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Background document

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1. Modelling framework

Increased demand for biofuels is expected to produce changes in the present land-use configuration. Many countries and regions are establishing biofuel mandates and others are planning production strategies to supply this demand. Biofuels production will require feedstock that will mainly be satisfied with agricultural crops, herbaceous and forest energy plantations, and forestry and agricultural residues. Feedstock demand will increase and competition with alternative uses of the same biomass and for land to produce this feedstock will take place. This will induce land-use pressure and may generate, in consequence, land-use changes. Concerns about the effect of land-use change on biodiversity, food supply, soil and water quality and GHG balance have increased worldwide.

However, the amount, the location and the effect of this change is still unknown. Several research projects are ongoing in order to address these issues and the international scientific community is engaged to develop methodologies and data to gain insight on the impact of current and projected biofuels production on land-use changes.

Models try to represent a real world processes in a simplified manner in order to understand why they occur, where and in which quantity they occur and which are the consequences. The scope of land-use change modelling (Agarwal *et al.*, 2002) approaches include the following issues:

Determine the causes of the LUC: These models aims to explain why the land-use change occurs and try to identify the driving forces of the LUC. At the local/regional level, land-use change can be explained by local drivers (proximate causes). However, local drivers are generally linked to global trends (underlying causes) that influence their action. Current models rely on various approaches. However, linking local drivers to global trends is challenging. While macro-models try to explain why a representative actor (e.g. an industrial or agricultural sector) allocates land to a specific use based on the influence of global trends, regional/local models try to explain why an individual actor (e.g. a household) allocates land to a specific use based on the local drivers of change.
Some limitations have been identified in linking these two approaches.

Determine the amount and the location of the LUC: These models aim to analyze the spatial and temporal dynamics of change. They are based on spatial explicit and historical land-use data that is used to define a set of decision rules. These rules explain why an actor chooses a specific location and a specific time period to occupy a certain land with a certain activity. Global and local models are also available, and decision rules generally include a combination of local factors and global trends.

Determine the consequences of the LUC: These models look forward to analyze the effect of the LUC on the environment and on the society. Typical local models analyze biodiversity losses, soil degradation, population migration and redistribution and carbon stock changes. Global models are mainly focused on determining the impact of LUC on greenhouse gas emissions.

Models' integration is a key issue to better understand the LUC process. Some initiatives are being developed to link economic models, biophysical models, and land-use models to account for land-use change in biofuels production. Current global economic models represent each national economy as a residential sector and a set of industries (or economic sectors) that interact with the rest of the world through trade. The agricultural sector uses land as primary production factor. Under this approach biofuels demand at a specific time horizon is satisfied by allocating land for biofuel feedstock production. However, this allocation is based on the profit maximization of the agricultural sector as a whole and do not account for variability in the behavior of land-owners.

It would be worthwhile to investigate how local scale land-use decisions can be integrated into macro-scale models to increase outputs quality of world-wide land-use changes due to increased biofuels demand. The problem relies in linking local driving forces of LUC with global trends.

The main issues to be addressed can be divided in three sections:

Local drivers of land use change

- Which are the main local drivers of land-use change in each specific location?
- Which is the contribution of biofuels feedstock production to this change?
- Which are the available local/regional models of LUC? Which methodology, dataset and limitations do they involve? How adaptable are these to new regions?

Global drivers of land-use change

- Which are the main global trends influencing land-use changes and biofuels in a world-wide scale?
- Which is the contribution of increased biofuels feedstock demand to this change?
- Which are the available multi-region models to estimate direct and indirect LUC due to biofuels? Which methodology, dataset and limitations do they involve? How can these be improved?

Linking local and global drivers

- Which integrated models already exist?
- How can local drivers be incorporated in global models?
- How can global trends be incorporated in local models?
- Which are the limitations and drawbacks of these integrations?

In this background document existing methods, models and applications have been reviewed. We draw up a number of questions and research topics that may be the subject of further research and clarification.

2. Local drivers of land use change

2.1. Local drivers

Local drivers account for the proximate causes of LUC. Geist and Lambin (2002) have reviewed the local drivers of deforestation, including:

- **Infrastructure extension** (transport, markets, settlement, public services, private company)
- **Agricultural expansion** (permanent cultivation, shifting cultivation, cattle ranching, colonization)
- **Wood extraction** (commercial, fuelwood, polewood, charcoal production)
- **Other factors** (pre-disposing environmental factors, biophysical drivers, social trigger events)

However, generally these factors are interconnected and it is difficult to assess the contribution of each factor and the time sequence. For example, Fitzherbert *et al.* (2008) have studied deforestation processes in Southern-Asia. Specific concerns exist about palm oil production and their implications for deforestation in case of an increased demand for palm-oil as feedstock for biodiesel production. They state that much uncertainty exists about local drivers of deforestation. For instance, national statistics do not allow determining if palm-oil production is a driving force of deforestation (Dennis et al., 2005; Hansen, 2005; Grainger, 2008) as palm-oil can contribute as the primary motive for clearance of natural forests; by replacing forests previously degraded by logging or fire; as part of a combined economic strategy (e.g. timber, paper pulp) used to offset the costs of plantation establishment; or indirectly, through improving road access to previously inaccessible forest or displacing other crops/pastures into forests. Moreover, deforestation can take place initially for other reasons and then this land can be subsequently be used to produce oil palm.

2.2. Biofuels modelling

Extensive research and literature exists about local drivers of land use change concerning **deforestation processes** (Angelsen and Kaimowitz, 1999; Cunha da Costa R., 2004), **arable land conversion** (Xie *et al.*, 2004), **pasture expansion** (Wassenaar *et al.*; 2006), **methodological challenges** (Busch; 2006; Lambin *et al.*, 2001; Burgi *et al.*, 2004) and **development of land-use indicators** (Farrow and Winograd, 2001). However, biofuels production has boomed up in recent years and according to our knowledge this factor has not been yet included as a local driver of land-use change.

Biofuels' impact on land-use change has focus until know on mapping the spatial distribution. Biofuels impact on land allocation at the country level has been analyzed by Schaldach *et al.*, (2008) for the Indian context. Some data have been developed to account for spatial dynamic of biofuel feedstock. Sugarcane dynamics between 1988 and 2003 have been studied by Quartaroli *et al.* (2006a,b) using Landsat satellite images and agricultural census data in the northeast part of the Sao Paulo State in Brazil. Some other initiatives to map **spatial distribution of Brazilian sugar cane plantations** have been performed by the INPE (National Institute for Space Research) and UNICA (National Union of Sugar Cane Industries), based on field studies, statistical data and satellite images. However, data is only available for recent years (2005-2006) and not in an operational way. The Canasat project maps sugar cane plantations but no information is given of the displaced activities (INPE, 2007).

2.3. Modelling techniques

Several modelling techniques exist to analyze local driving forces and spatial and temporal dynamics of land-use change at the local/regional level (Lesschen *et al.*,2005). Analysis of driving forces is based on **statistical methods and space-time dynamics analysis** is commonly based on cellular automata and neural networks. Individual decision making processes, that is, why and how a land-owner chooses for a specific land-use integrates these techniques with agent-based modelling.

2.3.1. Non-spatial methods

Non-spatial models mainly focus on explaining driving forces of LUC based on **statistical analysis and regression models.** Several techniques exist to aggregate/group or reduce the number of variables (factor analysis, principal components, canonical correlation, cluster analysis). Regression analysis allows determining correlation between a dependent variable (the one studied) and a set of independents variables that try to explain the process under study. Different regression techniques exist, including linear, logistic, multinomial, ordered logit, tobit and simultaneous regressions. Logistic regression is the most commonly used in land-use change modelling. Regression analysis should be complemented with other statistical tests in order to evaluate causality patterns (Scrieciu, 2006)

Hietel *et al.* (2007) have used a statistical approach to assess correlations between land cover changes and local socio-economic variables in a rural landscape in Germany. The statistical significance of socio-economic driving forces was assessed using a Monte Carlo permutation test to select the main variables. Then, correlations between these variables and land-cover changes were evaluated using a redundancy analysis (RDA). Linear correlations were tested by detrended correspondence analysis (DCA). Redundancy between variables was eliminated analyzing multi-colinearity. Variables giving high correlations can be used as socio-economic indicators of land cover changes.

2.3.2. Spatial explicit methods

Local land-use models rely generally on spatial explicit models. Spatial methodologies for assessing LUC do not use a unique source. The general approach consists in linking **satellite images, aerial photographs, remote sensing data and statistical census data**. Different authors have used different combination of sources (Cardille and Foley; 2003; Chowdhury, 2006).

In spatial explicitly models it is difficult to obtain satellite images and define land-use categories on the same area and the same period. Availability of images is restricted by atmospheric conditions and satellite orbital frequency. Moreover, when covering large areas a significant number of images are required and the quality of the images can vary from one image to another. Consequently, land-use changes modelling based of satellite images needs the support of other information. Modelling techniques can be adapted to any location. However, the application of a specific method depends on the research question to be solved and on the availability of data.

The main research topics are centered on **drivers of deforestation in Latin America** (especially in the Amazonian Forest) **and in Southern-Asia** (Fragomeni Simon and Garagorry, 2005; Rudel, 2007). Some studies have evaluated land-use dynamics in the agricultural frontier of the Amazonian forest (Souza, 2006; Morton, 2006). They have linked Landsat images, deforestation data, with vegetation phenomenology information (MODIS) and field studies on location of deforested areas, cropland and pastureland. They have found that significant forest territory has been deforested for cropland and pasture land. Moreover, a direct correlation was found between deforestation rate and soybean market price.

Geo-statistical techniques allow integrating spatial data with statistical analysis and can be used to find correlations between biophysical and socioeconomic spatial variables and land-use change (Dutra Aguiar *et al.*, 2007). The method is useful to determine transition probabilities in land-use dynamic approaches. A generalized linear mixed model was used to analyze the effects of driving forces in land-use change by Braimoh and Onishi (2007).

Cellular automata is a powerful technique to analyze land-use changes at the local/regional level. They are dynamic models where the system's behavior is based on a set of probabilistic or deterministic rules that determine the state of a discrete cell in space and time characterized by local interactions (Irwin and Geoghegan, 2001). Walsh *et al.* (2007) studied the relation between social, biophysical and geographical driving forces of land-use dynamics. The CLUE (Land-use Change and its Effects) model is a cellular automata georeferenced model for the analysis of LUC (Veldkamp and Fresco, 1996). The model allows making a spatially explicit, multi-scale, quantitative description of land-use changes through the determination and quantification of the important drivers of agricultural land-use on the basis of the actual land-use structure. Results of this analysis are incorporated into a dynamic model, which describes area changes of the different land-use types. Apart from tracking historical LUC, the model explores possible land-use changes in the near future under different development scenarios, having a time horizon of about 20 years. Current applications concern bio-energy allocation simulation and Brazilian case study development. The model has also been used, among other applications, to study pasture expansion into forest based on location and contextual factors.

Agent-base models are dynamic models based on heterogeneous agents with bounded rationality and imperfect information that are able to learn and adapt their behavior in function of their expectations and the interaction with other agents in a common environment. ABM allows modeling the system dynamics and accounting for spatial features of the system. A review of applications of agent-based modelling to land-use change is given by Matthews and Gilbert (2007) based on the purpose of their application, namely, according policy analysis and planning, participatory modelling, explaining spatial, patterns of land use or settlement, testing social and science concepts, and explaining land use functions. According to our knowledge no agent-based model has been yet applied to explain land-use patterns due to biofuels production.

2.4. Research topics and questions

Local land-use models are characterized by their **heterogeneity in their geographical coverage**, the methods used to analyze driving forces and the variables included in the models to explain the LUC. Spatial explicit models are often limited by the lack of data. Research questions in this area may include:

How to harmonize methodologies to determine and integrate local and global driving forces, including biofuel demand into land use models?
How to deal with time dynamics and fast development in the biofuel industry?
Which are the possibilities and drawbacks of model integration at the local level?

Research questions on biofuels LUC at the local level may include:

How do feedstock logistics and biofuel plants location influence local land-use patterns?
How does feedstock competition influence land allocation for biofuels production? What is the role of national/regional policies and incentives on this competition?
Which are the decision rules that guide an agricultural producer to produce feedstock for biofuels?
How do does crop management and intensification affect agricultural expansion?

3. Global drivers of land use change

3.1. Global drivers

Global drivers of land-use change accounts for macroscopic issues (Geist and Lambin, 2002), including for example:

- **Demographic factors** (natural increment, migration, population density, population distribution, life cycle features)
- **Economic factors** (market growth and commercialization, economic structure, urbanization and industrialization, special variables such as price increments)
- **Technological factors** (agro-technical change, application in wood sector, management practices, and agricultural production factors)
- **Policy and Institutional factors** (formal policies, climate policies, food security policies, property rights policies)
- **Cultural factors** (public attitudes, values and beliefs, individual and household behavior)

General scientific consensus exists about using an **economic approach** to address land-use changes due to biofuels production with regard to the influence of agricultural commodity prices in land-use decisions. All the available studies at the moment use general/partial equilibrium models (Rajagopal and Zilberman, 2007; Witzke *et al.*, 2008). Indirect land-use change due to biofuels increased demand has gained much importance in the scientific community and the public and policy debate. At present, only rough estimations based on hypothetical cases are available. These estimations give a range of values that shows the magnitude of the effect, and focusing primarily on negative impacts (i.e. deforestation).

Even though much effort has been done to improve modelling of biofuels and land-use changes in these models, many problems are still unsolved. Furthermore, **the assumed equilibrium conditions supposed some limitations** in representing a global economy and trade interactions between regions that may be overcome through model integration with other modelling approaches.

Equilibrium models are state-of-the-art to analyze policy impacts on international trade and market driven processes. They have been used, and were proven successful to analyze climate change and agricultural reform policies and are now being applied to determine the impact of biofuel mandates on commodity prices, land distribution and GHG emissions reduction.

Equilibrium models apply theory of general (or partial) equilibrium that explains the relation between supply, demand and prices through the satisfaction of a set of equilibrium equations. While, general equilibrium (GE) models represents the global economy and the interactions and feedbacks between different sectors (markets), partial equilibrium (PE) models gain in a detailed description of a specific sector and finds equilibrium for a specific market.

Computable general equilibrium models are top-down models that link general equilibrium theory with realistic data of a global economy in order to find the supply, demand and price levels that support equilibrium across interconnected markets of an opened economy (Wing, 2004). National economies are represented through a Social Accounting Matrix (SAM) that expresses in monetary terms (the payment flow) how the household's income is generated (through the provision of primary factors) and distributed between final products (through purchasing of products). Through the introduction of market distortions they are used to show the impact of a change in the price (or the quantity) of a commodity over the production and consumption of other commodities.

Three CGE models have recently included biofuels in their global economic model and have determined the impact of biofuels demand on land-use changes worldwide. These models are the extended **GTAP-E model** (Purdue University), **the EPPA model**[1] (Massachusetts Institute of Technology) and the **LEITAP**[2] **model** (Wageningen University), all based on the GTAP database[3]. Within PE models several efforts have been recently done and a certain number of models have been used to study the effect of biofuels demand on land-use distribution. These models focus mainly on the agricultural markets. The main difference with GE models is that biofuels are not linked with the energy sector and biofuels demand is introduced as an increased demand in a specific crop or a demand for land input. As biofuels links the energy and the agricultural sectors PE models should be integrated to assess land-use changes. Some approaches links PE agricultural models to GE models including the energy sector.

[1] http://globalchange.mit.edu/igsm/eppa.html
[2] http://www.lei.wur.nl/UK/newsagenda/Dossiers/Biobased_economy.htm
[3] https://www.gtap.agecon.purdue.edu/databases/v7/

3.2. General equilibrium models

3.2.1. GTAP

The GTAP[4] (Global Trade Analysis Project) is a static multi-region CGE model that was designed to analyze trade interaction in an opened global economy (Hertel and Tsigas, 1997). The model represents the global economy as a multi-region open economy with government interventions. Each regional economy is represented by a representative household and a set of producers of specific goods and services. A dynamic version of GTAP was developed but not yet applied to biofuels modelling (Ianchovichina and McDougall, 2001).

In the newest version of the GTAP Database (version 7), the world is split in 113 regions each with 57 sectors. 12 of these sectors are primary, agricultural sectors (8 crop sectors and 4 livestock sectors). Version 7 of the GTAP Database represents the world economy in 2004.

As biofuels are not incorporated separately in the GTAP Database, it is not immediately possible to model the indirect land use changes from increased biofuels production. However, several efforts have been made to model biofuels based on the adapted GTAP-E model (Burniaux and Truong, 2002). Biofuels have been introduced by Birur *et al.* (2008) and further analysis has been made to study the influence of co-products (Taheripour *et al.*, 2008), the impact of international biofuel mandates (Hertel *et al.*, 2008a), the interaction between biofuel mandates, land-use and greenhouse gas emissions (Alla *et al.*, 2008), and the indirect land-use impact of U.S. biofuel policies (Keeney and Hertel, 2008). Several improvements have also been done in modelling land supply and land heterogeneity in the GTAP model including a disaggregation of land by agro-ecological zones at the country level and the integration of land supply curves (Lee *et al.*, 2008; Hertel *et al.*, 2008b; Golub *et al.*, 2008 and Monfreda *et al.*, 2008).

The GTAP model was used by Kloverpis *et al.* (2008) to evaluate land-use changes due to crops consumption. Indirect-land use for a given crop is modeled as expansion and intensification processes, assuming crop displacement as an intermediate state to a new general equilibrium. They proposed some adjustments of the GTAP model to account for long-term scenarios, agricultural expansion (based on the introduction of supply curves), dynamic technological improvements, conversion of outputs in physical units, separate modeling of inputs to agricultural production and model down-scaling to country-specific results. Main focus is in modeling of the intensification process. An application of the approach to wheat consumption in Brazil, China, Denmark and USA is being developed (Kloverpris *et al.*, under preparation).

3.2.2. LEITAP

The LEITAP model was developed to analyze the impact of biofuels' introduction on the global economy, based on the GTAP model. However, some adaptations have been made to include biofuels based on the GTAP-E version of the model by modifying the energy production structure in the original model (Woltjer *et al.*, 2007). The approach includes the analysis of long-term land-use dynamics due to biofuels introduction (Woltjer *et al.*, 2008), the impact of EU biofuel policies (Banse *et al.*, 2007) and the impact of first and second generation biofuels (Banse *et al.*, 2008).

[4] https://www.gtap.agecon.purdue.edu/models/current.asp

3.2.3. EPPA

The Emissions Prediction and Policy Analysis (EPPA) model was designed to analyze the impact of climate change policies on the global economy and on greenhouse gas (GHG) emissions world-wide. It is a recursive-dynamic multi-regional CGE model based on the GTAP database, aggregated in 16 regions and 21 sectors. It works in a recursive 5 years interval, modeling the 1997 world economy from 2000 to 2100 and is suited for long-term analyses. Due to its focus on climate change policies, regions were aggregated in Annex B and Non-Annex B countries of the Kyoto Protocol and sectors were aggregated as energy, non-energy and advanced energy technologies. The model aims to analyze the degree of introduction and the shift in energy technologies in response to climate change mitigation policies. The model structure is the same as in GTAP but the database was extended to better account for GHG emissions, using US Environmental Protection Agency (EPA) inventory data and including a detailed representation of the energy sector. The model was used to estimate the impact of the demand for second generation biofuels on land conversion (Reilly and Paltsev, 2008; Gurgel *et al.*, 2008).

3.3. Partial equilibrium models

3.3.1. FAPRI

The Food and Agricultural Policy Research Institute have developed a set of multi-region partial equilibrium models including the dairy, coarse grains, oilseeds, rice, livestock and sugar models. These models can be linked between each other to analyze area, production, usage, stocks, prices, and trade of a set of products in several countries and in a global scale. The model was developed to analyze the impact of US policies on global markets, so emphasis is put on modelling the US economy (Tokgoz *et al.*, 2007).

In Searchinger *et al.* (2008), the FAPRI international model[5] is used to allocate displaced corn production for other purposes and soybean displaced from rotation in the same land. However, because a partial equilibrium model of agricultural commodities is used, interaction with other economic sectors is not accounted for. The approach does not account for other ILUC sources. Converted land is assigned based on the proportion of lands that have been transformed into cropland in the past and no specific modeling of the spatial allocation of indirect effects was done. Cropland conversion in other countries due to US ethanol production is quantified and CO2 emissions for each region are calculated and expressed per liter of ethanol. This data is used as input for the GREET[6] model to calculate the GHG balance of US corn-based bioethanol.

3.3.2. GLOBIOM

The Global Forest and Agricultural Sector Optimization Model (IIASA) is an extended version of the US and EU FASOM models that were developed to analyze changing policies, technologies, resources, and markets and to assess the impact of carbon sequestration policies. It is a spatial partial equilibrium model of the forest and agricultural sectors. The objective function to be maximized is the social welfare expressed as the discounted economic surplus (the difference between demand for all products and supply of all production factors minus the production costs) subjected to technical, environmental and social constraints. This expression

[5] http://www.fapri.iastate.edu/models/
[6] http://www.transportation.anl.gov/software/GREET/

of the objective function is analogue to the producer/consumer profit/utility maximization applied in other GE and PE models, but computational work is faster. The model is useful to analyze land use changes due to a specific database on land suitability. However, no link with the energy sector exists. The model was used to analyze the interaction between biofuels production and deforestation (Havlík *et al.*, 2008)

3.3.3. AGLINK/COSIMO

The AGLINK-COSIMO model is a dynamic multi-region PE model of the agricultural sector developed by the OECD and the FAO. The model is used to develop medium-term scenarios of supply, demand and agricultural product prices and to analyze the impact of agricultural policies. However, the model has limitations in modelling land-use changes as agricultural land is considered as constant.

3.4. Other partial and general equilibrium models

Other partial and general equilibrium models have been developed to determine land-use changes due to biofuels (and even bioenergy) production, but they are limited to direct changes and the national level. But, extension of these models may be feasible to account for indirect LUC.

An applied general equilibrium model was used to estimate the role of multi-product[7] crops for bioelectricity generation in Poland based on climate policies. The competition between agriculture and biomass for limited land resources was studied and changes in this production share have induced significant changes in land allocation (Ignaciuk and Dellink, 2006). The impact of biomass subsidies and conventional electricity taxes in biomass and agricultural commodities and on the share of bioelectricity in total electricity production was assessed using a partial equilibrium model. The model was used to determine the impact of these policies on GHG emissions, land reallocation and food and electricity prices in Poland (Ignaciuk *et al.*, 2006). The Australian Bureau of Agricultural and Resource Economics (ABARE) has developed a country-specific dynamic mathematical programming competitive equilibrium model that solves jointly the allocation of land and other inputs between regions, activities and time periods. The Transplant model is able to assess competition for land and other inputs among competing agricultural activities. The model is currently used to provide emissions projections to 2020 for Australian agriculture to the Australian Greenhouse Office. They are currently working in integrating other land-use activities such as forestry, plantations, re-vegetation and land clearing into the existing framework (ABARE, 2007).

3.5. Other techniques

3.5.1. System dynamics

System dynamics is a methodology for studying and managing complex feedback systems. Feedback refers to the situation where two variables are reciprocally influenced through a chain of causes and effects. The relation between the two variables can not be studied independently and so the whole system is evaluated as a feedback system. The methodology identifies a

[7] Crops that are used simultaneously for more than one function (e.g. sugarcane production for food and bioenergy).

problem, develops a dynamic hypothesis explaining the cause of the problem, builds a computer simulation model of the system at the root of the problem, tests the model to be certain that it reproduces the behavior seen in the real world, devises and tests in the model alternative policies that alleviate the problem, and implements this solution.

System dynamics technique has been used to develop a global land-use and energy model (GLUE) (Yamamoto *et al.*, 1999, 2000, 2001). The model evaluates the biomass resources potential for bioenergy production through two sub-models. The land-use model accounts for food and wood sectors and includes land-use competition among various uses of biomass applications. The bioenergy supply calculated in the land-use sub-model is substituted for demand of coal in the energy sub-model. The GLUE-11 divides the world in 11 regions and calculates bioenergy potential based on the past records and makes future estimations up to 2100 with a one-year time step. The interactions between land-use change and socio-economic and energy variables can be studied.

3.5.2. Agent-based models

ABM modelling allows overcoming some limitations of CGE models. AMB is useful when the process to be modelled is mediated by heterogeneous agents and includes a high degree of uncertainty.

Little work has been done on the representation of global processes. Furthermore, ABM models have been applied to show how macroscopic patterns can emerge from the bottom up through the simultaneous dynamic interaction of autonomous agents. Little work has been done to analyze the impact of policies oriented processes and as a decision-making tool (Bao Le *et al.*, 2008).

Some drawbacks of ABM have also been identified. ABM models generally focus on the micro-level based on a spatial explicit representation with detailed data of a specific region. Moreover, the criticism to ABM models relies on the claim for unrealistic and subjective assumptions of the modelling approach, namely, the absence of external sectors (rest of the world), simplified accounting of margins and shipping costs, an arbitrary approach for tax and tariff modelling, an arbitrary updating scheme and assumptions about representation of real time.

Consequently, some authors have proposed to integrate CGE models with ABM to represent macroscopic economic processes under a deterministic theoretical framework and realistically capturing the decision making process of heterogeneous agents in a specific sector. These options account for using results of an ABM model as inputs to a macro-level CGE model or vice versa, incorporating an ABM into a dynamic CGE model (McFadzaen *et al.*, 2001) or incorporating a CGE model into an ABM (Deguchi, 2004). Parker *et al.*, (2002) gives an extensive review of ABM applied to land-use change modelling.

According to our knowledge no AMB model at a global scale has been used to analyze biofuels production. However, Wu *et al.*, (2007) have applied an integrated modelling framework to model individual agricultural producer decisions on sown area of major crops in a global scale. This is a first attempts to account for local drivers in global models.

3.6. Research topics and questions

Due to the complex characteristic of global economic interactions and the adaptive capacity of economic actors, uncertainties arise about how biofuels will be supplied and how will land distribution be affected. Some of these uncertainties deal with:

- The time dynamics of introduction of second generation biofuels to reduce land pressure
- The capacity of adaptation of biofuels suppliers toward the most sustainable and viable practices
- The influence of biofuel trade agreement between producers and consuming countries
- The influence of co-products availability on livestock and pasture dynamics
- The influence of biofuel feedstock prices on crops management strategies
- The influence of oligopoly market conditions and imperfect market competition on biofuels production and trade
- The impact of the emergence of new biofuel producing countries and new biofuel mandates

Some improvements are seen in modelling biofuels and land-use changes in economic equilibrium models. However, some issues are still unsolved. For example:

- How to harmonize land-use terminology (e.g. degrades land) and databases?
- How to improve spatial representation and heterogeneity of non-land inputs and production technologies in global-models?
- How to increase downscaling of production patterns and agricultural management practices?
- How to include agricultural management practices in land-use classification?
- How to improve disaggregation of biofuel feedstocks and modelling of biofuels as a sector?
- How to account for time dynamics and their implications on 1) land-use transition paths 2) technological change in biofuels production 3) agricultural intensification and 4) forest growth and forest land allocation?
- How to increase integration of biofuels in the energy sector and how to increase modelling of petroleum products and biofuels competition?
- How to better account for co-products and increase the development of multi-product production function?

Moreover, in order to account for LUC, some limitations are inherent to modelling assumptions in economic equilibrium models. These limitations account for:

- How to account for emergent biofuel producers and new biofuel mandates during the projection period?
- How to account for imperfect biofuels markets?
- How to model the adaptability of the system to changes in time?
- How to account for actors' heterogeneity?
- How to account for non-equilibrium conditions?
- How to improve modelling of preferences and expectations in land-owners and biofuel producers decisions?
- How to account for random events (e.g. short-term price increments)?

4. Connecting local drivers to global trends

4.1. Models integration

Some integrated models linking land-use-energy-agricultural models have already been developed. A consistent review of integrated models for land-use change analysis is given by Schaldach and Priess (2008). The review included the description of CLUE, GEONAMICA (MODULUS, 2000), ITE^{2}M (Frede *et al.*, 2002) LANDSHIFT (Alcamo and Schaldach, 2006; Schaldach *et al.*, 2008) and IMAGE as integrated modelling frameworks. Model coupling seems to be the way to integrate local drivers and global trends.

A first attempt to **link global trends with regional land-use models** in order to account for distribution of biofuel crops was developed by Hellmann and Verburg (submitted), linking the LEITAP[8] (a modified version of GTAP), the IMPAGE[9] and the Dyna-CLUE[10] models. The CLUE (Land-use Change and its Effects) model is a georeferenced model for the analysis of LUC (Veldkamp and Fresco, 1996). The integrated model allows making a **spatially explicit, multi-scale, quantitative description of land-use changes** through the determination and quantification of location factors of land-uses based on the actual land-use structure. The approach allows determining explicitly the location of crops expansion and consequently, the direct land-use effects of biofuels. The model was applied to biodiesel and bioethanol production in the European context. ILUC are assumed to occur, but no treatment of this issue is proposed. However, an extension of this methodology to account for displacements may be feasible.

Wu *et al.*, (2007) have linked a multinomial logit model with a partial equilibrium model (IFPSIM) (Ohga and Gehlar, 1993) and a crop yield model (EPIC[11]) to analyze future changes in wheat, soybean, rice and corn area in a worldwide scale taking into account yield improvement, market prices of crops and local conditions in a GIS-based platform. According to our view this type of model integration will allow to overcome some of the limitations stated in the previous section.

4.2. Research topics and questions

Research questions in this area account for how to integrate local and macroscopic factors and how to deal with models integration. Some of the research questions concerns:

How to deal with inputs and outputs compatibility between models?
How to deal with different spatial resolution and data aggregation between models?
How to estimate correlation between local and global factors?
How to define the model structure?
How to select the models to be coupled?

[8] https://www.gtap.agecon.purdue.edu/resources/download/3258.pdf
[9] http://www.mnp.nl/en/themasites/image/index.html
[10] http://www.cluemodel.nl/index.htm
[11] http://www.brc.tamus.edu/simulation-models/epicapex.aspx

5. Conclusions and expected outcomes

Several methods exist that can be applied to study local driving forces of LUC due to biofuels production. Global-scale models currently present some limitations to account for this effect that should be overcome with further research and new modelling approaches.

Collaborative works is needed at international level in order to develop appropriate methodologies to account for land-use change in biofuels production and to generate reliable estimation of biofuels impacts on land allocation and re-distribution.

In the perspective of these challenges, the “Biofuels and Land-Use Change” workshop aims to provide the Roundtable on Sustainable Biofuels a better understanding of local drivers of land-use change due to biofuels productions and how these drivers can be better accounted in global macro-economic models.

To this end, the workshop will humbly try to:

- Review the state-of-the-art in biofuels LUC modeling at the local/regional and global level
- Identify the main limitation of current modelling approaches and data gaps
- Discuss further research needs and next steps in biofuels LUC modeling
- Discuss how to better account for biofuels LUC in Sustainability Standards
- Offer possibilities of interactions between participants and exchanges for future progresses.

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