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A NOVEL HYBRID ARCHITECTURE FOR AGRICULTURE AND LAND USE IN AN INTEGRATED MODELING FRAMEWORK

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MATISSE Methods and Tools for Integrated Sustainability Assessment

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MATISSE (Methods and Tools for Integrated Sustainability Assessment) aims to achieve a step-wise advance in the science and application of Integrated Sustainability Assessment (ISA) of EU policies. In order to reach this objective the core activity of the MATISSE project is to improve the tools available for conducting Integrated Sustainability Assessments.

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The MATISSE Working Papers can be downloaded at www.matisse-project.net

Preface

About the MATISSE project

The MATISSE (Methods and Tools for Integrated Sustainability Assessment) project is funded by the European Commission, DG Research, within the 6th Framework Programme. The project is interested in the role that Integrated Sustainability Assessment (ISA) could play in the process of developing and implementing policies capable of addressing persistent problems of unsustainable development and supporting transitions to a more sustainable future in Europe. The core activity of MATISSE is to develop, test and demonstrate new and improved methods and tools for conducting ISA.

This work is carried out through developing and applying a conceptual framework for ISA, looking at the linkages to other sustainability assessment processes, linking existing tools to make them more useable for ISA, developing new tools to address transitions to sustainable development and applying the new and improved tools within an ISA process through a series of case studies.

The extent to which the case studies are carrying out a complete ISA for their area of focus varies between attempts to cover all phases of an ISA process to partial implementation of the process. Equally, different case studies are oriented to developing and testing tools and approaches to some, but not all, of the methodological challenges of ISA. The case studies are complementary, however, and the set of cases offers the opportunity to address a wide range of methodological challenges and to explore linkages between cases. An evaluation of practical experiences with ISA implementation in the case studies will provide guidance on the further improvement of methods and tools. Results will also contribute to more informed policy advice.

What is ISA?

Within the MATISSE project, Integrated Sustainability Assessment (ISA) has been defined as a cyclical, participatory process of scoping, envisioning, experimenting, and learning through which a shared interpretation of sustainability for a specific context is developed and applied in an integrated manner, in order to explore solutions to persistent problems of unsustainable development. ISA is conceptualised as a complement to other forms of sustainability assessment, such as Sustainability Impact Assessment, Integrated Assessment and Regulatory Impact Assessment. Whereas these other forms of assessment fulfil the pragmatic need for *ex ante* screening of incremental sectoral policies that are developed within the prevailing policy regime, ISA is conceptualised as a support to longer-term and more strategic policy processes, where the objective is to explore persistent problems of unsustainable development that have a systemic pathology and possible solutions to these. ISA is therefore oriented toward supporting the development of cross-sectoral policies that specifically address sustainable development and at exploring enabling policy regimes and institutional arrangements.

MATISSE Working Papers

Matisse Working Papers are interim reports of project activities that are published in order to illustrate ongoing work and some provisional conclusions, as well as providing the opportunity for discussion of the approaches taken by the project and interim results. This discussion should be both within the project and between project members and the broader scientific and policy communities. Readers are encouraged to contact the authors to discuss the content of MATISSE Working Papers.

Jill Jäger and Paul Weaver

Editors of the MATISSE Working Paper Series

ABSTRACT

As part of a cluster workshop on sustainability of hydrogen transport technologies held in Frankfurt on 21st February 2006, MATISSE researchers conducted break-out discussion groups with, and distributed self-completion questionnaires to, stakeholders in hydrogen transport technology. The break-out group discussions revealed that stakeholders do not hold naïve views about the potential for hydrogen by itself to meet requirements for sustainability within either transport or wider energy systems. Most stakeholders did not equate hydrogen transport technology with sustainable mobility. For *sustainable transport*, stakeholders acknowledged the importance of modal shift and reduced demand (through more public transport use, congestion charging, teleworking, etc.); two groups emphasised a need for societal value change (e.g., away from aspirations to own powerful/luxury cars). Furthermore, for many (though not all) stakeholders the future involves hydrogen technologies co-existing with other transport technologies, e.g., biofuels and hybrid vehicles. Several participants pointed to the risks associated with focussing on one technological solution to the exclusion of possible alternatives. Nevertheless, stakeholders were broadly positive about hydrogen technologies; many pointed to the potential for hydrogen to offer a solution to problems of emissions, energy security and international competition. Participants highlighted a range of requirements that hydrogen - or indeed alternative technological, institutional and behavioural options for sustainable transport/energy systems - must meet to be defined as “sustainable”. These requirements go beyond simply considerations of hydrogen production and supply to include sustainable levels of mobility and societal values that impact on travel choices.

Table of Contents

List of Figures

List of Acronyms

EFI-GTM: European Forestry Institute-Global Trade Model

EPIC: Environmental Policy Integrated Climate

EUFASOM: European Forest and Agricultural Optimisation Model

GEM-E3: General Equilibrium Model Energy/Economy/Environment

GHG: Greenhouse Gazes

IEA: International Energy Agency

MATA: Multilevel Analysis Tool for Agriculture

NEMESIS: New Econometric Model for Environmental and Sustainable Development and Implementation Strategies

SCEES: Central Service of Statistical Enquiries (French Ministry of Agriculture and Fishing)

STICS: Multidisciplinary Simulator for Standard Cultures

A NOVEL HYBRID ARCHITECTURE FOR AGRICULTURE AND LAND USE IN AN INTEGRATED MODELING FRAMEWORK

1 Introduction

Currently skyrocketing food prices are a growing concern for governments and populations even in developed countries as underlined by the IMF and the World Bank. These tensions in food markets are due not only to conjectural causes; over the long run indeed, both the increasing demand for biofuels in order to make up for the decline of fossil fuels reserves and uncontrolled urban development entailing great pressure on cultivated lands modify the role of agriculture and the amount of its production dedicated to food. The necessity of controlling net greenhouse gas (GHG) emissions to the atmosphere complicates the matter, since biofuels have been proposed for a long time as a candidate for facilitating transitions towards a carbon-free energy systems (IPCC 1995), even though the amount of net carbon savings when used as a substitute for fossil fuels remains controversial (Stockholm Institute report for Greenpeace International 1993).

Hence there is a need to understand better the relations between land use, energy production (oil, gas, biofuels) and climate change. This poses the challenge of organizing a consistent dialogue between two fields of knowledge that have been historically disconnected. Energy and agriculture experts belong to different "clubs" and publish in different types of journals. Both are interested in the long-term balance between supply and human needs, but they do not have the same attitude about the temporal and spatial scale of economic analysis. Energy economists are used to considering very long time horizons, because of the capital intensity and lifetime of infrastructure, whereas agricultural economists focus more on the short- and medium-term functioning of agricultural markets; the former accept rather easily to conduct analysis at a rather high level of aggregation, which the latter are reluctant to do. The response to this challenge of a common language has to be made in a context where the general equilibrium effects matter as much as the sector-specific parameters and where it is unsure that conventional computable general equilibrium models are suited to capture the transition problems in which a major part of sustainability issues lie.

This paper describes work carried out in the MATISSE project, which attempts to respond to these challenges by exploring, the potential of a novel modeling architecture composed of a hybrid macroeconomic model (IMACLIM), a model of agricultural activities (AGROPOL) and a model of land-use (Nexus). This modeling structure is meant to cope with issues related to land-use competition and to comparing alternative allocations of land between food production, carbon sequestration and bio-energy.

The paper describes this structure, presents its overall rationale and discusses the problems that have to be solved before delivering a tool capable to support very controversial policy debates in this area. In other words, this paper can be read as a presentation of a specific modeling strategy, and of the current state of development of a novel modeling tool, one first application of which has been conducted in WP4 of the MATISSE project to provide insights about the large-scale development of Brazilian biofuels in the context of a global policy aiming at a 450 ppm CO2-equivalent stabilization target. It can also be read as showing a blueprint for any attempt to deliver relevant tools to support both an interdisciplinary dialogue and science-policy dialogue.

This working paper is structured as follows. Section one describes the rationale of the IMACLIM-R framework. Section two presents the structure of the nexus land use and AGROPOL models developed during the MATISSE project.

2 A hybrid approach to capture transition issues towards sustainable development

2.1 Rationale of the IMACLIM-R modeling blueprint

The overall rationale of IMACLIM-R stems from the necessity to understand better, amongst the drivers of baseline and policy scenarios, the relative role of *(i) technical parameters* in the supply side and in the end-use equipment, *(ii) structural changes* in the final demand for goods and services (dematerialization of growth patterns), *(iii) micro- and macroeconomic* behavioral parameters in opened economies. This is indeed critical to capture the mechanisms at play in transforming a given environmental alteration into an economic cost and in widening (or narrowing) margins of freedom for mitigation or adaptation. The specific way through which IMACLIM-R reaches this objective derives from a twofold diagnosis:

- The recognition that endogenizing technical change to capture policy-induced transformation of technical systems should be broadened to the endogenization of *structural* change. As noted by Solow (1990), the rate and direction of technical progress depend not only on the efficiency of physical capital on the supply side but also on the structure of final households' demand. Ultimately they depend upon the interplay between consumption styles, technologies and localization patterns. The point is that drastic departures from currents trends possibly required by sustainability targets cannot but alter the very functioning of the macroeconomic growth engine.
- Although computable general equilibrium models represented a great progress in capturing economic interdependences that are critical for the environment-economy interface, their limitation is in the study of equilibrated growth pathways, often under perfect foresight assumptions, whereas sustainability challenges include long-term risks. The existence of sustainability challenges is intrinsically rooted in the existence of both non-optimal baseline scenarios and collectively myopic conduct due to controversies about long-term risks. These controversies and the delay in perceiving complete impacts cannot but inhibit their internalization in due time and trigger higher transition costs necessary to adapt to unexpected hazards. This makes it necessary to describe an economy with disequilibrium mechanisms fueled by the interplay between inertia, imperfect foresights and 'routine' behaviors. For instance, an economy with structural debt or unemployment and subject to volatile energy prices will not react in the same way to environmental shocks or policy intervention as an economy situated on a steady state growth pathway.

2.1.1 A Dual Vision of the Economy: an easier dialogue between engineers, economic modelers and social scientists

IMACLIM-R is based on an explicit description of the economy both in money metric values and in physical quantities linked by a price vector[1]. The existence of explicit physical (and not only surrogate) variables is based on the Arrow-Debreu axiomatic. In this context, it provides a dual vision of the economy allowing one to check whether the projected economy is supported by a realistic technical background and, conversely, whether the projected technical system corresponds to realistic economic flows and consistent sets of relative prices. It does so because its physical variables allow a rigorous incorporation of sector-based information about how final demand and technical systems are transformed by economic incentives, especially for very large departures from the reference scenario. This information encompasses (i) engineering- based analysis about economies of scale, learning-by-

[1] For the very subject of climate change mitigation, which implies the necessity to account for physical energy flows, modellers use so-called 'hybrid matrices' including consistent economic input-output tables and physical energy balances (see Sands et al., 2005). In IMACLIM-R we aim at extending physical accounting to other non-energy relevant sectors such as transportation (passenger-kilometres, ton-kilometres) or industry (tons of steel, aluminium, cement).

doing mechanisms and saturations in efficiency progress (ii) expert views about the impact of incentive systems, market or institutional imperfections and the bounded rationality of economic behaviors.

One major specificity of this dual description of the economy is that it no longer uses the conventional KLE or KLEM production functions which, after Berndt and Wood (1975) and Jorgenson (1981), were assumed to mimic the set of available techniques and the technical constraints impinging on an economy. Regardless of questions about their empirical robustness[2], their main limit, when representing technology, is that they resort to the Sheppard's lemma[3] to reveal 'real' production functions, after calibration on cost-shares data. And yet, the domain within which this systematic use of the envelope theorem provides a robust approximation of real technical sets is limited by (i) the assumption that economic data, at each point of time, result from an optimal response to the current price vector[4] and (ii) the lack of technical realism of constant elasticities over the entire space of relative prices, production levels and time horizons under examination in sustainability issues[5]. Even more important, the use of such production functions prevents one from addressing the path-dependency of technical change.

The solution adopted in Imaclim-R is based on the 'belief' that it is almost impossible to find tractable functions with mathematical properties suited to cover large departures from reference equilibrium over one century and flexible enough to encompass different scenarios of structural change resulting from the interplay between consumption styles, technologies and localization patterns (Hourcade, 1993). Instead, the production functions at each date and their transformation between t and t+n are derived from a recursive structure that allows a systematic exchange of information between:

- An annual static equilibrium module, in which the equipment stock is fixed and in which the only technical flexibility is the utilization rate of this equipment. Solving this equilibrium at *t* provides a snapshot of the economy at this date: a set of relative prices, levels of output, physical flows, profitability rates for each sector and allocation of investments among sectors;
- Dynamic modules, including demography, capital dynamics and sector-specific, reduced forms of technology-rich models, which take into account the economic values of the previous static equilibria, compute the reaction of technical systems and send back this information to the static module in the form of new coefficients for calculating the equilibrium at *t+1*.

Each year, technical choices for new equipment are flexible; they modify at the margin the factors and overall productivity embodied in the existing equipment that result from past technical choices. This general putty-clay[6] assumption is critical to represent the inertia in technical systems and how the economy adapts not only to the level and direction of economic signals but also to their volatility.

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[2] Having assessed one thousand econometric works on the capital-energy substitution, Frondel and Schmidt conclude that "*inferences obtained from previous empirical analyses appear to be largely an artefact of cost shares and have little to do with statistical inference about technology relationship*" (Frondel and Schmidt, 2002, p.72). This comes back to the Solow's warning that this '*wrinkle' is acceptable only at an aggregate level (for specific purposes) and implies to be cautious about the interpretation of the macroeconomic productions functions as referring to a specific technical content'* (Solow, 1988, p. 313) .

[3] Sheppard's (1953) lemma states that the first derivative of the cost function with respect to an input price equals to the input.

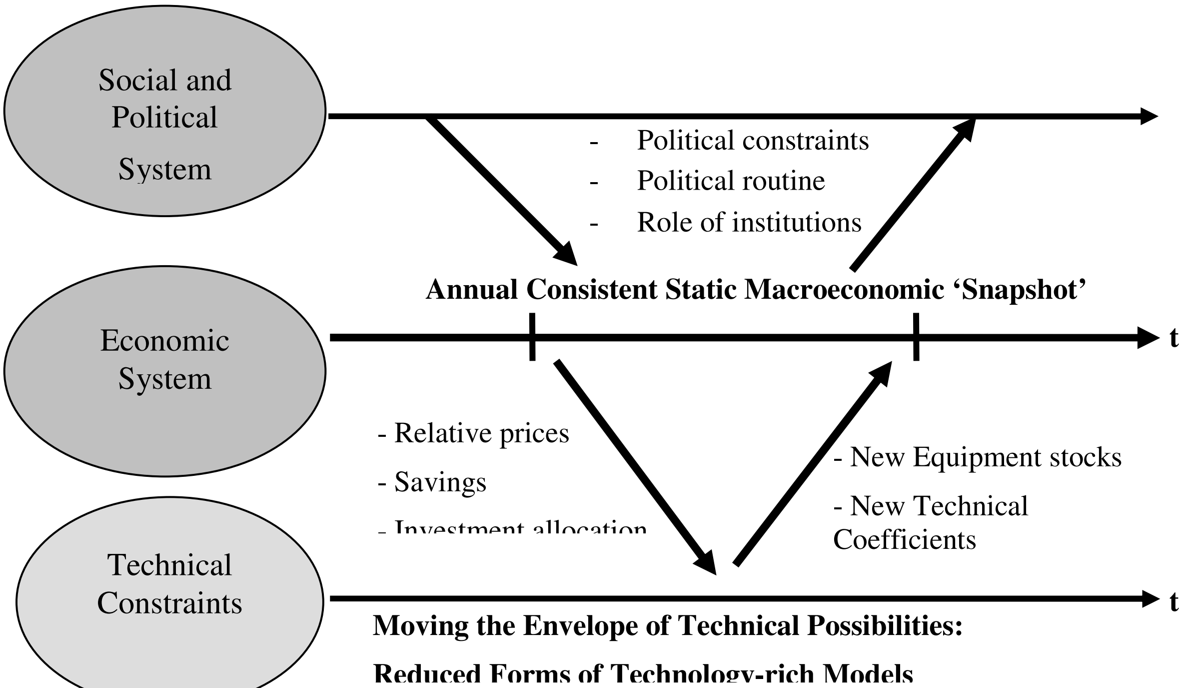
[4] "*Total-factor-productivity calculations require not only that market prices can serve as a rough-and-ready approximation of marginal products, but that aggregation does not hopelessly distort these relationships.*" (Solow, 1988, p. 314)

[5] Babiker, M.H., J.M. Reilly, M. Mayer, R.S. Eckaus, I. Sue Wing and R.C. Hyman (2001). « The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Emissions, Sensitivities and Comparison of Results. Massachusetts Institute of Technology ». *Joint Program on the Science and Policy of Global Change report #71* (http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt71.pdf)

[6] Doing this we neglect the existing possibilities of 'retrofitting' existing capital from one technology to another one, or from one sector to another sector. This can be modified easily in the modules describing capital dynamics. In the current version of the model our choice is to represent somehow the upper bound of inertia.

This modular structure allows the coupling of a rather aggregated static equilibrium with sector-specific, bottom-up reaction functions (transportation, energy, land-use) that capture explicit and tangible drivers of structural and technical changes in a compact way[7]. These reduced forms are calibrated to approximate the response of bottom-up models to a set of economic parameters (price signals, investments). The level of sector aggregation and the compactness of bottom-up modules can thus be adapted depending on the objective of the modeling exercise. One benefit of this modeling strategy is the ability to test the influence of the various assumptions about decision-making routines and expectations (perfect or imperfect foresight, risk aversion…) and to introduce, in an economically consistent manner, lessons from a broad range of social sciences about private and collective behaviors, attitudes and conducts.

Figure 1. Iterative Top-down / Bottom-Up dialogue in IMACLIM-R



2.1.2 Structure of the model

The model uses a recursive dynamic framework[8], where economic pathways are represented through a sequence of static general equilibria, linked by dynamic equations (Figure 1). 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, investment) sent to dynamic equations, which represent population dynamics, fossil fuel resource depletion and technical change. Technical change encompasses overall labor productivity and technical coefficients and results in a new production frontier used to compute the subsequent equilibrium.

This approach was developed in an effort to address four interrelated challenges:

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[7] Building these 'compact' bottom-up reaction functions avoids the daunting and perhaps useless task of building general equilibrium structures with as many product categories as in engineering-based descriptions of the energy systems.

[8] Similar to the option followed by EPPA (Paltsev et al., 2005 for the last version) or SGM (Edmonds et al., 1993) for instance.

i) to incorporate some of the factors that drive economic growth, rather than defining growth rates through entirely exogenous assumptions;

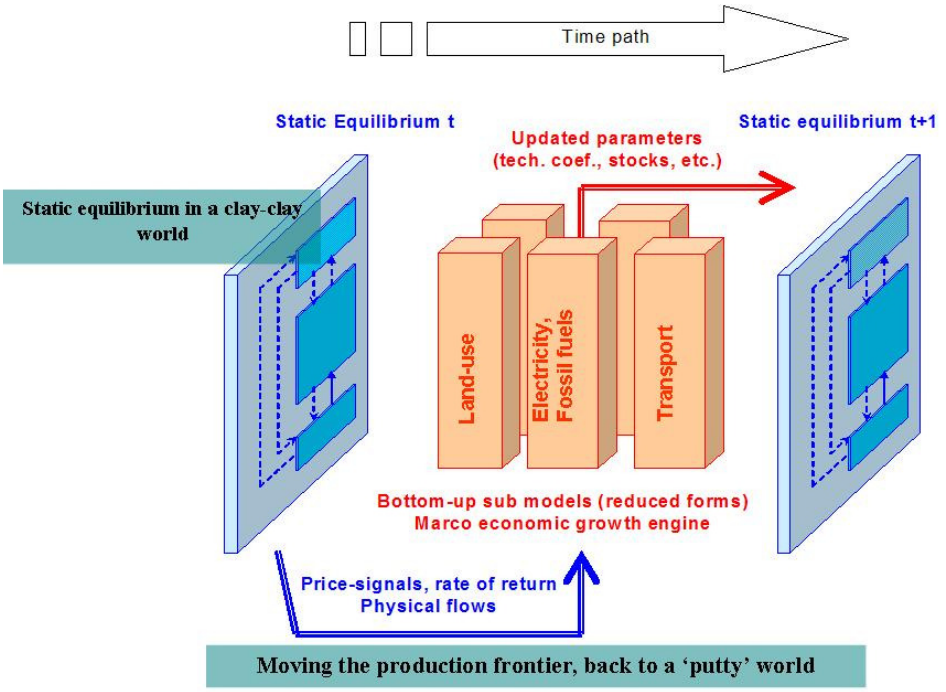
ii) to use in a consistent manner bottom-up expertise about technical change;

iii) to allow for the description of imperfect foresight (about future relative prices, final demand and profitability) and of possible decision routines[9] in infrastructure sectors;

iv) to capture possible transition costs towards long-run equilibria, transition costs that may result from the interplay between non-perfect foresight and the inertia of technical systems

The framework also allows one to a) represent baseline scenarios which can have a non-optimal use of production factors (structural unemployment, excess capacity or capacity shortages[10]) and b) account for the fact that economies adapt to climate targets within the constraints imposed by past decisions, including transaction costs of changing domestic social contracts. The model incorporates mechanisms driving the economy back to stabilized trajectories, which are reached if steady long-term signals are given to the agents (carbon and oil prices) and when the influence of inertia progressively recedes.

Figure 2. The recursive dynamic framework of IMACLIM-R



[9] The notion of decision routines encompasses here seemingly non-optimal choices due to the influence of institutional contexts and/or the incorporation of non-economic objectives (equity, security) in public decisions.

[10] Picturing non-optimal baselines and policies is important in the context of developing countries, since underdevelopment is the product of institutional and market failures (for that reason current work at CIRED aims to include public indebtedness in long-term simulations). It is also important for developed countries; for example the 4% GDP loss predicted in some studies as a cost of Kyoto target for the US relied specifically on the assumption of non-optimal responses (IPCC, TAR, WGIII).

In this modeling system, all flows are tracked at each point in time by a double accounting in both money metric values and in physical quantities, the two being linked by relative prices[11]. This hybrid accounting is used to by-pass difficulties linked to the representation of capital in usual production functions: at a given point, the model accounts for the available physical capacities of production and describes the financial flows serving to replace and expand them (see 3.2. below). It is worth noting that, in addition to facilitating the tracking of the sources of GHG emissions and of the dipping into fossil fuel resources, this methodology facilitates a transparent incorporation through physical, technical coefficients of bottom-up information regarding (i) the technical saturations of efficiency gains in energy and transportation equipments at a given time horizon and (ii) how the technical characteristics of energy (and transportation) systems react to relative price variations.

2.2 Summary of the structure of the model

IMACLIM-R is a multi-sector multi-region recursive growth model projecting, on a yearly basis, the world economy up to 2100. It is run for five regions (the four SRES regions – OECD90, REF, ASIA, ALM[12] – from which we set apart the OPEC region), 12 economic sectors (coal, crude oil, natural gas, oil products, electricity, construction, composite goods, air transport, sea transport, terrestrial transport, agriculture) and two transport modes auto-produced by households (personal vehicles and non-motorized transportation).

2.2.1 Static equilibrium under a given production frontier

Each *static equilibrium* is Walrasian in nature: it is characterized by annual flows of goods and money and a set of relative prices as they result from supply and demand behaviors, investment decisions, private and public income budget constraints and clearance conditions for international and national markets. The calibration of the static equilibrium at the benchmark year (2001) is based on data from the following sources: social accounting matrices from the GTAP Database Version 5; IEA/OECD physical database for energy, and data from Schäfer and Victor (2000) and the *World Road Statistics database* for transportation. The following is assumed for the current period, in order to solve for subsequent periods:

(i) Producers are constrained by fixed capacities (the depreciated sum of previous vintages) and the technical characteristics of the equipment stock that result from past decisions. This comes to a putty-clay assumption[13]. Hence, the variables of the model are prices p, wages w and utilization rate linked to the level of output (*UR*). Average production costs thus derive from fixed input-output coefficients IC_j, a fixed labor intensity l, and a static diminishing return factor Ω^{UR} which is a function of a flexible capacity utilization rate. A constant mark-up π is added to the mean cost[14]. For primary energy sectors, the mark-up increases as a function of cumulated production, in order to capture the scarcity rent in the long-run.

$$p = \sum_j p_j^{IC} \cdot IC_j + \left(\Omega^{UR} \cdot w\right) \cdot l + \pi \cdot p \quad (1)$$

with $$UR = \frac{Q}{Cap} \quad (2)$$

Equation (1) in fact represents the *inverse supply curve* of each sector, since it shows how the representative producer decides its level of output Q $(Q<Cap)$ as a function of all prices and wages.

[11] The flows of the five energy goods are expressed in Mtep; final consumption of transportation is indexed in terms of passenger-kilometers; housing area is tracked in terms of square-meters built.
[12] See (IPCC, SRES, 2000) or http://www.grida.no/climate/ipcc/emission/149.htm for a full description of these regions.
[13] This means that technical choices are made without inertia for new investments. They are then encapsulated into the capital stocks and cannot be modified.
[14] Such a constant markup corresponds to a profit-maximizing decision of producers when the diminsihing return factor follows an exponential function of utilization rate.

The desired level of output in each sector implies a labor demand $l \cdot Q$. The difference between total labor demand across all sectors and the current labor force[15] is unemployment. The level of unemployment has an impact on real wages through regional wage curves: wages tend to infinity as unemployment disappears and they tend to zero as unemployment rate tends to one. The calibration of these wage curves is based on Blanchflower and Oswald (1995).

(ii) *Consumers' final demand* is derived by solving the utility maximization problem for a representative consumer:

$$MaxU = \prod_{\substack{goods\ i \\ (composite, \\ construction)}} \left(C_i - bn_i\right)^{\xi} \cdot \left(A_{\text{agriculture}} - bn_{\text{agriculture}}\right)^{\xi_{agriculture}} \left(S_{\text{housing}} - bn_{\text{housing}}\right)^{\xi_{\text{housing}}} \cdot \left(S_{\text{mobility}} - bn_{mobility}\right)^{\xi_{\text{mobility}}} \quad (3)$$

with $S_{mobility} = CES\left(pkm_{\text{air}}, pkm_{\text{public}}, pkm_{\text{cars}}, pkm_{\text{non motorized}}\right)$ (4)

In equation (3), *C* represents consumed quantities of composite and construction materials, *A* represents food products, *S* represents services provided by energy and mobility, *bn* corresponds to the basic needs of final consumers for final goods and services and *pkm* represents the physical consumption of each mode of transportation as measured in passenger kilometres.

Note first that energy does not directly enter the utility function; it contributes to welfare through the services it fuels. The demand for these services is driven by private housing and transportation equipment. Energy consumption is then dependent upon the efficiency coefficients characterizing the existing stock of end-use equipment. Second, transportation modes are nested in a single index of mobility defined by equation (4). To account for preferences and spatial heterogeneity of their availability, the different modes of transport are assumed to be imperfect substitutes.

Equation (3) is maximized subject to income and time constraints. Income, defined by equation (5) equates the sum of savings, the energy bill (induced by residential needs and private transportation) and expenditure on other goods and services (including public transportation). Savings follow an exogenous saving rate. The time constraint (6) is derived from empirical findings (Zahavi and Talvitie, 1980) and represents average daily travel time of a household. For a given travel mode, the marginal consumption of time per kilometer is inversely correlated to the congestion which, for a given mobility demand, depends on the availability and efficiency of infrastructure and equipment.

$$Income = S + \sum_{\substack{\text{non-energy} \\ \text{non-transport} \\ \text{goods i}}} \mathrm{p_i} \cdot \mathrm{C_i} + \mathrm{p_{agri}} \cdot \mathrm{C_{agri}} + \left(\sum_{\text{energies Ei}} p_{Ei} \cdot \alpha_{Ei}^{\text{housing}} \cdot stock^{m^2} \right) + \left(p_{public} \cdot pkm_{public} + p_{air} \cdot pkm_{air} + \sum_{\text{Fuels Fi}} \left(pkm_{cars} \cdot \alpha_{Fi}^{cars} \right) \right) \quad (5)$$

$$Tdisp = \sum_{\text{Modes Ti}} \int_0^{\text{pkm}_{\text{Tj}}} \tau_j(u)du \quad (6)$$

Ultimately modal shares and mobility demand that result from utility maximization depend on both travel costs and travel time productivity of the various modes (average km travelled per unit of time). Through this channel, the quantity and cost efficiency of infrastructure stocks and the energy efficiency of vehicles have an impact on mobility demand, as well as the trade-off between mobility and other goods and services.

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[15] Active population follows exogenous trends for each region and incorporate fixed migration flows. These parameters are kept constant between the baseline and policy secenarios.

(iii) *Investment allocation* across regions and sectors is governed by the expectations of future profits. Part of the regional savings are reinvested domestically, the rest being redirected to an international capital pool, which in turn re-allocates them to regions according to the sectors' profitability. Allocation of investments does not, however, equalize the marginal productivity of new investments because investors account for idiosyncratic country-risk[16]. Future profits are imperfectly foreseen, as decision-makers interpret the current economic signals as the best available information about present and future economic conditions. Sub-sector allocation of investments across technologies are treated in the dynamic equations.

(iv) The equilibrium clears *international markets* for goods and capital. A conventional 'Armington' specification[17] (Armington, 1969) is adopted for non-energy goods though energy goods are considered to be homogenous commodities. Their trade rests on specific market shares and real physical account of quantities[18]. Capital and trade balances compensate each other, through variations of all regional prices[19].

The existence of short-term constraints on the physical capital and technical coefficients implies that market clearing is made through modifications to relative prices and sectoral levels of output. The equilibrium is thus second best and allows for capacity shortages, overcapacity and unemployment. The new relative prices impact on profitability rates and investment allocation. Inside each region, investments are converted into new productive capacities through a regional β-matrix[20], which allows for calculating the price of a new unit of production capacity for each sector. The over- or under-employment of factors of production can thus be released across time thanks to these investments and related incorporated technical change.

2.3 From static equilibria to growth dynamics:

As pictured in Figure 2, dynamic equations encompass both the evolution of the production frontier and movement along this frontier (input-output coefficients, sector-specific installed capital, public infrastructures, labor force) and of the constraints impinging upon the consumers' program (income, end-use equipment). They capture the joint effect of the macroeconomic growth engine and technical changes on the supply and demand-side.

The *growth engine* is composed of (i) exogenous demographic trends (UN estimations corrected by migration flows so that populations of low fertility regions are stabilized) and (ii) labor productivity changes (the labor intensity l in equation (1). It is fueled by regional saving rates and investment allocations across sectors. Even though they do not affect long-run growth rates, such as in the Solowian models, short-term adjustments condition output growth on the short and medium term. Productivity can be assumed either to follow an exogenous trend (without ITC) or to be driven by cumulated investment in the composite goods sector (with ITC), accounting for an investment externality on all other sectors. In both cases the parameters are calibrated on historic trajectories (Maddison, 1995) and 'best guess' estimates of long-term trends (Oliveira-Martins et al., 2005). In addition, the β-matrix values are increased to account for the part of productivity gains that comes from capital deepening[21].

Technical change at sector level (intermediate or end-use efficiency gains, costs of new technologies and substitutions between energy sources) are driven by the interplay between changes in relative prices and cumulated investments. Relative prices operate in the same way in both versions of the

[16] 'Country risks' represents the aggregate relative economic attractiveness of regions.
[17] The specification is based on the hypothesis that similar goods in different regions are not perfect substitutes.
[18] Armington specifications do not allow one to sum physical quantities that are imported and produced domestically, since they are supposed to be different kind of goods.
[19] The variation of the regional price index can be interpreted as implicit flexible exchange rates.
[20] With β_{ij} the physical amount of good i that is necessary to build in sector j the capacity to produce one physical unit of good j.
[21] The link beween labor productivity gains and capital deepening is calibrated on historical data gathered by Maddison (1995).

model by affecting choices of both firms and consumers in purchasing new equipment (the resulting new values of their energy and mobility demand being captured in the *following* static equilibrium). The calculation of the production frontier is based on a putty-clay assumption which implies that technologies are embodied in the equipment stocks resulting from the cumulated investment vintages. In the 'without ITC' version, the diffusion of autonomous technical change is thus constrained by the pace of replacement of capital. This creates short-run inertia, which is considered realistic for energy, transportation and heavy industry sectors. With ITC, this pace is also binding with the difference that 'learning-by-doing' and R&D mechanisms are also positively correlated to cumulated investments. It is thus possible to accelerate the efficiency gains in the energy and composite sectors (7) and the decrease of investments costs of carbon-free techniques (8). In addition, changes in relative prices of energy induce efficiency improvements in private cars, end-use equipment and in the composite sector.

IMACLIM-R, in some sense, describes such mechanisms through 'reaction functions', for example, through reduced forms of bottom-up information. It computes the evolution of coefficients of the technical input-output matrix, end-use efficiencies (7) and β-matrixes coefficients (8) as a function of historical investments, as well as variations of relative prices:

- endogenous variations of energy efficiency of production capacities and equipment:

$$\text{Energy Efficiency}^{(t)} = f\left(\sum_{\tau=t_0}^{t} Investments, \Delta p_{energy}^{(t)}\right) \qquad f'_{\Sigma I} > 0,\ f'_{\Delta p} > 0 \qquad (7)$$

- endogenous variations of investment costs for carbon-saving equipment (learning-by-doing and R&D):

$$\beta_{i,j,k}^{(t+1)} = g\left(\sum_{\tau=t_0}^{t} Investments_{k,j}^{(\tau)}\right) \qquad g'_{\Sigma I} < 0 \qquad (8)$$

for any low carbon energy *j* in country *k* and any investment good *i*

Such functions are calibrated on (i) explicit views of technical potentials in the form of asymptotes on energy efficiencies and on the shares of given energy carriers in end-use demand and energy supply, and (ii) on results from bottom-up models. They incorporate technical asymptotes translating expert judgments about the ultimate potentials of each technical bundle[22].

The key feature of the growth engine of IMACLIM-R, if compared with the growth engine of the overwhelming majority of general equilibrium models, is that it introduces an explicit difference between:

- The potential growth of a country or of a region that results from demographic trends, assumptions about the speed and duration of the catch-up of labor productivity of developing countries and about behaviors;
- The real growth at each point in time which results from the interplay between all the sources of friction between the national/regional economy and the rest of the world (technical frictions, lack of competitiveness, excess or under-capacity, trade balance constraints, heterogeneity in savings behaviors, changes in capital flows…)

This gap between the potential and real growth allows any form of transitory disequilibrium due to either policy shocks or unexpected feedbacks of routine behaviour to be represented. On the one hand,

[22] For example, in most of its applications, the response of the energy sector to policy shocks or variations in oil prices is captured by a compact module calibrated on the behaviour of the Poles model. Criqui P., (2001). "POLES: Prospective Outlook on Long-term Energy Systems." , Institut d'Économie et de Politique de l'Énergie, Grenoble, France, 9 pp. http://www.upmf-grenoble.fr/iepe/textes/POLES8p_01.pdf (accessed August 2006)

these disequilibria may last between one to three years; in this case one should not attribute a high predictive value to them and they should serve only to detect mechanisms likely to create short term tensions. On the other hand, they may last between up to twenty years; in this case, even though one should be cautious about their precise timing, they really point to structural problems that should not be discarded and do not appear in conventional smooth growth pathways.

In this sense IMACLIM-R is general equilibrium in nature although the term should be understood in a purely technical way of mass and money flows conservation, not as describing equilibrated growth pathways. It thus could be qualified as a general interdependence model.

3 Integration of agriculture and land-use in IMACLIM, the aggregation gap and beyond

Before the start of the MATISSE project, the IMACLIM-R architecture, designed to represent the linkages between energy and development, encompassed together with reduced forms of bottom-up models of the energy sector (electricity, refining, extraction), compact forms of models representing the major energy consuming sectors (transportation, buildings, cement, steel, aluminum). Agriculture was included in the composite goods.

Representing agriculture and forestry in such a setting poses a specific scale-integration problem for two major reasons:

- First, the production function of agricultural products is very site specific and product specific; whereas the production of steel and cement can be obtained with roughly the same level of efficiency in whatever region (with a plus or minus 30% of difference that does not matter at this stage) and can be aggregated, this is not the case for agricultural products without an in-depth examination of technical itineraries for a rather large set of products, the productivity of these itineraries being very site and climate specific.
- Second, related land-use changes matter as much as technical changes within a given technical itinerary in a specific region. These land-use changes within the agricultural sector (crops, pastures) have a large impact on forests and are in part driven by parameters far beyond the internal dynamics of the agricultural sector (migration and poverty, allocation of poverty rights on land, transportation infrastructures).

We will not review in this paper the great variety of modeling approaches and applications but point out that none of the existing models tackles directly these difficulties. It is then difficult to go further. Either the modeling of local land-use changes is made very realistic in partial equilibrium models like FASOM (Adams et al. 1996; McCarl 2004) but it is difficult to make the model applicable beyond the regional scale. Or general equilibrium models like GTAP Global Trade Analysis Project (Brockmeier 2001) have a high level of aggregation but their regional pertinence is weak. Integrated models like IMAGE (Alcamo et al. 1994) combine an economic analysis of world markets and policies in order to quantify demand and supply of land-intensive commodities, and the actual allocation of land-use to locations based on a geographic analysis. In these models, agricultural production is broken down into different farm types or production systems (in their great variety). However data are not available for all regions and the disaggregation in farm types cannot encompass the heterogeneity of agricultural itineraries.

These limits of current models have deep causes that cannot be removed without a long-term effort. These causes boil down to a scale integration problem that is not solely an aggregation problem (such as, for example, the mathematical problems of an unbiaised aggregation of utility or production function). This is a more fundamental problem of finding the relevant information (about technology, agricultural practices, multiple activity of farms, migration) at a very local scale and of summarizing it at a level that make sense for capturing global change mechanisms without forgetting the local behaviors that matter for policy-making.

This is why we built a modeling architecture coupling a land-use model (Nexus land-use) and a new agricultural model (AGROPOL), that are designed in such a way that they can be run with "poor information" to represent stylized mechanisms and can, in parallel, serve as the structure of a database facilitating the dialogue with local experts and agronomists in order to launch a process of improvement of information formatted in such a way that it can be immediately integrated in a modeling structure encompassing energy, industry and macro-economic mechanisms.

Obviously completing this process demands a long-term endeavor and policy-making cannot wait for the end of this endeavor. In the meantime, it is tempting to produce model results based on 'back-of-the-envelope' estimates of the missing coefficients. This is acceptable for rather compact models used to conduct numerical experiments, the results of which can be controlled analytically or by sensitivity tests. This is no longer the case when thousands of coefficients are involved and when more than 90% of them are missing. In this case, to provide figures anyway masks our ignorance and creates a feeling of distrust about numerical modeling, paving the way to policy formation totally driven by the convincing power of pure rhetorical arguments.

This is why, after describing the structure of Nexus-Land-Use and AGROPOL, we propose an interim structure that can be used to deliver robust and controllable insights on some important policy questions[23].

3.1 The NEXUS-land-use model

Integrating land use properties into the model is necessary to assess the complex relations between land allocation and the impact on the environment (carbon emissions, pollution…). In return, the global economy has a direct influence on the arbitration amongst different types of land management (agriculture, urban areas…).

3.1.1 Basic principles: representation, competition for lands and rents

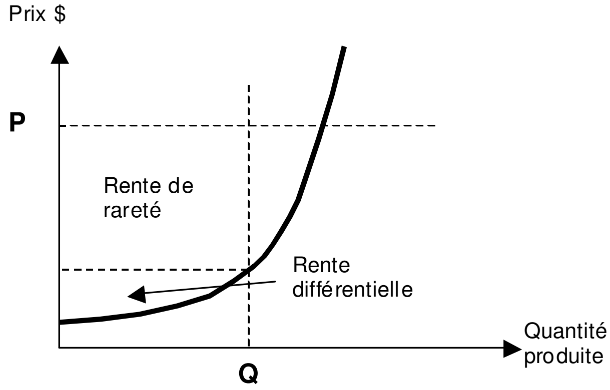
The Nexus-land-use model aims at assessing land-use trajectories consistent with the medium to long term evolution both of needs for food production and of production capacities worldwide in the agricultural and forestry sector. Nexus-land-use describes interactively the evolution of agricultural (crops and pastures) and forested land.

Three of the main characteristics of lands are immobility (which forces one to model land and localization), heterogeneity (which forces one to represent qualitative differences), and scarcity (limited amount of lands, which forces one to represent the boundaries of the land-use system). Aspects linked to variable quality of lands are taken into account in Ricardo's rent theory, and aspects with regard to spatialization (urban growth) refer to von Thünen localisation rents (e.g as a function of the distance to an urban center). The justification of the appearance of the differential revenues is presented initially by Ricardo.

The quality of land is our exogenous data, and the relative net surpluses of the various land-uses guide the optimal land allocation choice to different uses. The scarcity rent is not zero when the price of the production is higher than the marginal cost of production. The differential rent is the surplus that emanates strictly from the production factor remaining, i.e. the land. The sum of these two rents is covered by the concept of resource rent, as Figure 3 indicates.

23 For an illustration see the Brazilian case in the working paper *the Biofuels and the environment-development Gordian knot. Insights on the Brazilian exception*

Figure 3. Marginal cost curve and differential rent and scarcity rents.



The model of allowance in Ricardo is consolidated analytically and empirically by Lichtenberg (1989) [24] through a study related to the role of the differential land quality in agricultural crop choices and technological choices. Indeed, it concludes that there is a strong tendency to land-use specialization according to land quality: each crop type is associated only to one land quality type, on which this culture is the most advantageous. For example, certain cultures on which the outputs are very dependent on water (corn, soya) can grow only on lands of high quality. And technologies which increase soil quality, such as irrigation, can be viable only on specific lands (not sandy or not affected by erosion). Finally, Lichtenberg proposes to consider land quality as a vector of attributes that affect agricultural productivity, these attributes being the fertility, the water storage capacity, the topography and the soil depth. These attributes condition land is allocated across competing uses by producers. Furthermore, the price of consumed cereals (for example) is equal to the marginal cost of growing this commodity increased by the land rent defined per unit of the consumed cereal (Fig 3).

In its present version, Nexus-land-use was run on yield and cost data from AGROPOL, given data originally taken from FAO for agricultural areas in the base year, and GTAP for production costs and revenues for the base year, for 62 world regions. The cereal sector is composed of six separated sectors (rice, wheat, other grains, fruits and vegetables, oil crops, sugar crops), in order to take into account also industrial and energy crops, to enlarge the feed/food debate towards other uses like energy and non-alimentary uses (Fig. 4). The forestry part will not be treated in this paper, as it will be produced by the EFI-GTM model and entered exogenously into NEXUS. The bio-energy part is more difficult to handle and constitutes one innovation of our model.

Biomass appears (i) as a potential by-product of several land-uses, such as cane with sugar and beet, oilseeds, and some cereals, or (ii) as a dedicated culture (e.g. miscanthus, sugar cane for ethanol and bagasse etc...).

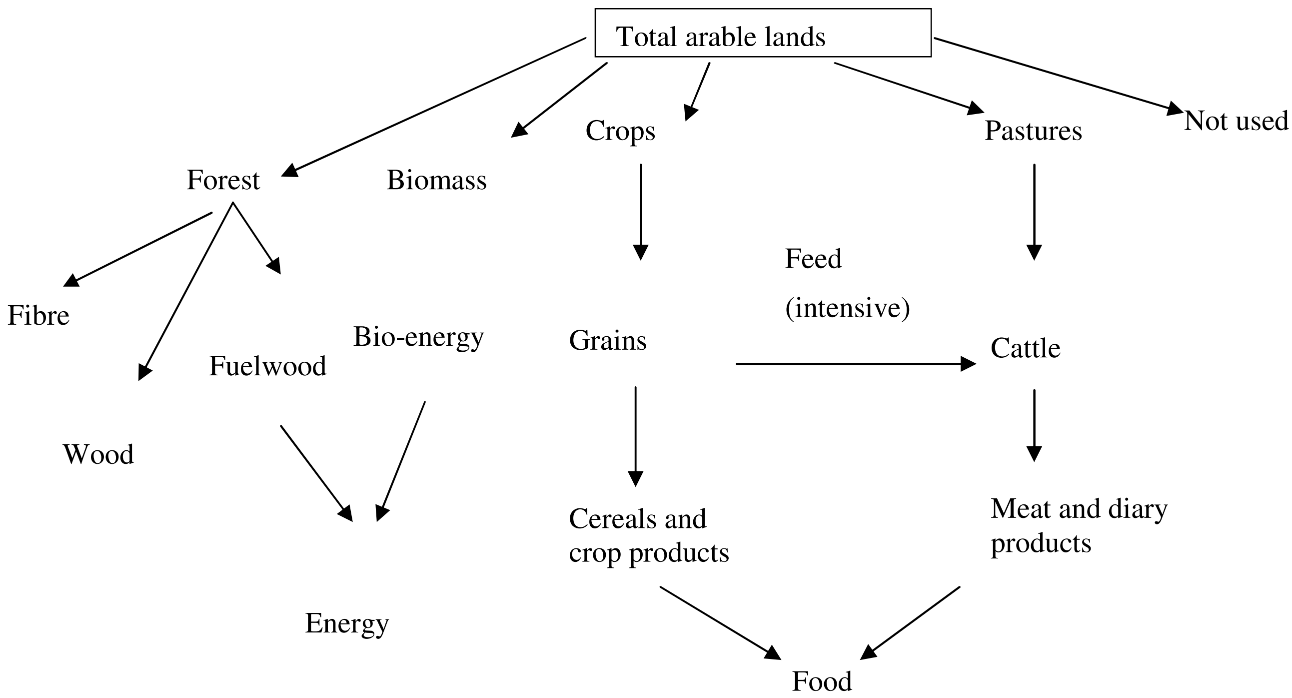
In a first step, we modeled only generic bio-energy crops for bio-fuel (e.g. alcohol of beet and cane, ester of colza) or electricity production with a conversion rate into final product (e.g. tons towards MBTU or Mtoe), the latter valorized in the markets (not endogenously computed like prices for agricultural commodities in NEXUS) but according to an exogenous price, linked to the price of gasoline or electricity. In a second step, we will introduce the potential valorization of co-products (agricultural waste, straws...) that would make the agro-alimentary and energy production complementary.

Consequently, in the present state of NEXUS, cereals may be converted to three kinds of end products: Food, Feed and Biomass. A question difficult to treat is that of the technical progress within the bio-energy sector as compared to the traditional and alternative energy sectors. Under different hypotheses

[24]Lichtenberg, 1989, «Land quality, Irrigation Development, and Cropping Patterns in the Northern High Plains », In *The Economics of Land Use*, edited by Parks and Hardie.

regarding the emergence of new low-cost alternative sources of energy (new generation of nuclear power, hydrogen), the bio-fuels sector could evolve to represent a significant percentage of the energy supply and demand, thus having a substantial impact on land-use worldwide, or on the contrary, bio-energy could represent a less advantageous option if land costs rise due to competition for agricultural or other uses (recreational), and if alternative sources of energy penetrate at lower cost. The next section details the model specifications and equations.

Figure 4. A more complete representation of land-use competition with alimentary and non-alimentary outputs



3.1.2 Demand for agricultural products

The demand side is represented by demand functions that capture changes. In this respect, Nexus-Land-use follows an "I = PAT" scheme of the effects of driving forces, which was first described by Ehrlich and Ehrlich and by Commoner (Meyer and Turner 1992). In this approach, I stands for impact, P for population, A for affluence, and T for technology.

Nexus divides each region and country in several "centers" of demand with the notation "k". For a good j, the demand function is defined as follows:

$$D_{jk} = A_{jk} \cdot P_j^{\alpha_{jk}} \cdot Y_k^{\beta_{jk}} \cdot N_k$$

Where:

- D_{jk} is the demand of good j in the center of demand k, expressed in millions of tons
- A_{jk} is a technical coefficient specific to each good
- P_j is the world price of good j in dollars per ton

- Y_k is the GDP per capita (in the center of demand k) in dollars
- N_k is the population in the center of demand k

α_{jk} and β_{jk} are respectively the price and income elasticities of demand of good j.

The final world demand for the final food commodity j is thus $D_j = \sum_k D_{jk}$

3.1.3 From agricultural demand to land use

The supply side of the model consists of products from agriculture and forestry. Land use is disaggregated at different levels: first, agricultural land uses are alternative to forest land uses; second, agricultural land uses are decomposed into croplands, pastures and fallow; third, forest land uses contain planted forests and managed forests. Nexus distinguishes between 3 forest types: planted forest, managed or secondary forest, and sink or primary forest. As our focus is on agriculture, we do not give more detail here on the forestry part of the model. Agricultural land uses contain paddy rice, wheat, cereal grains, vegetable and fruits, oil seeds, sugar cane and sugar beet, plant-based fibers, other crops (all adopted from GTAP 6), plus pasture and fallow.

The production of an agricultural primary output (po), in a production region r , is described by the following equation:

$$Q(po,u,r,t) = L(po,u,r,t) \cdot y(po,u,r,t)$$

Where :

- u refers to the land use category devoted to this production
- r refers to the production region
- $L(po,u,r,t)$ refers to the proportion of the available land in the region r devoted to primary production of po at time t
- $y(po,u,r,t)$ refers to the average yield of po in the region r at time t

Primary crop production is then devoted to human alimentation or used as fodder for livestock. In order to produce final food commodities, the food industry sector proceeds in two stages: first of all, the primary agricultural activity of production, then the industrial activity of transformation. This last operation implies a raw material loss; therefore the quantity of agricultural production is divided by a conversion rate. The case of meat production is similar to industrial transformation, but it can be achieved through two different production systems: intensive through animal feed production, or extensive via the pasture mode.

For the extensive grazing production, the average output in terms of digestible biomass, coming from the region r , denoted by $Q(pastures,r,t)$ amounts to:

$$L(pastures,r,t) \cdot y(pastures,r,t)$$

Then the livestock output from pastures, in terms of carcass weight, is:

$$Q(Carcass_a, pastures,r,t) = Q(pastures,r,t) \cdot \lambda_1(pastures,a,r,t)$$

Where a refers to the animal type and λ_1 is the feed ratio (in tons of carcass weight per ton of dry matter). For the intensive production system, the equations are similar, but with quantities, yields and feed ratios corresponding to feed crops.

Once the livestock output is obtained, the carcass weight is considered as an input for the meat and dairy transformation process, which is identical for both production systems. The final meat and dairy products are obtained by the use of a transformation coefficient.

Costs are obtained using constant average production costs by region, final output, and at a given time.

3.1.4 Nexus regions

Nexus uses a world disaggregation in 87 GTAP regions (version 6). These regions are then reaggregated in two different ways. This aggregation choice was imposed by the availability of data and parameters for the model. Nexus thus uses 3 different kinds of disaggregation:

- Disaggregation in 87 regions from GTAP 6
- Nexus-type disaggregation in 7 regions, which represent the demand centers: East Asia, Industrialized Countries, Latin America, North Africa, Sub-Saharan Africa, South Asia and Transition Countries;
- Disaggregation in 14 regions stemming from Sohngen et al. (1999), which determine the dynamics of forest growth of the model: South East Asia, Central Asia, South Central America, Africa, Europe, China, South Korea, Russia, India, Australia, Canada, Japan, New Zealand, and the United States.

3.2 Modeling agricultural activities and technical itineraries

3.2.1 AGROPOL: a two-step tool to represent technical itineraries

In contrast to the representation of technology in the bottom-up models of the energy sector, the representation of technologies in the agricultural sectors faces both a huge scale- integration problem and the problem of integrating many varied production techniques. We confront, on the one hand, the question of the site-specific parameters of the productivity of each technical route and, on the other hand, the question of how this productivity is also sensitive to the product mix.

This type of aggregation problem is best approached through a dialogue with agronomists to determine the minimal typology that can be supported by reasonable data for modelling exercises and which does not introduce bias that is too misleading from an agronomist viewpoint. It is important to avoid the trap of the one-to-one scale map.

Such an effort was carried out by Deybe and Fallot (2003) to process available information on agricultural practices and constraints affecting production, in order to determine the sector's response to a carbon price in a static economic optimisation model that runs for a set of 40 world sub-regions. The model Agripol[25] represents the agricultural sector as one income-maximizing economic agent in a set of world regions (40 in the original version) encompassing the world agriculture. This effort defined eight main product specializations (cattle-milk; cattle-meat; rice; other cereals; pulses and oil seeds; tubers and root-crops; frontier pastoral areas; bio-fuels) and four advanced production systems with different technical content and response functions (intermediate consumptions of factors, labour, productivity, etc...).

As Agripol is designed to include more than one single production system, it requires data on variable and fixed costs, on yields (per crop and animal production, including for by-products) and on GHG emission (CH_4, N_2O and CO_2) for each production system. Therefore, in practical terms, this requires one to overcome the crucial challenge of identifying and parameterizing, for each agricultural activity, a set of various alternative technical packages that are contrasted enough to have a meaningful impact on the environment and on the agricultural systems, but are not too numerous to be manageable. In total, there are no less than 20,000 parameters to be collected worldwide.

[25] Agripol aims at assessing the impact of carbon prices on agricultural activities

Facing difficulties in gathering data, we proposed to re-define the methodology, bringing together the construction of a coherent database-model-indicators architecture, in order to assess land-use scenarios for Europe in an Integrated Sustainability Assessment (ISA) framework (Weaver and Rotmans, 2006; Weaver et al., 2007_). Indeed we link the land-use model to a land-use database that explicitly describes the agro-economic features, production techniques, costs, yields, and GHG emissions, and thus assesses the technical package data through some case studies bearing both on existing and potential technical packages.

This approach led to the following architecture, where a new version of Agripol, called NEXUS, is linked upstream to a technico-economic engineering model AGROPOL, and down-stream to an indicator evaluation model called NEXUS-indicators. In the absence of pre-existing data, we thus propose to proceed in two steps:

- building a data base which could constitute a communication language between modelers and specialists for each technology, product or region; this data base is meant to become a ‘public good’ shared by a large scientific community and requires funding for a long-term effort.
- building an interim tool, capable of working with a lesser degree of detailed numerical information but that can incorporate informal information from various sources together with geographical data in order to get some robust orders of magnitude about the implications of the food-energy nexus.

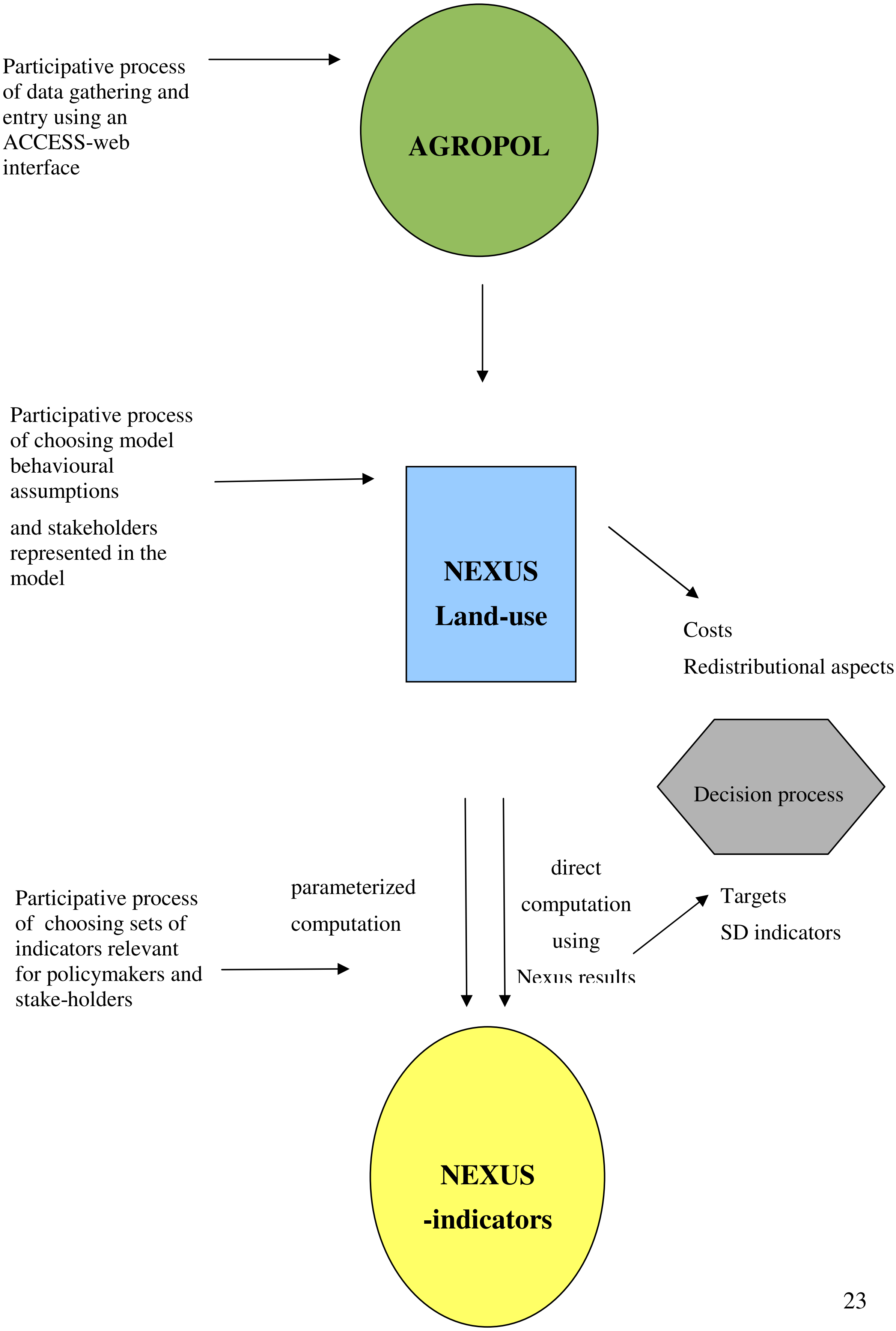
We named « AGROPOL » the tool aiming at collecting and processing data for the new land-use dynamics model, renamed NEXUS model[26]. Its general objective is to assess and document in a standardized way the costs and environmental externalities of the existing and potential techno-economic packages. These data serve for calibrating the NEXUS model and to parameterizing the evolution of exogenous coefficients (not endogenous to NEXUS) in the production and demand of agricultural products. We chose the Access[27] software to complete this tool[28]. Six main functions have been identified for this new tool (AGROPOL), as indicated in Figure 5.

[26] We chose the NEXUS name because it will be part of a suite of models dealing with the modeling of dynamics of other sectors of the economy worldwide (Nexus-transport, Nexus-energy, Nexus-residential), all linked to the IMACLIM recursive general equilibrium model in place at CIRED.

[27] The use of the database managing model *Access* allows registering and controlling rigorously the data derived from our own expertise or from exogenous sources. *Access* is widely installed in the scientific community.

[28] Derived from field inquiries or agricultural expert answers or from technically detailed databanks or from mail request to the agricultural operator who is attracted by the hope of getting in return an environmental check-up of the technical practices he has provided.   .

Figure 5. Overall AGROPOL-NEXUS architecture to substitute the AGRIPOL model in order to perform ISA for the land-use study in Europe



3.2.2 Stakeholders interaction

In the building of the NEXUS-land-use model, at this stage data from FAO, GTAP, FAPRI , World Bank, and OECD have been used, and these data are going to be disaggregated and refined later on with AGROPOL, potentially using data from, for example, ARVALIS ("Institut du vegetal"), SCEES and for which demands have been studied.

The construction of AGROPOL proceeds through interaction with actors in the agricultural sectors, who can submit data to the database. Consulting experts may also help fill the database, especially for non-EU regions (CIRAD experts for agriculture in developing countries, MATA models in developing countries), together with other knowledge resources (farmers, experts, observatories…).

3.2.3 Referencing and typing of technical data on practices

The following data are to be gathered for the AGROPOL interface:

- the main features of each agro-economic area where the activity to be entered take place (country, types of soil, climate , topography, farm size, etc …)
- the productive factor types and quantities (equipment, human labour, animal power, inputs) combined for a technical practice (that is a sequence of operations for months or years) and the resulting yields (quantities of the main product and its by-products, of mixed crops, of a crop rotation or a livestock unit, etc.).

The collected information in AGROPOL serves two goals

- one main goal which is to feed data into NEXUS.
- one associated goal of documentation of agricultural practices in a manner that is sufficiently precise, simple and condensed for the data to be used later: i.e., collecting and bringing together dispersed information, as one first step towards building a unique databank on world agriculture (technical packages and their impacts).

3.2.4 Standardized assessment of costs and margins

By always using the same defining formulas, factors and products, the tool will document systematically :

- the fixed costs (depreciation, interest on fixed capital, taxes, insurance, …),
- the variable costs (human and animal labour, seeds or seedlings, organic and chemical fertilizing, plant protection products, irrigation, fuel and electricity, repair and maintenance)
- and the (gross or net) margins from diverse technical practices.

This modelling can be based on exogenous prices (imported into AGROPOL from existing databanks, referring in some cases to country prices). But the option of modifying such reference prices (such as an energy price, a commodity price, wage, interest rate, etc…) remains open, which is conducive to a significant modification of the cost and margin analysis of alternative technical packages in the parameterization of NEXUS and within the NEXUS simulation.

3.2.5 Interfacing with biological and biophysical models

AGROPOL could ultimately be linked with biological and biophysical models, in order to be able to extrapolate a few observed cases of a developing technical option to other not-yet-observable agro-economic contexts. Indeed, a future land-use scenario could be built upon trajectories and land-uses very different from the existing ones at a particular place. Hence production potentials and costs for each competing practice have to be documented at each location, and these characteristics have to be entered into NEXUS.

Techno-economic data are context-dependent and location-dependent. In the absence of such data for potential practices, cost parameters might be extrapolated from plots or locations where these packages are found, but production parameters (yields) at the specified location would differ and could be assessed through modelling using biophysical models. Candidate models to update yields resulting from climate, soil, fertilizer or irrigation intensity level, tillage operation, rotations, are EPIC or the STICS model from INRA.

3.2.6 Interfacing with a standardized assessment of environmental externalities (NEXUS-indicators)

The most innovative and complex function of the AGROPOL tool will be the calculation of the GHG emission and sinks, and others externalities, summarized as indicators. This part of the database is rather an upstream part (after evaluations of land-use scenarios using the coupled AGROPOL and NEXUS models), so that we decided to separate it formally from the "parameter" database, defining thus a NEXUS-indicators assessment scheme. For GHG emissions, NEXUS-indicators will implement the methodology tier1 and/or tier2 of the IPCC . Even if NEXUS-indicators were much more detailed than the current regional inventories (derived from country inventories), it would compute environmental externalities (especially the emission/storage of GHG) by using methods that do not use too many data, much less than the existing biophysical models and possibly without increasing uncertainty.

By extension, Nexus-indicators can provide a framework for analyzing the life cycle data of a number of agricultural products, in terms of energy consumption or net GHG production at different producing stages (motorization, fertilizer use etc...).

3.2.7 Interfacing with NEXUS-land-use economic model

AGROPOL does not go beyond being an engineering model that does not endogenize the supply and demand effects. This part is left to the NEXUS model.

Thus AGROPOL, by documenting how each production and technical package has contrasting costs and externalities, is used to parameterize simulations and scenarios made with NEXUS (model of agricultural sectors in 62 world regions). NEXUS in turn could be run in parallel or in interaction with other sectoral models like EFI-GTM (within MATISSE, or more sophisticated models such as PRIMES , GEM-E3 , NEMESIS , or IMACLIM-R, which are general equilibrium multi-sectoral models.

Other agricultural models (alternatives to NEXUS) could be run jointly with AGROPOL, such as EUFASOM (a dynamic partial equilibrium sectoral model) or AROPAJ (a static sectoral model) specifically for the EU. But, because our emphasis in the developed scenarios will be on the sustainability of EU-land-use practices in interaction with an international context, the NEXUS model is more appropriate (since it models EU and other regions of the world interactively) than regional models where boundaries conditions (external demand, external offer) are prescribed.

NEXUS will thus be able to simulate and compare, with the homogeneous sets of parameters of AGROPOL (costs of factors, products and co-products, interest and discount rates, technical coefficients, etc), the productive (biomass), economic (income), social (employment), and environmental (GHG, water) advantages of various goods and of various ways to produce them in the EU and comparatively and interactively in other regions of the world.

3.3 An interim solution able to clarify burning controversies: competition for land, dynamics of land rents and the food-energy nexus

Completing the AGROPOL database in order to develop a model of choice of techniques and products in the agricultural sector is not a simple problem of statistics. Bridging the aggregation gap between 'grassroot' locally specific information and the relevant input parameters for integrated models will demand a long-standing collaborative effort of research teams in both developed and developing countries. Meanwhile, the land-use competition between food production, energy production and carbon sequestration will trigger probably harsh policy debates and the challenge is what modeling approach can be used to put some rationale into discussions without pretending to deliver uncontroversial answers.

We propose an answer in the form of a interim tool, based on the Imaclim-R model, in which the reduced form of the fully developed Nexus-AGROPOL architecture is replaced by the summing up of technical, economical and social expert advice within a framework securing their consistency. To put it in other way, instead of calibrating the key response functions of IMACLIM-R regarding agriculture to the behavior of a sector-based model, we try and use in a consistent fashion all the available, although often heteroclite, information, if this information is proven to be both relevant and of reasonable quality. This means also that the model is open to the huge diversity of alternative expert judgments; beyond sensitivity tests this enables the clarification of the real policy implications of pending controversies.

Without land constraints, the agricultural sector functions in IMACLIM-R as the other sectors: when the demand for food (or biofuels) becomes higher than supply (in fact when the rate of utilization of production capacities is higher than 80% to 90% depending on sectors), selling prices and profit margins increase, which trigger a new wave of investments. The introduction of land constraints in IMACLIM is made through treating land as a resource and agricultural land as a production capacity (upstream of the transformation sectors i.e. food processing and biofuel refining). The question then is to control the speed of the expansion of agricultural land.

Part of this expansion is due to an economic trade-off between various uses, but the cost-benefit equation of this trade-off is far more complex than the cost-benefit ratio of production. The distribution of real estate, migrations triggered by poverty, the direction of transportation infrastructures and also public policies that affect the expansion of the cities enter into the picture. In the absence of a land-use model capable of capturing the interplay between these factors, the procedure retained in IMACLIM-R is as follows:

- geographical analysis of the distribution of quality of agricultural land, of the forest lands that are not to be converted into agricultural lands (for given technological conditions) and, for given meteorological conditions, of the land suitable for crops candidates to produce bio-fuels (sugar-cane for example);
- determination of absolute caps to the allocation of agricultural land to bio-fuel production for a given technological route (here bio-ethanol). This leads to the definition of a total resource potential for biofuel production through this technology;
- calibration, in collaboration with agronomists and using local (incomplete but informative) data on the prices of agricultural land, of the marginal land-productivity curves for both areas not suitable for bio-fuels and for areas suitable for both food and bio-fuel production;
- socio-institutional analysis of the direction of expansion of bio-fuels production; this analysis incorporates the style of valorization of bio-fuels (large versus medium and small farms), the pre-existing and planned refineries and transportation infrastructures;
- determination of a maximum yearly rate of expansion of the land dedicated to bio-fuels on which caps will be placed in IMACLIM-R on the expansion of production capacity of bio-fuels and for the expansion of total agricultural land.

These two caps (on the ultimate potential and on the expansion rates) are the key parameters through which complex and statistically unregistered information can be included. When introduced in the model these caps operate as a “capacity constraint”. When the demand for fuel increases, the additional land dedicated to fuel production leads either to higher food imports or to an extension of cultivated area. Again the capacity cap on this expansion enters into play, and, when the total of cultivated land at one point in time approaches this cap, land rents and food prices both increase. This is the increase in the land-rents, which captures the degree of tensions between food and energy production; if the caps of the transformation rents of pastures and forest into agricultural land are not very binding, then the tension is low and the increase of food prices is low (for example in the Brazilian case).

The last important parameter to determine the tension between food and energy is the increase in the level of intermediate inputs (energy, fertilizers, pesticides; maintenance works, irrigation services) in order to upgrade productivity per hectare. This mechanism also tends to increase the production costs of food production but its other macroeconomic impacts differ, because they are channeled by a transformation in inter-industrial flows and not by a rise in land-rents.

Finally the overall environmental impact of an increase in the production of bio-fuels depends upon: i) the productivity differential between the land converted to fuel production and the pasture land or forest converted to food production, and ii) the surface of pasture or forest necessary to maintain the income level of the farmers to maintain the level of production in cattle or forest products. These substitution rates can be obtained either through econometrically-based relations about the historical rate of transformation between one hectare of crops and hectares of pastures and forests (such studies exist in countries like Brazil) or to use “back-of-the-envelope” indicators based on existing micro-economic data.

The advantage of this latter approach is that it can be applied in a world model despite the weakness of data in many world regions. Its key inputs indeed are robust: the maps of types of agricultural lands, their climatic conditions are well-known; the data about their productivity, although not harmonized, are rich enough, coupled with scattered data on the prices of land to build productivity curves and represent the evolution of the ‘Ricardian rent’. Our experience in the Brazilian case shows that, although fragmented, local knowledge about non-economic parameters of land-use change is rich enough to select yearly expansion caps that make sense in a public debate because they can translate various diagnoses and conjectures about the future in a very transparent way. The representation of technical change and of the change in the mix of food products is weaker.

This limit means that some issues, such as the long-term change in diets or the links between technical itineraries and land-use, cannot be addressed in a precise manner. However an aggregate representation of technical change that makes an explicit distinction between land productivity, labor intensity, energy intensity and capital deepening allows for making sensitivity tests based on richer bottom-up information that are controllable enough to provide robust insights about the nature of the food-energy nexus at a world level. This is possible once all the interdependency mechanisms are considered both at the domestic and world level, including the distributional impacts which will be better represented in the future versions of the model.

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