesel, corn ethanol (produced in a natural gas-fired dry mill), sugarcane ethanol and switchgrass ethanol - compared to gasoline and diesel. Net cumulative emissions take into account the uptake of CO2 resulting from the growth of new biomass. The payback period corresponds to the period between which the land is cleared (upfront emissions) and the point where the sum of fossil fuel emissions exceeds the sum of net biofuel emissions. This is represented on the graph by the distance between the origin and the point where the net cumulative emissions curves crosses the x-axis. As shown in fig. 5, corn ethanol exhibits the longer payback period (33 years) while it takes only 3 years for switchgrass ethanol use to offset upfront emissions. These results are therefore closed to the second and most favourable scenario of Searchinger et al. where the payback period for corn ethanol lasted 34 years.

To achieve a relevant comparison between the environmental impact of biofuels and fossil fuel, EPA chooses the net present value for emissions as a common metric. Fig. 6 and fig. 7 presents the results for two time horizon and discount rates: 100 years with a 2% discount rate, and 30 years with a 0% discount. These results are computed for a scenario where the productions of corn ethanol, corn stover ethanol, biodiesel, sugarcane ethanol and switchgrass ethanol are increased in 2022 by respectively 2.6, 7.6, 0.3, 2.5, 3.2 billions of gallons in comparison to a business as usual scenario where the productions are respectively of 12.4, 0, 0.4, 0.6 and 0 billions of gallons.

<u>Fig. 6</u> : Lifecycle GHG results using 100 year present value with 2% discount rate



<u>Fig. 7</u> : Lifecycle GHG results using 30 year present value with 0% discount rate



<u>Source</u> : United States Environmental Protection Agency

<u>Note</u> : range shows net emissions in the cases where all land conversion comes from forest (upper bound) or from grassland (lower bound).

Because of the time profile of biofuel emissions, a longer time period and a greater discount rate is more favourable for renewable fuels: with the first set of parameters, only one type of biofuel has a more negative impact than petroleum fuel (corn ethanol produced in dry mill facility fired with coal) against three with a shorter time horizon and a 0% discount rate (corn ethanol produced in dry mill facility fired with coal or natural gas, and soy-based biodiesel).

These results also indicate that ILUC emissions (represented in green on fig. 6 and 7) account for a significant part of total biofuel GHG emissions (at least 35% of the total emissions). However, as the time horizon gets longer and the discount rate greater, the value of the upfront emissions of land clearing is reduced and the ILUC share in total emissions becomes relatively smaller. Finally, this analysis confirms that 2nd generation biofuel, produced with cellulosic ethanol, have a real potential of mitigation as shown in fig 6 and 7.

4.3. The ILUC factor

A convenient way to include ILUC effects into a regulatory policy would be to increase the lifecycle GHG emissions from biofuels of an additional factor e_{iluc}, as proposed in the first draft of the recently adopted Renewable Energy Directive and Fuel Quality Directive (see section 5.3 for more details).

The Oeko Institut proposed the following methodology for the calculation of the factor e_{iluc} :
The approach of the Oeko Institut considers that all arable land used for additional incremental biomass feedstock production will induce indirect land use change risks due to displacement, but that the risk is small and can be ignored for feedstock produced from wastes and on degraded land and also on set-aside and idle land, as well as biomass feedstocks derived from intensified land use (higher yields).

The iLUC factor is derived by considering the potential release of GHG from land use change caused by displacement to be a function of the land used to produce agro products for export purpose on the basis that only trade flows will be affected by displacement. The approach assumes countries increase feedstock production in response to global supply and demand. (Fritsche 2008)

The effective calculation of the iLUC factor is done in several stages:

- First an additional land demand is estimated in four representative regions: Brazil, Indonesia, USA and the EU. This is made by projecting current patterns of land use for the production of traded agricultural commodities, and by considering that only the production for export of rapeseed, maize, palm oil, soy and wheat is concerned. The shares of displaced land is calculated using FAO data and taking into account specific yields ;

- An average CO2 emission per ha of displaced land is computed as the combination of the IPCC based direct land use change factor for a given type of conversion (amortised over a period of 20 years) with the probability of land use change to occur in each region for each commodity (e.g. grassland to maize in the U.S.). At this stage, this probability (also called risk displacement factor) is not scientifically estimated, but derived of explicit assumptions ;
- The multiplication of this CO2 emission factor with the land requirement of different types of biofuels production gives a "full" iLUC factor of 20t CO2/ha/yr corresponding to the case where each additional unit of biofuel production causes land displacement.

The authors suggest that in practice the risk will be lower for feedstock produced on idle land, through intensification of existing cultivation schemes and use of marginal land, etc. Indicative values for the ILUC factor for each are given for 3 category of risk of displacement: a "minimum" assuming 25% of all non zero risk biofuels are subject to theoretical full ILUC factor (=5 t of CO2/ha/year) ; a "medium" meaning a 50% share of non zero risk feedstocks (=10 t of CO2/ha/year) ; a "maximum" for the 75% level of the ILUC factor (=15 t of CO2/ha/year).

Table 2 : Life cycle GHG emissions of biofuels, including ILUC.

Biofuel, location	Life cycle GHG emissions (a) (g CO2-eq./MJ)			Relative to fossil diesel / petrol		
	Maximum	Medium	Minimum	Maximum	Medium	Minimum
Rapeseed to FAME (b), EU	260	188	117	201%	118%	35%
Palm oil to FAME, Indonesia	84	64	45	-3%	-25%	-48%
Sugar cane to ethanol, Brasil	48	42	36	-44%	-52%	-59%
Corn to ethanol, USA	129	101	72	50%	17%	-16%
Wheat to ethanol, EU	144	110	77	67%	28%	-11%
Short rotation crop to BtL (c), EU	109	75	42	26%	-13%	-51%

(a) Including cultivation, processing, by-products and ILUC
(b) Fatty acid methyl ester
(c) Biomass to liquid
Source : Fritsche (2008)

The results of an implementation of the ILUC factor on life cycle analysis are shown on table 2. They suggest that savings would be small for ethanol from corn and wheat, even in the most favourable case. Biodiesel from rapeseed exhibits negative ecological balance compared to fossil fuel in every case, while ethanol from sugar cane produced in Brazil would remain an alternative to conventional fuel to mitigate GHG emissions even with the highest displacement risk.

However this approach encounters some limits and has been highly criticised. The IEA workshop entitled "Land Use Changes due to Bioenergy: Quantifying and Managing Climate Change and Other

Environmental Impacts"[10] summarized this critics, estimating that the ILUC factor was not appropriate because:

1. It was not transparent enough;
2. The impacts should not be based on averages but should be system specific : the only heterogeneity factor comes from the risk displacement factor whose determination methodology is not scientifically explained ;
3. Simple approaches could get imbedded in policy and the factors may not be re-evaluated at regular intervals, so changes would not be detected ;
4. The emissions from ILUC may not be linearly related to the amount of biofuels produced.

The iLUC factor methodology is still in development and could be refined to better account for heterogeneity. A regular update of the values of the iLUC factor could also be considered. The question of transparency is more intricate. A refinement of the iLUC factor in a more system specific way could certainly be the beginning of a solution. But, to clarify this issue, a risk mapping exercise must be undertaken, in order to assess scientifically the probability of land use change in each region and for each type of commodity. Finally, since the iLUC factor has to be applied at an international scale, it is crucial to identify potential countries or areas under threat of ILUC, i.e. countries where export flows of agricultural goods could significantly rise because of biofuels production development in a given region of the world. This last requirement is a sine qua non condition to make the iLUC factor acceptable in the international negotiations.

The linearity of the ILUC emissions to the amount of biofuels produced is a point that remains to investigate. The sensitivity analysis that has been made within the framework of the EPA lifecycle analysis tends to demonstrate that renewable fuel volume has little influence on the incremental GHG emissions. However, this report doesn't consider this result as definitive and "intend to explore the sensitivity of the fuel volumes in more depth […]." This conclusion is actually contradicted by the output of the previously described GLOBIOM model which showed that the payback period decreases when the production level rises.

[10] IEA Bioernegy Task 38 Workshop. Helsinki.March 30th- April 1st, 2009.

5. Policy developments

The results of the reviewed studies have highlighted that, in the current state of knowledge, the extent of the ILUC effect remains very uncertain. The emissions reduction factor of corn ethanol produced in natural gas dry mill, as computed by the EPA life cycle analysis, could be, according to the hypothesis, very positive, involving a reduction of about 40% of GHG emissions compared to fossil fuel, as well as significantly negative, increasing the emissions of about 20% (see section 4.2.2). Facing such uncertainties, the question is to know how to design policies to promote efficient biofuel production with respect to climate change mitigation. This section presents strategies that have been already adopted or that are envisaged.

5.1. Priority objectives in supporting biofuels

Most of industrialised countries have undertaken public support policies for biofuel. Motivations behind these policies are numerous and complex[11], and environmental concerns and mitigation of climate change are often far from being their main considerations.

In a context of rising prices of crude oil and geopolitical tensions, securing energy supply has been at centre of biofuel support in many countries. In the USA, the Renewable Fuel Standard program (commonly known as the RFS program), setting requirements for biofuel production until 2022, is integrated in the Clean Energy Act of 2007, which has been significantly renamed Energy Independence and Security Act. Other concerns, such as reducing import dependence of oil supplies; rural development and sustaining farm income have also been major motivations of biofuel support policies. This great variety of objectives has prompted the implementation of different policy measures. Among them, national targets for renewable energy have been set in most of industrialised countries (see table 3). These targets are rather ambitious for many of these countries, and the EU 27 should not be able to achieve a share of renewable energy in the total primary energy of 12% in 2010[12].

With the rise to power of the environmental concerns, and the necessity to respect the international commitments, the objective of GHG emissions reduction became more sensitive. Political decision makers are now aware that the cost of underestimating emissions of biomass fuels will be very high, because this would entail both greater climate damage and wasted investment of excess biofuel

[11] Biofuel support policy : an economic assessment – OECD 2008.
[12] European Commission report on renewable energy – April 2009.

infrastructure[13]. For this reason, regulatory legislations will have to take account of the indirect effects and uncertainties on the ecological impact of biofuels.

Table 3 : Targets for renewable energy and fuels in 2010

Countries	% of RES in total primary energy	Fuels from RES[1]
EU-27	12%	5.75%
Austria		Mandatory target of 5.75%
Belgium		5.75%
Cyprus [2, 3]	9%	5.75%
Czech Republic	5-6%	5.55%
Denmark	20% in 2011	5.75%
Estonia	13%	5.75%
Finland		Mandatory target of 5.75%
France	10% in 2010	7% (2010), 10% (2015)
Germany	4%	Mandatory target of 5.75%
Greece		5.75%
Hungary		5.75%
Italy		2.5%
Ireland		NA
Latvia	6%	5.75%
Lithuania	12%	5.75%
Luxembourg		5.75%
Malta		NA
Netherlands	10% by 2020	Mandatory target of 5.75%
Poland	7.5% by 2010 14% by 2020	5.75%
Portugal		5.75%
Slovak Republic		5.75%
Slovenia		Mandatory target of 5%
Spain	12.1%	Mandatory target of 5.83% in 2010
Sweden		5.75%
United Kingdom		Mandatory target of 5% of transport fuel suppliers' sales by 2010
Other OECD Countries		
Australia		350 million litres
Canada		5% renewable content in gasoline by 2010 2% renewable content in diesel fuel and heating oil by 2012
Japan		50 million litres of biofuels by 2011(domestic production)
Norway		No
New Zealand	90% of total electricity	Mandatory target of 3.4% of total transport fuel sales by 2012
United States		36 billion gallons by 2022

1. Fuels from RES in majority produced from biomass.

2. Footnote by Turkey.
The information in this document with reference to « Cyprus » relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognizes the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

3. Footnote by all the European Union Member States of the OECD and the European Commission.
The Republic of Cyprus is recognized by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus."

Source: Biofuel support policy: an economic assessment – OECD 2008

5.2. ILUC in the U.S. Renewable Fuel Standard Program

The Renewable Fuel Standard (RFS) program as required by the Energy Independence and Security Act of 2007 prescribed an increase of the volume of total renewable fuel from 9.0 billion gallons (Bgal) in 2008 from 36 Bgal in 2022. These targets shall be met under established eligibility criteria, including mandatory GHG reduction thresholds for the various categories of fuels. Biofuels GHG emissions are evaluated over the full lifecycle, and compared to the lifecycle emissions of 2005 petroleum baseline fuels[14]. Table 4 presents performance reduction thresholds as established by EISA.

[13] Indirect land use emissions in the life cycle of biofuels: regulations vs science. Adam J. Liska and Richard K. Perrin.
[14] U.S. Environmental Protection Agency regulatory announcement.

Eligibility criteria also concern land that can be used to grow biofuel feedstocks. For example, Agricultural land must have been cleared or cultivated prior to December 19, 2007 and actively managed or fallow, and non-forested.

American congress recently amended the EISA to include indirect land use change effects in the life cycle analysis. This decision has sparked off fierce debate. Critics of ILUC inclusion claim that no reliable methods exist to measure highly speculative ILUC data and that "there are no empirical data or proven methodologies that can positively link land conversions halfway around the world to a farmer's decision here in the United States"[15]. As for the proponents, they argue that the inclusion of ILUC will "improve the ability of investors and developers to distinguish promising approaches from dead ends and drive investments and innovation towards these feedstocks and technologies" (Environmental Defense Fund, et al. 2008). To bring an answer to this debate, EPA, which develops and enforces U.S. environmental regulation, has proposed a methodology that accounts for all of the important factors that may significantly influence the outcome of lifecycle analysis, including indirect land use changes. A detailed description of this approach is presented in the previous section 4.2..

Table 4 : Lifecycle GHG thresholds specified in EISA

Fuel Category	Thresholds (percent reduction from 2005 baseline)
Renewable fuel	20%
Advanced biofuel	50%
Biomass-based diesel	50%
Cellulosic biofuel	60%

Source : U.S. Environmental Protection Agency

5.3. ILUC in the European directive on renewable energy

The European Parliament and the Council directive on the promotion of the use of energy from renewable sources emphasizes the sustainability concept. For this purpose, a special attention is paid to indirect land use changes, and paragraph 85 of the directive states:

> *The sustainability scheme should promote the use of restored degraded land because the promotion of biofuels and bioliquids will contribute to the growth in demand for agricultural commodities. Even if biofuels themselves are made using raw materials from land already in*

[15] Cooper, G. 2009. Hearing on low carbon fuels standard. Testimony to Committee on Transportation and Housing—California State Senate on behalf of Renewable Fuels Association. March 16, 2009

arable use, the net increase in demand for crops caused by the promotion of biofuels could lead to a net increase in the cropped area. This could affect high carbon stock land, which would result in damaging carbon stock losses. To alleviate that risk, it is appropriate to introduce accompanying measures to encourage an increased rate of productivity on land already used for crops, the use of degraded land, and the adoption of sustainability requirements […]. The Commission should develop a concrete methodology to minimise greenhouse gas emissions caused by indirect land-use changes. To this end, the Commission should analyse, on the basis of best available scientific evidence, in particular, the inclusion of a factor for indirect land-use changes in the calculation of greenhouse gas emissions and the need to incentivise sustainable biofuels which minimise the impacts of land-use change and improve biofuel sustainability with respect to indirect land-use change. In developing that methodology, the Commission should address, inter alia, the potential indirect land-use changes resulting from biofuels produced from non-food cellulosic material and from ligno-cellulosic material.

Article 17 specifies this requirement by enacting sustainability criteria for biofuels and bioliquids. Just as the EISA, a mandatory GHG reduction threshold is set and only biofuels allowing a GHG emissions saving of at least 35% will be taken into account for the European targets for renewable energy. It is furthermore stated that biomass fuels shall not be made from raw material obtained from land with high carbon stock, namely wetland, continuously forested areas and peatlands.

Article 19 defines the methodology for the calculation of the GHG emission saving from the use of biofuel as the sum of the emissions flux occurring during the production and consumption process. At this stage, ILUC are not included but "the Commission shall, by 31 December 2010, submit a report to the European Parliament and to the Council reviewing the impact of indirect land-use change on greenhouse gas emissions and addressing ways to minimise that impact. The report shall, if appropriate, be accompanied, by a proposal, based on the best available scientific evidence, containing a concrete methodology for emissions from carbon stock changes caused by indirect land-use changes". In this prospect, several policy options are considered by the Commission. They were presented in a document, which circulated for comment in July 2009 and was entitled "Indirect land use change – Possible Elements of a policy approach – preparatory draft for stakeholder/ expert comments". The list of options consisted of:

A. Extend to other commodities/countries the restrictions on land use change that will be imposed on biofuels consumed in the European Union
B. International agreements on protecting carbon-rich habitats
C. Do nothing
D. Increase the minimum required level of greenhouse gas savings
E. Extending the use of bonuses[16]

[16] The existing sustainability scheme provides a bonus of 29 CO2eq/MJ in calculating the greenhouse gas impact attributed. Under this approach, this bonus could be increased; it could be extended to biofuels that do not come from land; and it could be extended to biofuels from idle land to biofuels from land that is severely degraded or heavily contaminated

F. Additional sustainability requirements for biofuels from crops/areas whose production is liable to lead to a high level of damaging land use change
G. Include an indirect land use change factor in greenhouse gas calculations for biofuels
H. Other policy elements that respondents may wish to raise.

5.4. Reducing Emissions from Degradation and Deforestation a way to reduce ILUC emissions?

According to the outcome of the GLOBIOM Model, regulation of deforestation may involve significant reduction of indirect land use changes. The Reduced Emissions from Deforestation and Degradation (REDD) initiative is intended for encouraging virtuous behaviour in terms of forest preservation in developing countries.

At this stage of the negotiations, two strategies to implement the REDD mechanism are studied (Pirard 2008):

- Rewards based on demonstrate quantified reductions: this approach is similar to a cap-and-trade mechanism. An agreement has to be made on a reference value, corresponding to the level of deforestation that has to be reached. Participant countries are then free either to effectively achieve this target or to renounce to rewards (which is equivalent to buy deforestation credits to other countries). It is therefore an asymmetrical scheme in which countries can gain but never lose (Karsenty 2008) ;
- Sponsoring relevant policies measure: rather than rewarding result, this approach is designed to support efforts that demonstrate performance in some extent. “Financial support could be provided for land reform, land use planning and identification of lands without forest cover, technical and financial assistance to agriculture intensification, and control and monitoring of illegal logging – as long as scientific assessments confirm the positive outcomes of these actions” (Pirard 2008).

Killen et al. (2009) argued that the implementation of an effective mechanism to discourage deforestation, such as the REDD initiatives, could significantly contribute to solve the problem of indirect land use change resulting from bioenergy, showing that forest cover could be increased of about 10%, this extension occurring mainly on surfaces cultivated for biofuel[17]. Such a strategy could however heighten in return the pressure on crop price unless agricultural management system evolves to increase yields (Havlik et al. 2009). Studies linking REDD and ILUC are nevertheless still rare and further researches need to be made on this topic.

[17] This study has been conducted on 5 regions: Madagascar, Liberia, Paraguay, East Kalimantan (Indonesia) and Colombia.

Conclusion

In spite of the intense research works, no clear consensus has been reached on the topic of indirect land use changes. According to the different studies, the ILUC extent could be whether very high, with a displacement of 10.5 Mha of land and a payback period of 167 years (Searchinger et al. (2008)), or rather low, with a payback period of less than 20 years (EPA and Valin et al.(2009)). Furthermore methodologies to compute the global ecological assessment of biofuel, integrating indirect land use change, have been proposed but not fully validated. Whether the scientific research is in the position to accurately orientate the political decision remains thus an open question. In this prospect, we propose the following recommendations for further research works:

1. The great variety of results comes from the important number of assumptions that can be made to model ILUC. In order to facilitate the comparison between the different studies, simulations should be made from a common set of hypothesis concerning notably: the elasticity of food demand, the yield evolution with respect to price and technologic advancement, mandates volume and trade liberalisation ;

2. To determine a confidence interval, sensitivity analysis should be run on each of this parameter. In addition, econometric works should be conducted to estimate the value of some key parameters, such as food demand and yield elasticity with respect to prices. The linearity of ILUC emissions to biofuel production should also be tested to confirm or infirm the validity of the ILUC factor approach ;

3. Land use modelling tools should be adapted to better account for indirect land use changes. For this purpose, two methodologies are possible: the integrated models which simulate land use changes into a unique and coherent modelling structure, and the model clusters linking different modelling tools. Both of methodologies have advantages and drawbacks: integrated models are coherent (especially concerning the prices) but may lack of precision; model clusters offer a precise description of agronomic and economic parameter but don't guarantee price consistency. Besides special attention should be paid to the description of supply response (yield reaction) and to spatial features. The geographic relocation of displaced activities and the heterogeneity of land cover across

countries are indeed of critical importance to estimate GHG emissions (Keeney and Hertel (2008)) ;

4. A last point concerns the simulations of different regulatory policies with a view to testing their relevance. Thus, it would be of special interest to consider a scenario where a price is attributed to the carbon forest following a REDD policy design. It would be also interesting to analyse the impact on land use change of different incentive policies to develop biofuels production (subvention or mandates).

BIBLIOGRAPHY

Adams, D.M., R.J. Alig, J.M. Callaway, B.A. McCarl, and S.M. Winnett. 1996. The Forest and Agriculture Sector Optimization Model (FASOM): Model Structure and Policy Applications. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. Research Paper PNW-RP-495. 60 p.

Alcamo, J., Leemans, R. and Kreileman, E. (Eds), 1998. Global change scenarios of the 21st century. Results from the IMAGE 2.1 model. Pergamon & Elseviers Science, London, 296 pp.

Baier S., M. Clements, C. Griffiths, and J. Ihrig. 2009. Biofuels Impact on Crop and Food Prices: Using an Interactive Spreadsheet. Board of Governors of the Federal Reserve System. International Finance Discussion Papers number 967.

Bio Intelligence Service. 2008. Elaboration d'un référentiel méthodologique pour la réalisation d'Analyses de Cycle de Vie appliquées aux biocarburants de première génération en France.

Birur D., T. Hertel and W. Tyner. 2008. Impact of Biofuel Production on World Agricultural Markets: A Computable General Equilibrium Analysis, GTAP Working Paper No. 53, 2008

Bosello F. and Roson R.. 2007. Climate Change and CGE Models: A Proposal to Estimate Climate Change Damage Functions, paper presented at the GTAP Tenth Anniversary Conference "Assessing the Foundations of Global Economic Analysis", 7-9 June 2007, Purdue University, West Lafayette, USA

Dale, B. 2008. "Response to Science Papers by Fargione, et al., and Searchinger, et al.". Departement of Chemical Engineering and Matrials Science, Michigan State University.

De Koning G.H.J., A. Veldkamp, P.H. Verburg, K. Kok, A.R. Bergsma. 1998. CLUE: A tool for spatially explicit and scale sensitive exploration of land use changes. Waegeningen Agricultural University.

De Vries, B., Bollen, J., Bouwman, L., den Elzen, M., Janssen, M.and Kreileman, E., 2000. Greenhouse gas emissions in an equity-, environment- and service-oriented world: an IMAGE-based scenario for the 21st century. Technological Forecasting and Social Change, 63: 137-174.

Decreux Y., Valin H. (2007), MIRAGE, Updated Version of the Model for Trade Policy Analysis: Focus on Agriculture and Dynamics, document de travail CEPII 2007-15.

Dorin B., T. Brunelle, R.Crassous, V. Gitz, T. Le Cotty. 2009. Compétition énergie-alimentation dans l'usage des sols – Eléments d'analyse et de modélisation perspectives globales de développement des biocarburants. Revue du Conseil Français de l'Energie.

Fargione J., Hill J., Tilman D., Polasky S., Hawthorne P. 2008. Land Clearing and the Biofuel Carbon Debt. Science 319 (5867): 1235-1238

Fritsche, U. et al.. 2008. The "iLUC Factor" as a Means to Hedge Risks of GHG Emissions from Indirect Land Use Change Associated with Bioenergy Feedstock Provision, working paper prepared for BMU, Darmstadt, Oeko Institut.

Gnansounou E., L. Pannichelli, A. Dauriat, Juan David Villegas. 2008. Accounting for indirect land-use changes in GHG balances of biofuels. Ecole Polytechnique fédérale de Lausanne. Working paper 437.101.

Gusti, M., P. Havlik and M. Obersteiner. 2008. Technical Description of the IIASA Model Cluster, The Eliasch Review; Office of Climate Change, UK

Havlík P., M. Obersteiner, E. Schmid, U. A. Schneider. 2009. Biofuels and LUC in multiple policy setting: Integrated modelling approach. Presentation to the IEA Bioernegy Task 38 Workshop. Helsinki.March 30th- April 1st, 2009.

Heistermann, M., C.Mueller, and K.Ronneberger. 2006. Land in Sight? Achievements, Deficits and Potentials of Continental to Global Scale Land-Use Modeling, Agriculture, Ecosystems and Environment, 114, 141-158.

Hertel, T.W.. 1997. Global Trade Analysis Modeling and Applications. Cambridge University Press.

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories.

Jayet. 2004. AROPAJ – Manuel pour l'utilisateur. INRA Unité d'économie. Centre de Grignon.

Karsenty A. 2008. The architecture of proposed REDD schemes after Bali: facing criticial choices. International Forestry Review Vol10 (3).

Keeney R. and Hertel T. 2008. The indirect land use impacts of U.S. biofuel policies: the importance of acreage, yield and bilateral trade responses. GTAP Working Paper n°52.

Killeen T.J., Goetz Schroth, Will Turner, Celia A. Harvey, Marc K. Steininger, Christine Dragisic, Russell A. Mittermeier. 2009. Stabilizing the Agricultural Frontier: Leveraging REDD with Biofuels for Sustainable Development. Conservation International, USA

Klepper, G., S. Peterson, K. Springer. 2003. DART97: A Description of the Multi-regional, Multi-sectoral Trade Model for the Analysis of Climate Policies. Kiel Working Paper 1149, Institute für Weltwirtschaft, Kiel.

Klijn, J.A., L.A.E. Vullings, M. v.d. Berg, H. van Meijl, R. van Lammeren, T. van Rheenen, A.A. Tabeau, A. Veldkamp, P.H. Verburg, H. Westhoek and B. Eickhout. 2005. The EURURALIS study: Technical document. Alterra Report 1196. Wageningen, The Netherlands, 15 pp.

Korves R.. 2007. The potential role of corn ethanol in meeting the energy needs of the United-States in 2016-2030, prepared for the Illinois Corn Marketing Board, Pro-Exporter Network.

Kretshmer B. and S. Peterson. 2008. Integrating bioenergy into computable general equilibrium models – A survey. Kiel Working Paper n°1473.

Liska A. J. and R.K. Perrin. 2009. Indirect land use emissions in the life cycle of biofuels: regulation vs science. Biofuels, Bioprod. Bioref.

Organisation for Economic Co-operation and Development, Biofuel support policies (OECD Publishing, 2008)

Pirard R. 2008. Reducing Emissions from Deforestation and Degradation in non Annex 1 countries. The Climate Group. Briefing Paper.

Reilly J. and S. Paltsev. 2008. Biomass Energy and Competition for Land. GTAP Working Papar n°46.

Ronnberger, K., M. Berrittella, F; Bosella and R.S.J. Tol (2006), KLUM@GTAP : Introducing biophysical aspects of land-use decisions into a general equilibrium model. A coupling experiment. Working paper FNU-105.

Rosegrant M. W., Ringler C., S. Msangi, T. B. Sulser, T. Zhu, S.A. Cline. 2008. International Model for Policy Analysis Commodities and Trade (IMPACT): Model Description. International Food Policy Research Institute.

Sassi O., Crassous R., Hourcade J.-C., Gitz V., Waisman H., Guivarch C.. 2007. Imaclim-R : a modelling framework to simulate sustainable development pathways, International Journal of Global Environmental Issues.

Searchinger T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, T-H. Yu. 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. Science 319 (5867) : 1238-1240.

Searchinger T.. 2008. Responses to New Fuels Alliance and Doe analysts criticisms of Science studies of greenhouse gases and biofuels.

Union Européenne. Directive du Parlement Européen et du Conseil relative à la promotion de l'utilisation de l'énergie produite à partir de sources renouvelables. 2008/0016. PE-CONS 3736/08.

United States Environmental Protection Agency. 2009. Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard. EPA-420-D-09-001.

United States Environmental Protection Agency. 2009. EPA proposes New Regulations for the National Renewable Fuel Standard program for 2010 and Beyond. Regulaory Announcement EPA-420-F-09-023.

Valin H., B. Dimaranan and A. Bouet. 2009. Biofuels in the world markets: CGE assessment of environmental costs related to land use changes. XIIIth GTAP conference paper.

Wang, M. & Haq, Z. 14 February 2008; revised on 14 March 2008. Letter to Science.

ANNEX 1: Inventory of institutions and research teams currently working on ILUC (Europe and France)

Team / institution: Joint Research Center involving the Institute for Prospective Studies (IPTS), the Institute for Environment and Sustainability (IES) and the Institute of Energy.

Work Description: The Biofuels Thematic Programme for 2009 will focus on the definition, analysis, testing of sustainability criteria for biofuels production and use (to eventually support certification systems). Questions of land use and indirect land use changes (ILUC) associated with biofuel production and associated green-house gas (GHG) emissions will have priority (through modelling, observations and experimental measurements). The main objectives are:

- Coordination with researchers in other organisations and countries that are carrying out work in ILUC modelling, with a purpose of benefiting from the understanding developing in those other bodies and attempting to ensure a common view of the correct approach to understanding and accounting for ILUC emissions. The agroeconomic model LEITAP which can estimate how much land use change will occur, and in which countries, will be required, but JRC may also develop/use internal expertise. The thematic program may take advantage from interacting with the modellers in various institutions, ensuring that they are based on realistic and comparable biofuels scenarios ;
- Location of arable land expansion in different countries/regions ;
- Estimating soil Carbon (C) loss associated with scenarios of change in cropping system under demand for biofuels on the basis of world maps (soils and land use) ;
- Estimating annual farming GHG emissions (including Nitrous Oxide (N2O) from soils) from biofuels crops in EU-NUTS2 regions ;
- Estimating marginal annual farm emissions (per ton of crops) due to yield intensification.

Work Program: An interim report on the impacts of non-food usage of agricultural commodities for bio-energy, by means of agricultural sector models with feedback from an energy model has been handed in on September 2009, as well as a report on methods for improved assessment of the environmental impacts of different types of land use to enable cross-comparison with other impacts in life cycle assessments of biofuel's options. On 2009-11-30, scientific support to the development of biofuels certification systems technical and reports on methods to assess forest area and forest area changes in EU on the basis of the JRC high-spatial resolution maps should be published. Assessment of the GHG emissions related to the production and use of biofuels for transport has to be achieved for the 2009-10-30.

Team / institution: Kiel Institute for the World Economy in partnership with the University of Bonn and the Institute of Rural Studies at the Federal Agricultural Research Centre.

Work Description: The project NaRoLa (Renewable Resources and Land Use - Integration of bioenergy into a sustainable energy strategy) is funded by the German Federal Ministry of Education and Research. The aim of the project is to get a better understanding of the land use conflicts resulting from the cultivation of energy plants as well as of the economy-wide effects of bioenergy use. The main research focus will be on Germany, though international economic feedback effects will be taken into account. Research questions deal with the impact of bioenergy on land use, sectoral production, factor inputs and incomes. To answer these questions, an integrated modeling approach has been chosen that combines the following models: The DART model of the Kiel Institute will be coupled with the regionalized agricultural and environmental information system RAUMIS, which maps in detail the German agricultural sector and its land use. The results received based on this modeling process shall then serve to formulate policy advice on the integration of bioenergy into a sustainable energy system. Another project within this research focus is the certification of biofuels.

Work program: A forthcoming article entitled "the economic effects of the EU biofuel target" whose abstract is the following (Kretschmer B. et al.) : The CGE model DART is used to assess the economic impacts and optimality of the different aspects of the EU climate package. A special focus is placed on the 10% biofuel target in the EU. In particular we analyze the development in the biofuel sectors, the effects on agricultural production and prices and finally overall welfare implications. The main findings include that the EU emission targets alone only lead to minor increases in biofuel production. Additional subsidies are necessary to reach the 10% biofuel target. This in turn increases European agricultural prices by up to 7%. Additional welfare losses compared to a cost-effective scenario where the EU 20% emission reduction target is reached occur due to separated carbon markets and the renewable quotas. The biofuel target has relatively small negative or even positive welfare effects in some scenarios.

Team / institution: AgFoodTRADE gathering eleven research institutions (INRA, AgroParistech, IFPRI, CEPII, IPTS…)

Work Description : AgFoodTRAde (launched in 2008) is a project dealing with "New Issues in Agricultural, Food and Bioenergy Trade". The purpose is to build on existing knowledge, data, and modelling instruments to address issues of interest for international trade and trade negotiations.
The project builds on past research in international trade analysis and modelling to assess the consequences of trade negotiations and public policies on agricultural production, markets and trade. The program of work emphasizes issues that are often overlooked such as:

- the impact of demand from energy markets which affect agriculture; the demographic changes, which in some developing and transition countries modify the demand for food;
- the concentration of firms in many global markets, which could modify the expected size and distribution of gains from trade liberalization among stakeholders;
- the impact of trade liberalization on price volatility, and potential remedies;
- the growing importance of sanitary and technical measures and their potential impact on food security, health issues, and trade.

Work program: The program of work includes the development of indicators an methodologies; the development of three large scale models (a general equilibrium model of the world economy, a model of EU agriculture and a spatial model of agricultural trade); the development of databases on trade and tariffs; the evaluation of trade agreements and policy reforms using welfare analysis, with a particular emphasis on case studies in Europe as well as in developing countries.

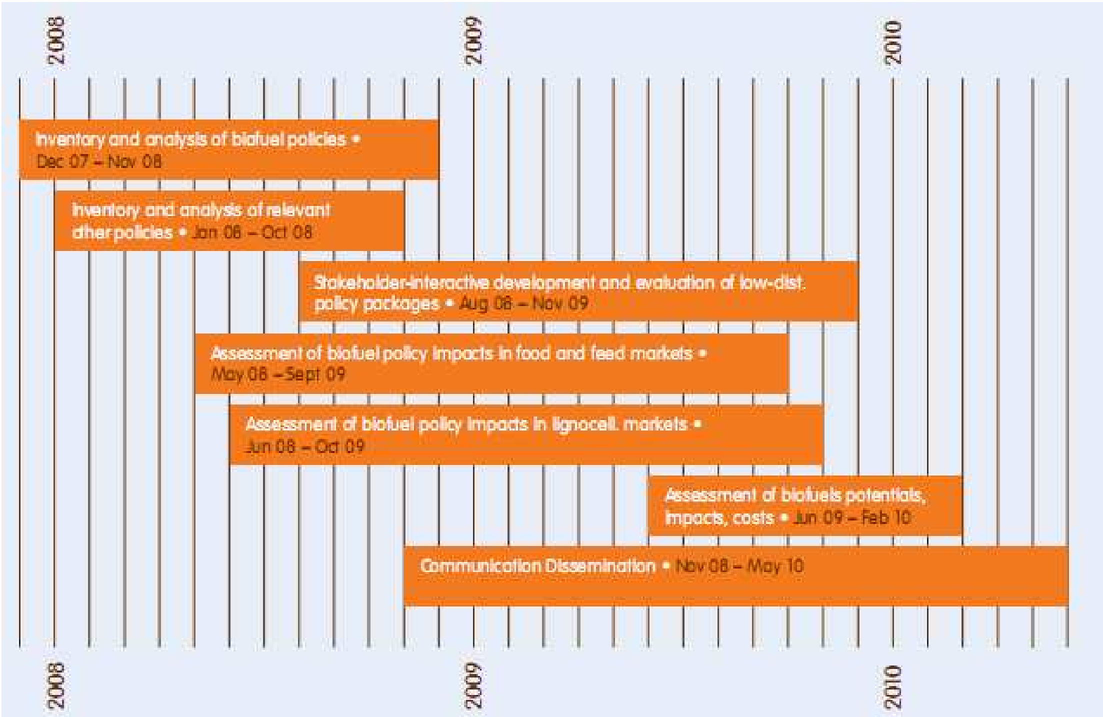
Team / institution: IIASA

Work Description: The IIASA is involved in two projects related to land use changes and biofuels:

- Effective and Low-Disturbing Biofuel Policies (ELOBIO). The main objective of this project is to develop least-disturbing policy options which would enhance biofuels but minimize the impacts on e.g. food and feed markets and markets of biomass for power and heat ;
- LUC study on Biofuels impact on Food Security (commissioned by the OPEC Fund for International Development (OFID)). The objective of the study is to assess, for developing countries and in particular for poor rural populations, the various implications of an accelerated increase of biofuel production. It relies on LUC's analytical tools and quantitative models to support its findings and conclusions. The study has a global scope and will report results

by geographical regions for the medium-term (2015-2020), for the long term (2030) and for the very long-term (2050) ;

Work program: The Timeline of ELOBIO is the following:



LUC study on Biofuels impact on Food Security entailed four parts: Part I - Overview, Current Status and Global Trends; Part II - Implications for Sustainable Agriculture; Part III - Implications for Food Security and Rural Development; Part IV - Suggestions for Policies Actions.

Team / institution: IEA Bioenergy (task 38: Greenhouse Gas Balances of Biomass and Bioenergy Systems).

Work Description: Key objectives of the task are:

- Increase the understanding of GHG outcomes, on a life-cycle basis, of bioenergy and carbon sequestration, especially for bioenergy technologies approaching a break-through, such as second generation biofuels; foster international collaboration and common views of key technical and methodological issues;
- Develop, improve, compare and make available models and tools for assessing GHG balances of bioenergy and carbon sequestration systems on the project, activity, and regional levels, also in the context of economic efficiency, and a broader set of goals, including energy security, environmental and socio-economic issues;
- Disseminate best practice in biomass based GHG emission reduction, and support technology transfer and implementation of GHG mitigation projects;
- Aid decision makers in selecting mitigation strategies that optimise GHG benefits, e.g. allocating biomass to energy vs. use as raw material; considering costs and benefits, as well as the practicalities of different mitigation strategies.

Work program: the work program for the period 2007-2009 entails some of the following activities:

- Develop a methodology for economic assessment of biomass based GHG mitigation options including the costing of other positive and negative externalities besides GHGs;

- Develop standards for GHG performance in the context of bioenergy policies (such as EU directives, renewable portfolio standards, emissions trading and project-level GHG offset mechanisms), with the goal to provide incentives to optimize GHG benefits.
- Extend methodologies for estimating GHG impacts of bioenergy and land use in developing countries (CDM and other projects) to assist sustainable use of biomass and bioenergy in these countries;
- Further improve and make available methods for optimisation of GHG reduction strategies for biomass: carbon sequestration, indirect and direct substitution, synergies, biomass recycling and cascading;
- Address methodologies for GHG balance of biomass trading chains, and securing that imported biomass is renewable;
- Analyse options for the accounting of carbon sinks and bioenergy in the Kyoto Protocol's second commitment period, with main focus on the implications for bioenergy and bio-based materials.

Team / institution: Roundtable on Sustainable Biofuels (secretariat based at the Ecole Polytechnique Fédérale de Lausanne).

Work Description: The Roundtable on Sustainable Biofuels is an international multi-stakeholder initiative developing principles and criteria for sustainable biofuels production that will be simple, accessible and implemented worldwide, generic to all crops, adaptable to new information and in line with WTO rules.

Work program: The Timeline of the initiative is the following :

- 'Version Zero'of the principles and criteria published August, 2008
- Global stakeholder feedback gathered through March 31, 2009.
- Transition to new governance structures and approve Version One by June 2009.
- Encourage/foster crop-specific better practice definitions (e.g. jatropha)
- Develop generic indicators, benchmark against existing standards
- Collaborate with other partners to measure & mitigate indirect effects
- Coordinate pilot testing of draft standards in real supply chains in 2009