A New Land Use Modelling Architecture: The Nexus Land Use

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Issues related to food, biomass energy and forest preservation are generally analysed in a separate approach, exploring the potential of one variable given a reasonable evolution of the other. However, the current situation is caracterised by the combination of three challenges that have to be simultaneously taken up: meeting growing food needs related to demographic evolutions and dietary changes in emerging countries, finding new energetic options to replace depleting fossil resources, and mitgating climate changes with higher organic carbon stocks and low carbon energies. Thus, rather to test the possibility of moving one of the three cursors, for instance by studying scenarios where biofuel production is increasing, the question is now to see what happen when the three cursors are simultaneously pushed up.

To explore this subject and to conjointly assess energetic system, food demand and the evolution of environmental constraint we develop a new land use modelling architecture composed of four models: Imaclim-R [Sassi et al., 2010] which gives insights on the energetic dimensions and provides a general equilibrium framework; Agribiom [Dorin et al., 2009] which produces consistent scenarios of food biomass uses to 2050; Orchidee [Krinner et al., 2005] which calculates the evolution of yields according to climate conditions and carbon concentration, and the Nexus Land Use which computes land use evolutions, energetic consumption for biomass production and profit of the agricultural sector according to the outputs of the previous models.

This article focuses on this last model, to present its structure and the hypothesis on which it relies before to be coupled with Imaclim-R. It also aims at exploring the Nexus Land Use capacities to shed a new light on the analysis of land use policies. In this prospect, we review in a first part the various generations of land use models. We detail in the second part our modelling assumptions and principles. Finally, after having described the scenarios underlying the projections, we present our results and conclude on the mutual compatibility of mitigation strategies using land resources.

1 A brief review on land use modelling: An evolution toward an integrated approach

Political concerns about ecosystems and land use have deeply changed in the recent years. Because of the climatic risk and the depletion of fossil resources, new services are required from ecosystem. In addition to the traditional issues of feeding the world and protecting local biodiversity, they now sprawled on broader fields, such as offering new energetic options and mitigating GHG emissions. Such orientations have profound implications as this increasing demand for services provided by a finite system may create a common pool resources problem [Gardner et al., 1990]. To avoid rivalry between multiple objectives, decisions related to land use must take into consideration the following elements:

- The local point of view is no more sufficient as a modification of the land cover in one region of the world can induce land use change in an other region through price mecanisms [Searchinger et al., 2008];
- Because they use the same limited asset, decisions or behavior changes related to food, biomass energy, grasslands and forest can interact on each other and must therefore be assessed conjointly.

Modelling tools, which are meant to meet political requirements, have followed this evolution. Originally designed to evaluate local and specific issues, they have evolved toward a more integrated approach. Thus, we distinguish in the bulk of land use models, first generation models, dedicated to high resolution analysis, from second generation models, devoted to comprehensive studies. The modelling architecture presented in this article belongs to this new generation of integrated large scale models. It is specifically designed to evaluate policies affecting land use by endogenously determining agricultural intensification choices, which are generally viewed as a key factor in bridging the conflict on land uses[1], as well as land use evolutions. In this extent, the Nexus Land Use provides an extensive view of land use emissions by evaluating both energetic consumption and ecosystem conversions. The model also brings a high level of consistency between biomass uses and resources thanks the biomass balance model Agribiom. It is finally intended for filling in some of the modeling deficits identifed by Heistermann et al. [2006].

2 Modelling methods

The Nexus Land Use is designed to be inserted within the Imaclim-R architecture as a dynamic module representing agriculture decisions about land uses. Imaclim-R uses a recursive dynamic framework, where economic pathways are represented through a sequence of static general equilibria, linked by dynamic equations. These successive equilibria are computed under the constraints imposed by the availability of production factors and inter-sectoral technical relations at each point in time. The outcome is a set of values (output levels, price structure, and investment) sent to dynamic equations, which represent population dynamics, fossil fuel resource depletion and technical change.

The Nexus Land Use determines the reaction of agricultural systems — such as intensification of production, extension of cultivated land, distribution of land uses between food and non-food production — to a food and

[1] Growing within Limits. A Report to the Global Assembly 2009 of the Club of Rome

surface demand deduced from the economic indicators returned by Imaclim-R (indicators of activities and price signals).

Two uses of agricultural land are modelled: crops and pastures. Harvested crops lead to two products, food and non food. Food comprises comestible parts of harvested crop (grains, roots, fruits...). It also may be used as first generation biofuels and as feed. Non food corresponds roughly with cellulosic residues, they are considered to be of little economic value compared with food. They are freelyallocated based on needs for ruminants and can as well be used as second generation biofuels. Unused non food residues are left in the soil. In contrast to pastures production, crop production can be intensified by using higher volume of inputs.

In each region, the available agricultural land is divided into classes based on their potential food yield drawn from LPJmL [Bondeau et al., 2007]. Extensive pastures are assumed to be situated on lower yield classes. Actual yields are computed in each land class as the result of profit function maximisation on each specific area. They are considered to be a function of energetic consumption. Thus their determination allows to calculate the amount of energy used for biomass production, and to evaluate the impact of increasing energy prices on land use changes.

According to the extent of the land products demand, the agricultural sector can adjust their production following two types of trade-off: intensification of production either by using higher volume of inputs to increase yields or by substituting grazing with feed; and "extensification" by increasing the size of cultivated areas. The extent of each trade-off depends on the food price which is computed according to a supply-demand equilibirum, and on energy prices. Food price is used to dertermine the land scarcity rent, by assuming that profit on the last land class of crop is null. Evolution of forest area can be represented either by a land supply function or by a exogenous scenarios. In this paper, we use the latter method.

The model consistency with regards to physical values is guaranteed by the use of agronomic parameters from Bouwman et al. [2005] and by the biomass balance model Agribiom. This model is devoted to the analysis of the world's production, trade and use of biomass. Physical balance in calories between food biomass resources and their use is the core issue and driver of Agribiom. Such balances are worked out on past 43 years (1961-2003) or simulated on various geographical scales (from a country to the whole world).

3 Scenarios description

We intend in this article to test the Nexus Land Use functioning independenlty, before coupling it with Imaclim-R. Thus, food and surface demand come here from exogenous scenarios, rather than being endogenously computed from indicators returned by Imaclim-R. We build for this purpose 3 scenarios corresponding to the most common demand sources for surfaces, namely food, energy, and forests. We define for each of these dimensions an alternative contrasted variant in order to test the mutual compatibility of mitigation policies using land resources. Current studies on land use policies generally focus on one of these dimensions [Keeney and Hertel, 2008], letting the other constant, to conclude on the feasibilty to produce food or bioenergy, or to protect forests. In contrast, this analysis explores the consequences of a simultaneous increase of the demand for surfaces to produce food, bioenergy and forest.

4 Results

For each scenario and variant, we compare the evolution of energetic consumptions, soil carbon stock and profit of agricultural sector, in order to compute the economic and environmental cost of each type of policies. This analysis allows to assess the consequences of policies promoting biomass fuel, in a context of growing food needs, and conjointly implemented with a forest preservation program.

References

Alberte Bondeau, Pascalle C. Smith, Sönke Saehle, Sibyll Schaphoff, Wolfgang Lucht, Wolfgang Cramer, Dieter Gerten, Hermann Lotze-Campen, Christoph Müller, Markus Reichstein, and Benjamin Smith. Modelling the role of agriculture for the 20th century global terrestrial carbon balance. *Global Change Biology*, 13(3):679–706, 2007. doi: 10.1111/j.1365-2486.2006.01305.x.

A.F. Bouwman, K.W. Van der Hoek, B. Eickhout, and I. Soenario. Exploring changes in world ruminant production systems. *Agricultural Systems*, 84(2):121–153, 2005. ISSN 0308-521X. doi: DOI: 10.1016/j.agsy.2004.05.006. URL `http://www.sciencedirect.com/science/article/B6T3W-4D1R2W8-1/`.

Bruno Dorin, Thierry Brunelle, Renaud Crassous, Vincent Gitz, Jean-Charles Hourcade, and Tristan Le Cotty. Compétition énergie – alimentation dans l'usage des sols. eléments d'analyse et de modélisation des perspectievs globales de développement des biocarburants. *Cahiers de l'Energie. Recherches*, 1, November 2009.

Roy Gardner, Elinor Ostrom, and James W. Walker. The nature of common-pool resource problems. *Rationality and Soci-*

ety, 2(3):335–338, 1990. doi: 10.1177/1043463190002003005. URL http://rss.sagepub.com/cgi/content/abstract/2/3/335.

M. Heistermann, C. Müller, and K. Ronneberger. Land in sight? achievements, deficits and potentials of continental to global scale land-use modeling. *Agriculture, Ecosystems and Environment*, 114(2):141–158, 2006.

R. Keeney and T. Hertel. The indirect land use impacts of U.S. biofuel policies: the importance of acreage, yield and bilateral trade responses. Technical report, 2008. GTAP Working Paper n52.

G. Krinner, N. Viovy, N. deNoblet, J. Ogée, J. Polcher, P. Friedlingstein, P. Ciais, S. Sitch, and I.Prentice. A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system. *Glob. Biogeochem. Cycles*, 19, 2005.

Olivier Sassi, Renaud Crassous, Jean-Charles Hourcade, Vincent Gitz, Henri Waisman, and Celine Guivarch. IMACLIM-R: a modelling framework to simulate sustainable development pathways. *International Journal of Global Environmental Issues*, 10(1/2):5–24, 2010. doi: 10.1504/IJGENVI.2010.030566.

Timothy Searchinger, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science*, 319(5867):1238–1240, 2008. doi: 10.1126/science.1151861. URL http://www.sciencemag.org/cgi/content/abstract/319/5867/1238.